A BLENDED LEARNING APPROACH TO ADULT ADVANCED CARDIAC LIFE SUPPORT TRAINING FOR HEALTHCARE PROFESSIONALS

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List of Abbreviations

ACLS	Advanced Cardiac Life Support course
AHA	American Heart Association
ALS	Advanced Life Support course
ARC	Australian Resuscitation Council
ATLS	Advanced Trauma Life Support course
CasTeach	Cardiac arrest simulation teaching session
CasTest	Summative course assessment using a cardiac arrest simulation scenario
CoSTR	Consensus on Science with Treatment Recommendations
e-ALS	Blended learning ALS course
EIT	Education Implementation and Teams
ERC	European Resuscitation Council
GRADE	Grading of Recommendations Assessment Development and Evaluation
HEE	Health Education England
ILCOR	International Liaison Committee on Resuscitation
ILS	Immediate Life Support course
LMS	Learning Management System
MCQ	Multiple Choice Questionnaire
NHS	National Health Service
NCAA	National Cardiac Arrest Audit
NI	Non-inferiority
NRT	Neonatal Resuscitation Training
PALS	Paediatric Advanced Life Support course
RC(UK)	Resuscitation Council (UK)

A Chronology of Advanced Life Support Training

1979	AHA ACLS introduced in USA	
1980		
1981		
1982	RC(UK) formed; AHA 'Emergency Cardiac Care' course, Runnymede UK	
1983	RC(UK) 'ALS Working Party' convened	
1984		
1985	First ACLS courses run in the UK	
1986		
1987		
1988		
1989		
1990		
1991	First RC(UK) ALS course run in the UK	
1992		
1993		
1994		
1995		
1996		
1997	ILCOR Advisory Statement	
1998	Dr Lockey joined RC(UK) ALS Subcommittee (Trainee Dr representative)	
1999		
2000	First ILCOR International Guidelines; ERC and RC(UK) Guidelines	
2001		
2002		
2003		
2004	Dr Lockey commenced 7 years as Chair of RC(UK) ALS Subcommittee	
2005	First ILCOR CoSTR; ERC and RC(UK) Guidelines	
2006		
2007		
2008	Two-year pilot e-ALS project commenced	
2009		
2010	ILCOR CoSTR; ERC and RC(UK) Guidelines	
2011		
2012	Definitive e-ALS course launched	*Paper 2*
2013		
2014		
2015	ILCOR CoSTR using GRADE; ERC and RC(UK) Guidelines	*Papers 3 & 4*
2016		
2017		*Paper 5*
2018		*Paper 1*
2019		
2020	ILCOR CoSTR using GRADE	
2021	ERC and RC(UK) Guidelines (Spring)	

Copyright Statement

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Abstract

Background: In-hospital cardiac arrest is a global public health problem, accounting for up to ten events per 1,000 hospital admissions every year. Advanced life support training is used worldwide to educate healthcare professionals in how to prevent and treat cardiac arrest. Stakeholders have challenged the amount of time and associated costs needed for this vital educational intervention.

Aim: To develop a new blended learning approach to advanced life support education for healthcare professionals to meet stakeholders' needs and evaluate whether this new approach is equivalent in terms of educational outcomes compared to the conventional instructor led approach.

Methods: Multi-methods were used to pilot, evaluate, improve and re-evaluate the Resuscitation Council (UK) e-ALS course.

Results: This research programme consisted of five publications. Findings from a systematic review and meta-analysis (Paper 1) showed a positive association between participation of healthcare professionals in an accredited advanced life support course and improved patient outcomes. An open-label non-inferiority randomised trial (Paper 2) was inconclusive in determining whether the e-ALS course produced educational outcomes equivalent to those of conventional instructor-led training. In parallel with this, a multi-methods study (Paper 3) concluded that participant satisfaction was mixed. These findings were used to inform the improvement of the e-ALS course. A descriptive analysis of 27,170 course participants (paper 4) showed that the revised version now demonstrated equivalent educational outcomes in comparison with the conventional course. Finally, an additional descriptive analysis (Paper 5) showed that younger participants, those with prior experience of a life support course, or those from a relevant clinical background were more likely to have a successful course outcome for e-ALS.

Conclusion: Advanced life support training results in improved patient survival and a blended learning approach (e-ALS course) delivers equivalent educational outcomes to the conventional ALS course, but with half of the required face-to-face time and cost.

Chapter 1: Introduction to the portfolio

Cardiac arrest occurs when the heart fails to effectively circulate blood around the body resulting in a loss of blood flow to vital organs (*Advanced Life Support Course Provider Manual*, 2015). The commonest cause of cardiac arrest is coronary artery disease and globally it is one of the top three causes of death accounting for an estimated 15 to 20% of all deaths (Aufderheide et al., 2013, p. 1289; Graham, McCoy, & Schultz, 2015, p. 1; Taniguchi, Baernstein, & Nichol, 2012, p. 1). It is estimated that more than 700,000 people die of cardiac arrest every year in the USA and Europe alone (Mozaffarian et al., 2016, p. 447). Whilst data is scarce from other parts of the world, evidence exists that cardiac arrest is also a major public health problem in low and middle-income countries (Wong et al., 2019, p. 6). The consequential impact of cardiac arrest is economic and societal in terms of lives lost as well as the costs involved with providing medical care for survivors with poor neurological function (Graham et al., 2015, p. 1). If a patient sustains a cardiac arrest whilst in hospital, the chance of them surviving to hospital discharge is approximately 20% which highlights the importance of recognising the deteriorating patient at risk of cardiac arrest (Nolan et al., 2014, p. 987; Sandroni, Nolan, Cavallaro, & Antonelli, 2007, p. 237). This is despite the fact that one in four patients have a potentially reversible cause for their cardiac arrest (Bergum, Nordseth, Mjølstad, Haugen, & Skogvoll, 2010, p. S43). Between April 2018 and March 2019, there were 14,139 reported adult cardiac arrests in 192 UK National Health Service (NHS) acute hospitals reporting to the National Cardiac Arrest Audit registry (*Key Statistics from the National Cardiac Arrest Audit 2018/19*, 2019, p. 1). In addition, it has been reported that an estimated 290,000 in-hospital cardiac arrests occur in the USA each year, representing 9 to 10 events per 1,000 hospital admissions (Andersen, Holmberg, Berg, Donnino, & Granfeldt, 2019, p. 1200). This is likely to be reflected elsewhere in the world, although the majority of published data comes from the UK and USA.

An encouraging fact is that the UK in-hospital cardiac arrest rates have improved over the last 20 years, and this may be due to various factors such as improvements in guidelines and treatment options, as well as a greater understanding of which patients would not benefit from active cardiac resuscitation. The earliest published data, from one UK hospital in 1999, showed an in-hospital cardiac arrest rate of 3.6 per 1,000 admissions (Hodgetts, Kenward, Vlachonikolis, Payne, & Castle, 2002, p. 125). The first published data from NCAA in 2014 showed that this had improved to 1.6 per 1,000 hospital admissions (Nolan et al., 2014, p. 987). In 2019, these figures had further improved to 1 cardiac arrest per 1,000 hospital admissions (*Key Statistics from the National Cardiac Arrest Audit 2018/19*, 2019, p. 1).

The trend in the UK is therefore one of improvement of in-hospital cardiac arrest rates. In addition, there has been an improvement in patient survival rates to hospital discharge between 2014/15 and 2018/19 (18.2% to 23.5%) (*Key Statistics from the National Cardiac Arrest Audit 2018/19*, 2019, p. 1). Aside from the aforementioned factors, there is one key educational intervention that has spanned this period of time. The Resuscitation Council (UK) [RC(UK)] Advanced Life Support (ALS) course, which was first introduced in the UK in 1985, is a two-day face-to-face course. It delivers a standardised national approach to the teaching of internationally developed resuscitation guidelines to healthcare professionals for the management of patients at risk of or in cardiorespiratory arrest (Perkins & Lockey, 2002, p. S81). The course teaches the knowledge, skills, and behaviours required to recognise and treat the deteriorating patient, deliver standardised cardiopulmonary resuscitation (CPR) in adults, manage a cardiac arrest by working with a multidisciplinary team in an emergency situation, and utilise non-technical skills to facilitate strong team leadership and effective team membership. It is targeted at healthcare professionals who play an active role in the management of cardiac arrest in hospitals, or who are actively involved in the education of these people. Suitable candidates include doctors, nurses, nurse practitioners, paramedics, outreach clinicians, and resuscitation officers. From January to December 2019, a total of 25,695 candidates attended 1,322 ALS courses across 212 centres in the UK. Over 1.3 million candidates worldwide attend either this course or an equivalent course (ACLS) administered by the American Heart Association (AHA) every year (Lockey, Lin, & Cheng, 2018, p. 48).

Despite the widespread implementation of the ALS course in the UK, concerns have been raised by key stakeholders, including the National Health Service (NHS) and Health Education England (HEE), about the time needed for instructors to teach, as well as the time required for candidates to be released from work to attend the course. In addition, there has been increased scrutiny by the same stakeholders on the costs of such training. These concerns have also been expressed in other parts of the world and no doubt exist in many other healthcare systems that deliver advanced life support training (Arithra

Abdullah et al., 2019, p. 1; Darr, 2000, p. 116). In response to these concerns, the RC(UK) has introduced a blended learning approach to ALS training, otherwise known as the e-ALS course.

In this first chapter, I will describe the origins and structure of the ALS course and outline my development as a researcher. I will then present the aims and objectives of this programme of research. In Chapter 2, I will introduce the primary papers that will then be discussed in more detail in Chapter 4, as well as an associated secondary portfolio that provides supporting evidence. In particular, I will articulate the unifying theme between these papers and make clear my contribution to each paper. In Chapter 3, I will articulate the processes by which the high standards of clinical content and educational delivery of advanced life support training are developed and maintained. In addition, I will present a critical review of the literature regarding blended learning approaches to healthcare education and its alignment with educational theory as a background to this work. In Chapter 5, I will discuss the implications and common themes from the included papers, before providing a conclusion highlighting how I have achieved the aims and objectives in Chapter 6.

1.1 Context

Modern day adult cardiac resuscitation training can trace its roots back to the late 1970's. The AHA had been running ACLS courses in the USA since 1979 following their third national conference on CPR and, over the next two decades, the concept would become a global entity. The AHA ACLS course is now recognised in over 60 countries worldwide. The RC(UK) ALS course, which was first introduced in the early 1980's, has also been adopted by the European Resuscitation Council (ERC) (Baskett, 2004, p. 311) and the Australian Resuscitation Council (ARC) for use throughout their networks. The course materials and assessments are identical and the ERC ALS Manual (Lott et al., 2015, p. 1) contains only minor edits to reflect differing clinical practice outside the UK. The ALS/ACLS course is therefore an international multi-professional educational approach designed to equip healthcare professionals with the knowledge, skills and attitudes to successfully manage critically unwell patients.

Cardiovascular disease is highly prevalent worldwide and training healthcare professionals how to successfully manage someone in cardiac arrest has societal and economic benefits (Graham et al., 2015, p. 1). The various formats of advanced cardiac life support training are undertaken by over 1.3 million participants every year across many parts of the world including low, medium and high resource settings (Lockey et al., 2018, p. 48). The delivery of advanced cardiac life support training requires resource in terms of equipment, cost of course facilities, and the expenses of faculty. These costs may be prohibitive in some parts of the world. There has been considerable research analysing the benefits of training in newborn and trauma resuscitation in developing countries (Berkelhamer, Kamath-Rayne, & Niermeyer, 2016, p. 573; Meaney et al., 2010, p. 1462), but very little research addressing adult advanced cardiac life support training in low to medium resource environments. It is important therefore that research is undertaken to highlight cost effective strategies to improve outcomes (Aufderheide et al., 2013, p. 1289). The development of a blended learning approach to advanced cardiac life support education described in this programme of research will help to increase the availability and feasibility of training in these settings.

In countries like the USA and the UK, the resource needed to run advanced life support courses is usually within the means of healthcare budgets. Whilst the ACLS course was first described in the USA, it was only a few years before a similar concept was developed in the UK. In the spirit of international collaboration, the AHA delivered an "Emergency Cardiac Care" course in 1982 in Runnymede, UK, to a representative group of UK resuscitation leaders. Following several exchange visits by these leaders, a version of the AHA ACLS course was adapted and imported. The first courses were run in the UK in 1985 (Lockey, 2017, p. 1). Before the ALS course existed in the UK, there was no specific structured resuscitation training, multi-professional or otherwise, for healthcare professionals. Over the years since its inception, the content of the course and the way it has been delivered has evolved as a result of published evidence in the scientific and educational literature. The RC(UK) ALS sub-committee, which oversees the governance of the course in the UK, updates the course materials content when new guidelines are produced. The sub-committee also reviews the educational efficacy of the course and amends the way the course is delivered based upon contemporary educational evidence.

There are currently two variants of the RC(UK) ALS course - the full two-day conventional face-to-face version (c-ALS) and the blended learning version with e-learning modules and one day of face-to-face learning (e-ALS). All candidates receive a course manual four weeks prior to attending the course

(*Advanced Life Support Course Provider Manual*, 2015, p. 1). This manual, now in its 7th edition, provides the theoretical background to the course and is also intended to supply a broader explanation and context to the practice of resuscitation. The candidates are expected to read the manual to understand the underpinning theoretical approach to cardiac arrest management prior to attending the course.

Candidates attending the conventional ALS Course complete a pre-course multiple choice questionnaire (MCQ) prior to attending the two-day face-to-face course. The programme (Appendix 1) is a mixture of didactic and interactive sessions. There are five lectures covering important theoretical elements as well as a demonstration of a cardiac arrest simulation. Eight workshops are used to deliver small group teaching of key resuscitation skills, including airway management and defibrillation. The learning from all of these elements is then consolidated with a series of cardiac arrest simulation teaching sessions, known as the CasTeach. During these sessions, the candidates take turns to lead a cardiac arrest team composed of their colleagues in a variety of simulated scenarios using a resuscitation training manikin. All candidates undergo formative assessment throughout the course on their CPR, airway, and defibrillation skills. At the end of the course, they also undertake an MCQ and a cardiac arrest simulation test, known as the CasTest. In this CasTest, each candidate is assessed on their ability to manage a simulated patient in cardiac arrest. The assessment is carried out by two instructors using one of four standardised scenarios. For each element of performance, the candidate is objectively marked using a scoresheet that contains essential and non-essential items, with achievement of all essential items needed to pass the test. These testing scenarios differ in the clinical scenario presented, but all contain the same elements (assessment of the deteriorating patient, patient in either ventricular fibrillation or ventricular tachycardia requiring defibrillation, patient in non-shockable rhythm, and post-resuscitation care). They have previously been validated to ensure that they are equivalent in terms of difficulty (Perkins et al., 2007, p. 484).

Candidates who enrol on the e-ALS course have access to a broad range of e-learning material in addition to the course manual including online modules and additional resources via the Learning Management System (LMS). These modules can be accessed by computers, tablets, and smartphones. None of the modules are mandatory, thus allowing the candidate to self-direct their learning in the same way as they would with a paper manual. The online modules cover the content that is delivered by lecture on the c-ALS course and they are designed to be completed over six to eight hours. Each module has a clear statement about its learning outcomes. A variety of styles are used including video presentations, case-based examples, infographics, and inbuilt quizzes. Candidates are also directed towards additional resources including external reports and YouTube videos. Finally, candidates are required to complete the pre-course MCQ, which is built into the LMS. They subsequently attend a one-day face-to-face course (Appendix 2), where the assessments are identical to the ones on the c-ALS course.

The e-ALS course was introduced in the UK as a result of the concerns raised about the amount of time needed for candidates and faculty to attend the conventional ALS course, as well as the expenses needed to deliver a two-day course. At present, the RC(UK) e-ALS course is run solely in the UK. The papers in this programme of research have been published in international journals with the intent to share best practice. There is already evidence of similar courses that have subsequently been developed internationally (Arithra Abdullah et al., 2019, p. 1).

1.2 The researcher

I am a full-time Consultant in Emergency Medicine at Calderdale and Huddersfield NHS Trust. I have held this role for 18 years and during this time have also held additional roles including College Tutor, Foundation Training Programme Director, Clinical Director, Simulation Lead, and Director of Medical Education. Outside my work for the Trust, I am an Associate Postgraduate Dean for Health Education England. I have worked in a voluntary capacity with the RC(UK) since 1998, starting as a junior doctor representative on the ALS Sub-Committee before progressing to become the Chair of that Sub-Committee for 7 years. I then spent 8 years as Honorary Secretary until 2018 when I had the privilege and honour to be elected as Vice President of the Council. I am scheduled to become President of the Council in 2021. In parallel with this, I have also worked with the ERC as a lead educator trainer. I held the position of Chief Editor for the ERC ALS course manual in 2010 and have been personally responsible for introducing the ALS Course to many countries throughout Europe, North Africa and the

Middle East. In 2005 I was invited to represent the ERC as part of the International Liaison Committee on Resuscitation (ILCOR) process, which generates recommendations for guidelines for the management of cardiorespiratory arrest.

I have a research career spanning 22 years. During this time, I have published 14 editorials (7 as lead author), 32 papers (10 as lead author), 2 books, and 2 course manuals. I have been cited 2,031 times, my h-index is 23, and my i-10 index is 37 (data accessed on 19 February 2020). The majority of my research outputs relate to emergency medicine and life support education. I have a range of publications with methodologies including qualitative analyses, case-controlled studies, randomised controlled trials, systematic reviews, and meta-analyses.

Over the last 20 years, I have engaged in a programme of research that has contributed to the transformation of the way that life support education is delivered and the contemporary publications from that programme are presented in this portfolio. In the late twentieth century, the RC(UK) ALS course was predominantly a didactic teaching programme, whereas today it is much more interactive and embraces the benefits of modern technology for a blended approach to learning that includes a combination of face-to-face tuition and pre-course e-learning. This evolution has been achieved specifically from a programme of research that I have led and contributed to.

1.3 Aims and objectives of research

The aim of this research programme was to develop a new blended learning approach to advanced life support education for healthcare professionals to meet stakeholders' needs and evaluate whether this new approach was equivalent in terms of educational outcomes compared to the conventional instructor led approach.

In order to achieve this aim, the key objectives for this research were as follows:

- Evaluate the impact of prior participation of one, or more, members of the adult resuscitation team in an accredited advanced life support course on patient outcomes to establish the importance of this educational intervention.
- Determine whether a blended approach to advanced life support training, that includes e-learning, produces educational outcomes equivalent to those of conventional instructor led training.
- Evaluate the acceptability of a blended learning approach to healthcare professionals undertaking advanced life support training.
- Describe the variables associated with favourable course outcomes from a blended learning approach to advanced life support training.

Chapter 2: Eligible research and unifying theme

In this chapter, I will provide a brief overview of the portfolio of eligible research. This will include a discussion of the unifying themes that link the work together. The portfolio consists of five primary papers which collectively demonstrate a range of methodological approaches that, with the accompanying commentary, provide detail of this programme of research. Included within this portfolio is evidence of research collaboration and leadership at both an international and national level.

The unifying theme of this portfolio is that it describes a programme of research consistent with contemporary educational theory that has led to the delivery and validation of a blended learning approach to advanced life support education. This approach succeeds in meeting the challenges set by modern-day international health services for local implementation without compromising the ability to deliver important educational outcomes. Paper 1 presents the underpinning evidence that highlights the importance of conventional advanced life support education in terms of improved patient outcomes. The remainder of the papers are linked by their description of a process that has resulted in the development of the e-ALS course which is equivalent in terms of educational outcomes to the conventional course. The unifying theme is therefore that process of developing a different educational strategy with the intention of delivering the same patient benefit.

The primary papers demonstrate a range of research methodologies. Paper 1 presents a systematic review with a meta-analysis using GRADE methodology (Schünemann, 2013, p. 1) to evaluate the impact of prior participation of one, or more, members of the adult resuscitation team in an accredited advanced life support course on patient outcomes. This methodology was used as it is a structured and transparent approach that considers the specific effect of an intervention at outcome level, which was consistent with the design of the studies identified. Paper 2 was an open-label non-inferiority randomised trial. A non-inferiority approach was used as it was felt that the incremental benefits of the e-ALS course would be marginal and that the numbers needed for a superiority trial would be unfeasible. Paper 3 was a mixed-methods study that was key to identifying the perspectives of candidates exposed to e-learning on an ALS course. A mixed methodology approach was used to quantitatively analyse course content and presentation rating scores, as well as qualitatively analyse free text feedback. Papers 4 and 5 both used a descriptive analytical approach to present the educational outcomes and factors that related to e-ALS course success from a large amount of data held on the RC(UK) learning management system. My personal development has included learning about each methodological approach. I received online and face-to-face training in GRADE methodology as part of my work for ILCOR, as this methodology has been used since 2010 for the task force review process. My learning for the remainder of the methods used has been through a combination of tutorial, peer, and self-learning. In particular, my development has been to learn the relative strengths and weaknesses of each research approach, and this will be elaborated upon further in my commentary on each aspect of my research portfolio.

The secondary portfolio is relevant to the background of the ALS course and, whilst not discussed in detail, will be referred to in the wider discussion. It is included here to demonstrate the broader contribution to knowledge beyond the scope of this thesis. This portfolio includes published research relating to international and national guideline development. It also contains papers relating to ALS CasTest scenario validation and a randomised controlled trial analysing the effect of a specific pre-course e-learning product on educational outcomes. In addition, I have edited and contributed to the writing of one book and two manuals that are used as the pre-course reading material for candidates. The ALS Course manual is used as pre-course learning material for all RC(UK) ALS course participants (*Advanced Life Support Course Provider Manual*, 2015, p. 1). I have been a member of the editorial board since the 4th edition in 2000. The number of course participants per year, and therefore the number of manuals issued, is 23,000. Similarly, the ERC utilises an ALS course manual based upon the RC(UK) manual but adapted for European practice ("Advanced Life Support Course Provider Manual," 2001, p. 1). I was Chairman of the editorial board for this manual in 2010 and co-ordinated the edits and updates needed for a European version. The number of course participants per year, and therefore the number of manuals issued, is 10,500. Finally, I am co-editor of the ‘Pocket Guide to Teaching for Clinical Instructors’, currently in its third edition. This book is used as the pre-course learning for instructor training for UK and European life support courses including the ALS course (Bullock, Davis, Lockey, & Mackway-Jones, 2016, p. 1). It covers the educational theory promoted by the Lead Educators for the RC (UK), Advanced Life Support Group, and the ERC.

Table 2 provides detail of my academic contribution to each of the primary papers and also the papers in the secondary portfolio. For each paper, I have indicated when I have been involved in the conception and design, data collection, data analysis and interpretation, drafting the paper, critical revision of the draft, and final approval of the paper. In addition, I have detailed my contribution and role with regard to two course manuals and one book.

In conclusion, the published work in this portfolio represents a programme of international research that has led to the development, piloting, evaluation, improvement, and re-evaluation of a blended learning approach to adult ALS training, as well as empirical research that has demonstrated a positive association between accredited adult advanced life support courses and improved patient outcomes.

2.1 Contribution to each submission

Paper	Citation	Type of Paper	Conception and Design	Data Collection	Data analysis and interpretation	Drafting the paper	Critical revision of draft	Final approval of paper
PRIMARY PAPERS								
1	**Lockey AS**, Lin Y and Cheng A. Impact of adult advanced cardiac life support course participation on patient outcomes – a systematic review and meta-analysis. Resuscitation 2018;129:48-54	Systematic review and meta-analysis	X	X	X	X	X	X
2	Perkins GD, Kimani PK, Bullock I, Clutton-Brock T, Davies RP, Gale M, Lam J, **Lockey A**, Stallard N. Improving the efficiency of advanced life support training. Annals of Internal Medicine 2012;157:19-28	Open-label non-inferiority randomised trial	X				X	X
3	**Lockey AS**, Dyal L, Kimani PK, Lam J, Bullock I, Buck D, Davies RP and Perkins GD. Electronic learning in advanced resuscitation training: the perspective of the candidate. Resuscitation 2015;97:48-54	Multi-methods	X			X	X	X
4	Thorne CJ, **Lockey AS**, Bullock I et al. e-learning in advanced life support – an evaluation by the Resuscitation Council (UK). Resuscitation 2015(90):79-84	Descriptive analysis	X			X	X	X
5	Thorne CJ, **Lockey AS**, Kimani PK et al. e-Learning in Advanced Life Support – what factors influence assessment outcome? Resuscitation 2017;114:83-91	Descriptive analysis	X			X	X	X
SECONDARY PORTFOLIO								
	Finn JC, Bhanji F, **Lockey A**, Monsieurs K et al. Part 8: Education, implementation and teams 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Resuscitation 2015;95:e203-224	Guideline Development		X	X	X	X	X
	Cheng A, **Lockey A**, Bhanji F et al. The use of high-fidelity manikins for advanced life support training – a systematic review and meta-analysis. Resuscitation 2015;93:142-9	Systematic review and meta-analysis	X	X	X	X	X	X
	Greif R, **Lockey AS**, Conaghan P et al. European Resuscitation Council Guidelines for Resuscitation 2015. Section 10 Education and implementation of resuscitation. Resuscitation 2015;95:288-301	Guideline Development		X	X	X	X	X
	Lockey AS, Bullock I, Mackie K and Soar J. Resuscitation Council (UK) Guidelines 2015	Guideline Development	X	X	X	X	X	X
	Perkins GD, **Lockey AS**. The Advanced Life Support Provider Course. BMJ 2002;325:S81-83	Editorial	X	N/A	N/A	X	X	X
	Perkins GD, Davies RP, Stallard N, Bullock I, Stevens H, **Lockey A**. Advanced life support cardiac arrest scenario test evaluation. Resuscitation 2007;75(3):484-90	Cluster randomised study	X			X	X	X
	Perkins GD, Fullerton JN, Davis-Gomez N, Davies RP, Baldock C, Stevens H, Bullock I, **Lockey AS**. The effect of pre-course e-learning prior to advanced life support training: a randomised controlled trial. Resuscitation. 2010 Jul;81(7):877-81	Randomised controlled trial	X			X	X	X
	Advanced Life Support Manual (7th Edition) 2016, Resuscitation Council (UK)			Member of Editorial Board				
	Advanced Life Support course manual (Guidelines edition) 2010, European Resuscitation Council			Chairman of the Editorial Board				
	Bullock I, Davies M, **Lockey A** and Mackway-Jones K. Pocket Guide to Teaching for Clinical Instructors (3rd Ed) 2015, Wiley Blackwell Publishing			Editor				

Table 1 *– Published research (clustered into themes: blue = Primary Papers, consisting of evaluation of impact of advanced life support and development and evaluation of e-ALS course; yellow = guideline development; grey = miscellaneous; orange = book and course manuals) with author contribution.*

Chapter 3: Background

In this chapter, I will describe within an international context the educational provenance of the ALS course. This description will include the drivers for the development of a blended learning approach to advanced life support training, and I will use the Formula for Survival (Soreide et al., 2013, p. 1487) as a template. A review of published systematic reviews and meta-analyses on the impact of blended learning in health professional education will be presented thereafter. This will set the scene for the published works that comprise my portfolio. A section on educational theory and how this relates to ALS training is also included.

3.1 Educational provenance of the adult advanced cardiac life support course

In this section, I will discuss the key factors that have shaped the development of the ALS course, using the 'Formula for Survival' as a structure (Soreide et al., 2013, p. 1487). This is a framework that describes educational efficiency as a key component for patient survival, a concept that is central to the papers presented in this portfolio. The Formula is significant as it places into international context the importance of guideline quality, efficient education of caregivers, and implementation of guidelines at a local level. It was initially developed following a meeting of international experts in Utstein, Norway, in 2001 and was presented as part of an Advisory Statement on Education and Resuscitation (Chamberlain & Hazinski, 2003, p. 11) by the International Liaison Committee on Resuscitation (ILCOR).

The Formula for Survival outlines three key factors for patient survival; namely guideline quality (medical science), efficient education of caregivers (educational efficiency) and effective implementation at a local level (local implementation). Following a further meeting in 2006 of thirty-five international experts, a simplified visual format for the Formula for Survival was developed (Figure 1).

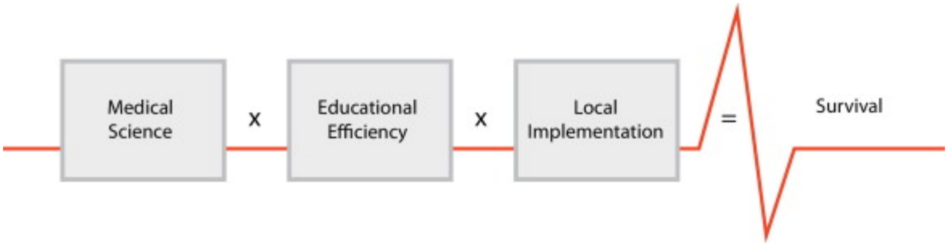

***Figure 1** – The Formula for Survival*
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The first factor in the Formula relates to medical science, and this refers to the importance that any developments in clinical practice are underpinned by high quality evidence. The responsibility for the ongoing evidence evaluation process lies with ILCOR, which is a global alliance of all major organisations with an interest in the development of resuscitation. ILCOR is responsible for producing the Consensus on Science with Treatment Recommendations (CoSTR) publications at an international level that are then synthesised by national resuscitation councils into guidelines. It was formed in 1992 and is currently composed of the AHA, the ERC, the Heart and Stroke Foundation of Canada, the Australian and New Zealand Committee on Resuscitation, the Resuscitation Councils of Southern Africa, the Resuscitation Councils of Asia, and the Inter American Heart Foundation. Its vision is to "save more lives globally through resuscitation" and it seeks to achieve this by "promoting, disseminating, and advocating international implementation of evidence-informed resuscitation and first aid, using transparent evaluation and consensus summary of scientific data" (Neumar & Perkins, 2018, p. 1085). The first Advisory Statements were published in 1997 (Cummins & Chamberlain, 1997, p. 2172), followed by the first international CPR guidelines in 2000 (AHA, 2000, p. 1). These were then followed by the publication of the first CoSTR in 2005 (Biarent, 2005, p. 1). These have been built upon with further iterations in 2010 (Nolan et al., 2010, p. e1) and 2015 (Nolan et al., 2015, p. e1). Each aspect of resuscitation relating to adult, paediatric, and newborn patients has been subjected to an in-depth systematic review to identify the most effective methods for conducting resuscitation. In the 2015 cycle, there were 165 research questions that were analysed using GRADE methodology (Schünemann, 2013, p. 1) by 232 reviewers from 39 countries. The resulting CoSTR was used as the basis for the development of standardised European guidelines for resuscitation (Monsieurs et al., 2015, p. 1). The ERC Guidelines are further adapted for the UK, and I was the lead author for the 2015 UK education guidelines process (Lockey, 2015, p. 1).

The second factor in the Formula relates to educational efficiency, and this is important as there are many different educational approaches that could be used for teaching resuscitation practice. This factor recognises the importance of researching and validating the best ways to deliver teaching to optimise educational and clinical outcomes. Historically, ILCOR had only convened clinical taskforces, but in 2006 a decision was made to add an 'Education Implementation and Teams' (EIT) taskforce in recognition of the importance of this topic. The output from this taskforce informs how the clinical material should be taught and implemented. The 2010 ILCOR process delivered a thorough review of 32 topics, presented as worksheets, for EIT relating to resuscitation (Soar et al., 2010, p. e288). These worksheets provided a detailed summary of each review including detail of the question posed, search strategies, synthesis of evidence, and conclusions. The consultation process was strengthened as feedback was also invited from the general public through an open website. For the 2015 cycle, a smaller number of EIT topics (17) were selected to reflect the increased workload needed to complete the reviews using GRADE methodology (Bhanji et al., 2015, p. S242).

The EIT CoSTR publications provide a summary of all of the worksheets from the previous five years and they are important as they present the evidence relating to the educational efficiency of cardiac resuscitation training. It is therefore essential that the teaching and assessment strategies on ALS courses are robustly validated and that any new developments are evaluated with the same rigour to inform future CoSTR and guideline publications. The challenge with studies addressing the impact of educational interventions is that it is more difficult to design robust randomised controlled trials that are traditionally viewed as higher levels of hierarchical evidence (Greenhalgh, 1997, p. 243). When looking at relatively soft outcomes where differences between control and experimental groups are likely to be minimal, the number of subjects needed to prove superiority become less feasible as will be highlighted in the discussion about Paper 2. This has an impact in particular when studies are brought together in a systematic review and meta-analysis. GRADE methodology, which is used by ILCOR, is systematic and transparent and considers the magnitude of effect and the quality of evidence at an individual outcome level. It is an approach that is particularly suited to clinical research where different treatment strategies lead to significantly different outcomes. The challenge of using GRADE for educational papers is that the heterogeneity of studies along with risks of bias, inconsistency and imprecision means that recommendations are downgraded due to low or very low-quality evidence. This inevitably draws an unfavourable comparison when placed alongside recommendations for clinical interventions that are presented as high quality evidence. An alternative approach would be to perform scoping reviews as these can describe a wider range of methodologies of a heterogenous nature. This approach has been used by the AHA in 2018 to present a summary of the evidence relating to cardiac resuscitation (Cheng et al., 2018, p. e82). The limitation with this approach is that treatment recommendations cannot be made owing to the lack of bias assessment as part of the process. Irrespective of the approach used, however, it is important that educational efficiency has been highlighted as a key factor for patient survival.

The final factor in the Formula is local implementation, and this is important as different healthcare systems throughout the world have access to varying levels of resource. This means that some evidence-based interventions may not be feasible in every system. In addition, there may be different political, cultural, legislative or professional barriers that need to be addressed at a local level to implement effective strategies for resuscitation. For example, a 2015 EIT worksheet evaluating the efficacy of high versus low fidelity manikins for resuscitation training demonstrated moderate benefits with high fidelity manikins for improving skills performance at course conclusion (Cheng et al., 2015, p. 142). High fidelity manikins were defined as those that provide physical findings, display vital signs, physiologically respond to interventions (via computer interface), and allow for procedures to be performed on them (e.g. bag mask ventilation, intubation, and intravenous insertion). Commercially produced high fidelity manikins can retail for over £50,000 each and are clearly not a feasible concept for many low resourced areas of the world irrespective of any evidence to support their use. Another example is the recommendation that CPR education is added as a mandatory requirement to the national school curriculum in every country. There is published evidence that the implementation of such a strategy leads to significant increases in bystander CPR rates as well as tripling the survival of patients (Wissenberg et al., 2013, p. 1377). In addition, there is published evidence of the differing global educational strategies that can be used to deliver this training (Böttiger et al., 2019, p. 15). Despite having the necessary resources to deliver such an approach, only a third of European countries have a supportive political culture whereby legislation exists to support this recommendation (Bottiger et al., 2017, p. 792). This reinforces the importance of overcoming barriers to local implementation as a key factor for patient survival.

Over recent years, a new local implementation challenge has arisen in healthcare systems around the world. There are increasing pressures on the time available for faculty and students to attend courses and this has prompted the need to identify and evaluate alternative methods of delivery for advanced life support training. In the UK, the course length had already been reduced from three days to two days in 2006. The RC(UK) ALS sub-committee was made aware that an increasing number of courses were still being cancelled as instructors were struggling to get two days out of clinical practice to teach. In an era of austerity and greater scrutiny on study leave budgets, the candidates were also struggling to get study leave time and funding to attend the courses. With all of this in mind, in my capacity as Chairman of the ALS Sub-Committee, I decided to investigate the viability of a one-day face-to-face course with the didactic theoretical elements of the course delivered as pre-course e-learning. This blended learning approach would become known as the e-ALS course.

The positive interaction between all three factors of the Formula for Survival results in the single and most important output, namely ‘survival’. Kirkpatrick (Kirkpatrick & Kirkpatrick, 2006, p. 1) described a four-level training evaluation model to analyse the effectiveness and impact of training programmes, with the highest level being ‘impact upon important outcomes’. Patient survival rates must be regarded as an important outcome, therefore establishing the validity of the research presented in this portfolio.

Any variation in the ALS course should be robustly evaluated to ensure that new formats of educational delivery do not reduce the chances for patient survival. The e-ALS course is a blended learning approach and it is therefore an essential prerequisite to understand the strengths and weaknesses of such an approach, as well as any underpinning educational theory that supports its use.

3.2 Blended learning in healthcare education: a review of systematic reviews

In this section, I will present a review of systematic reviews and meta-analyses to evaluate and appraise research evidence concerning the impact of a blended learning approach for healthcare professionals on educational outcomes.

3.2.1 Background

To understand the concept of blended learning, it is important to define its constituent parts. Traditional learning involves face-to-face interaction that occurs at a specified time in a physical location (Harden & Crosby, 2000, p. 334). It includes direct interaction with a teacher, often in the format of a lecture, and its name reflects its use in traditional school classroom settings. The evolution of technology has led to the concept of e-learning, which is the provision of educational programmes through electronic systems (Clark & Mayer, 2016, p. 1). It has many other names, such as web-based learning, online learning, computer-assisted instruction, and internet-based learning. The impact of e-learning in healthcare education has been widely scrutinised with some authors postulating that it aids a transition to educators becoming facilitators rather than deliverers of education (Ruiz, Mintzer, & Leipzig, 2006, p. 207). One of the main strengths of e-learning is that it can give learners more freedom to choose what they learn, when they learn, and where they learn. By doing so, they can pace their learning to suit their needs and interests (Scott, Baur, & Barrett, 2017, p. 61). Well-designed e-learning packages can deliver greater elements of interaction, as opposed to the relative lack of interactivity in a mandatory series of lectures. This leads to a higher degree of cognitive engagement and, as a result, a greater degree of retention (Clark, 2002, p. 598). By building in an e-learning element to healthcare education and training, educators can also overcome the barriers to face-to-face training for healthcare workers including reducing travel time, reducing the necessity for rota coverage, and mitigating potential loss of income (Halverson et al., 2014, p. 136; Valentina et al., 2019, p. 17). This approach to the delivery of health education can also lead to cost savings for educational institutions, once these factors have been taken into account (Sissine et al., 2014, p. e196). Despite this, e-learning is not necessarily the best option for all learners. Some students may have less proficient computer skills leading them to become frustrated and disadvantaged with e-learning (Makhdoom, Khoshhal, Algaidi, Heissam, & Zolaly, 2013,

p. 12). Another disadvantage of a pure e-learning approach is that learners become more isolated and lose the benefits of communal learning with peers. This can lead to a feeling of loneliness or loss of interest in the subject matter (Carroll, Booth, Papaioannou, Sutton, & Wong, 2009, p. 235; So & Brush, 2008, p. 318).

The combination of face-to-face learning with e-learning was first described in the early 21st century and is referred to as blended learning (Voos, 2003, p. 2). It has been described as an approach that combines the advantages of face-to-face tuition and online courses, as well as increasing flexibility and reducing costs when compared with conventional classroom learning (Graham, 2006, p. 3; Harding, Kaczynski, & Wood, 2012). Technology should therefore be used to enhance teaching if appropriate rather than being the sole focus of a learning approach (Rowe, Frantz, & Bozalek, 2012, p. e216). It is important that there is coherence between the e-learning and face-to-face elements to ensure that they complement each other (Nortvig, Petersen, & Balle, 2018, p. 46). Simply adding an e-learning module or replacing didactic content onto a new platform is likely to add very little to the learning experience and may not improve student engagement (Garrison & Kanuka, 2004, p. 95; River, Currie, Crawford, Betihavas, & Randall, 2016, p. 185). In certain circumstances, it can potentially overwhelm the candidates by adding to the complexity of material and therefore lead to lower confidence ratings (Nacca, Holliday, & Ko, 2014, p. 913). If structured well however, the e-learning element can help prepare participants for the face-to-face element and further build upon their learning (Valentina et al., 2019, p. 17).

Blended learning has been used to train healthcare professionals in a variety of educational settings. At a time when its use for ALS training was first being considered, blended learning was being successfully used for situations as diverse as the development of spiritual and religious care competencies in palliative care (Smith & Gordon, 2009, p. 86), teaching human anatomy (Pereira et al., 2007, p. 189), and improving the educational delivery to teach children's pain management (Jonas & Burns, 2010, p. 1). Students valued the opportunity to understand underpinning principles by online discussion and reading, and felt that this enabled them to participate in more meaningful and deeper discussions in the face-to-face sessions (Smith & Gordon, 2009, p. 86). Whilst they were able to achieve competencies in knowledge, there were still concerns raised with regard to student satisfaction (Pereira et al., 2007, p. 189), availability of study time, and the level of computer expertise (Jonas & Burns, 2010, p. 1). More recent examples include the successful use of blended learning for simple tasks such as the retention of competence in using an IV pump, with a concluding statement that this had the potential to save lives (Terry, Terry, Moloney, & Bowtell, 2018, p. 15). The blended learning approach has also been used to train and prepare healthcare professionals to perform in a range of specific clinical situations, such as the avoidance of obstetric injuries (Ali-Masri et al., 2018, p. 258), the study of larger clinical topic areas like family medicine (Makhdoom et al., 2013, p. 12), an introduction to pathology (Herbert, Velan, Pryor, & Kumar, 2017, p. 197), and postgraduate studies in quality and patient safety (Westerlaken et al., 2019, p. 289). To better understand the impact of blended learning in the context of health professional education a review of systematic reviews and meta-analyses was conducted to evaluate current research on this topic.

3.2.2 Methods

A review of reviews is a process by which evidence is summarised from a series of systematic reviews, that includes the combination of different interventions, outcomes, problems, or populations (Becker & Oxman, 2008, p. 607). This enables the strength of recommendations to be discussed resulting in the best available evidence for key stakeholders. An initial scoping review of the literature identified a series of systematic reviews for the impact of blended learning in healthcare professional education, so a review of reviews was felt to be the best way to provide a summary of these recommendations.

3.2.2.1 Data Sources and Search strategy

The PICO format (**P**opulation, **I**ntervention, **C**ontrol, **O**utcomes) was used to formulate the research question: In healthcare professional education (P), does the use of a blended learning approach (defined as a combination of e-learning and face-to-face tuition) (I) as opposed to no intervention or any non-blended approach (C) result in improved educational outcomes (knowledge and skill acquisition) and participant satisfaction (O)? The following databases were searched on 22 November 2019: Medline, Cinahl, Embase, PubMed, Epistemonikos, and the Cochrane Systematic Review Database. The search was purposefully limited to healthcare databases in view of the population to be studied. In addition, the reference lists from short listed papers were hand searched. An updated search was performed on 31 January 2020 with no additional findings. As the concept of blended learning was not formally described until the early 2000s, the initial date for the search was set at 1 January 2000. The search strategy, including the number of studies identified, is presented in Appendix 3.

3.2.2.2 Review Selection

A PRISMA flow chart detailing the different phases of the systematic review is presented in Figure 2. A total of 142 reviews were identified from the primary search. The titles and the abstracts of the initial search results were independently examined by two reviewers (Dr Andrew Lockey and Assoc Prof Janet Bray, Monash University, Melbourne, Australia). Duplicate studies and studies that had no relevance to the research question were removed leaving 54 reviews. These were independently screened in more detail for eligibility by the same two reviewers based upon set inclusion and exclusion criteria, as described in section 3.2.2.3.

3.2.2.3 Inclusion and exclusion criteria

Reviews were included if they analysed quantitative, qualitative, or mixed methods studies. They were also included if they were written in English, included studies involving healthcare professionals conducted in healthcare settings, and included studies where a blended learning approach was the intervention.

Reviews were excluded if they were conducted before 2000, did not describe healthcare settings, did not involve healthcare professionals, or addressed e-learning alone as an intervention. Reviews of the ‘flipped learning’ approach were also excluded, as not all examples of flipped learning contain an e-learning component. In this model, instructional content is delivered outside the classroom by a variety of methods, of which e-learning may be one option, and elements that would previously have been considered as pre-course learning are moved into the classroom (McDonald & Smith, 2013, p. 437).

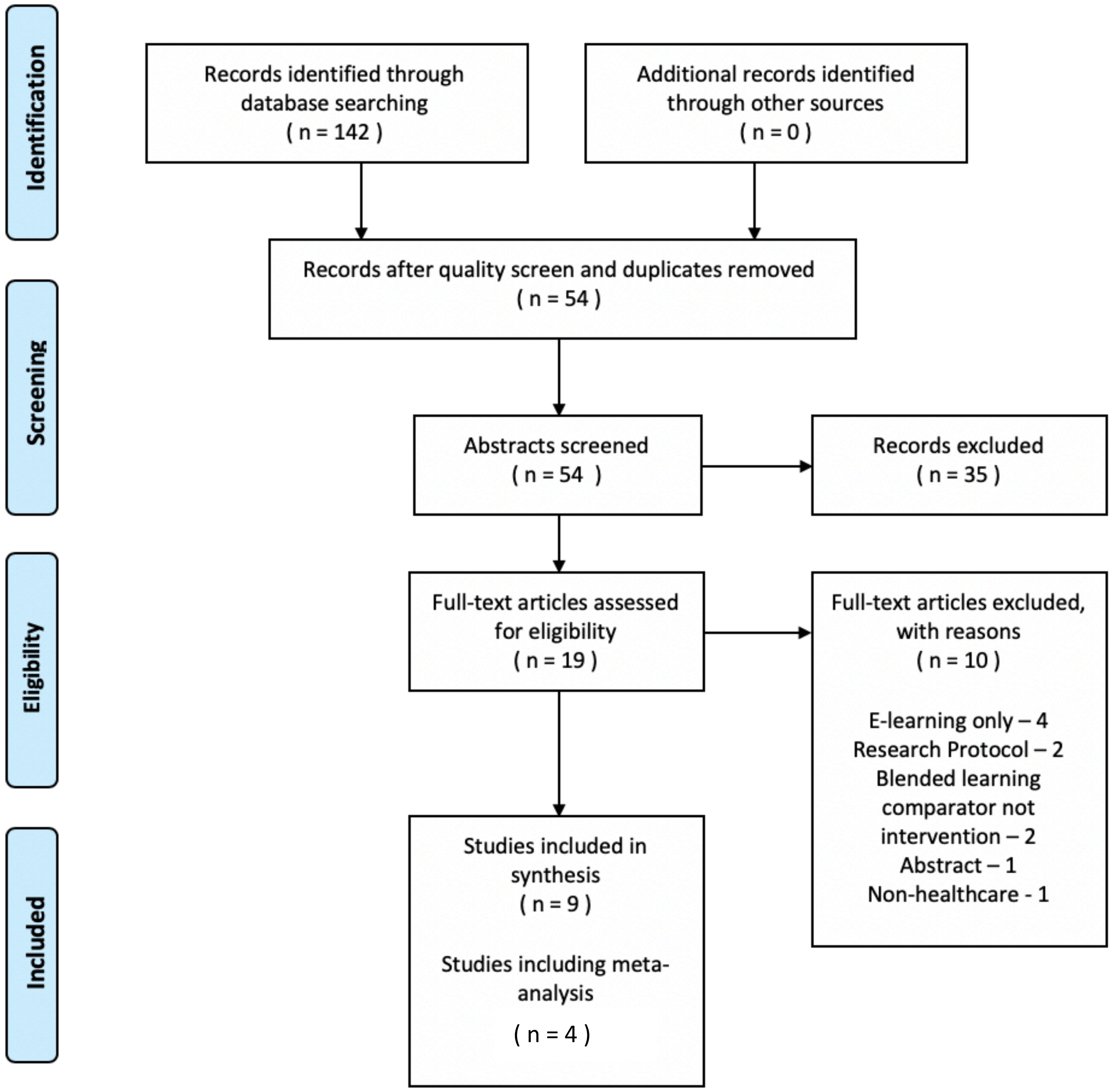

***Figure 2** – PRISMA Flow Chart: Review of Systematic Reviews*

3.2.2.4 Identification of reviews

The full texts were obtained for 19 reviews and these were screened by two independent reviewers (Dr Lockey and Assoc Prof Bray), resulting in nine reviews for full analysis. There was no difference in agreement between the two reviewers.

3.2.2.5 Study Quality Assessment

Each review was independently appraised for quality of evidence by two reviewers (Dr Lockey and Assoc Prof Bray) using the AMSTAR-2 tool, which is presented in Appendix 4 (Shea et al., 2017, p. j4008). The original AMSTAR tool was published in 2007 (Shea et al., 2007, p. 10) and has been widely used for critically appraising systematic reviews of randomised controlled studies. The tool was developed following a scoping review of existing rating instruments as well as validation using a panel of experts. It was specifically designed for use by healthcare professionals and policy makers and was felt to be intuitively straight forward to use as a tool with the result that the quality assessments were rapid and reproducible. It was felt by the authors that the tool needed to be updated to include the facility to critique studies including non-randomised, as well as randomised studies (Shea et al., 2017, p. 358). This reflects the increasing trend for non-randomised studies to be included within systematic reviews. The authors cite that "almost half of published systematic reviews now include non-randomised studies of intervention effects" (Shea et al., 2017, p. 358). Inclusion of non-randomised studies in systematic reviews brings specific challenges. By their nature, these studies are more likely to demonstrate a range of biases that may or may not be found in randomised studies. The tools needed to assess for risk of bias differ therefore in these studies. The authors convened an expert group in 2015 and also took into account published critique and feedback. The resulting tool has 16 domains and retained 10 of the original 11 AMSTAR domains. There are numerous other checklists that can be used to appraise systematic reviews and meta-analyses. Examples include the Critical Appraisal Skills Programme (CASP) checklist [www.casp-uk.net] and the Critical Appraisal Checklist for a Systematic Review produced by the Department of General Practice at the University of Glasgow, which was adapted from the CASP checklist [www.gla.ac.uk/media/Media_64047_smxx.PDF]. Neither of these checklists contain any questions that are not already included in AMSTAR 2.

Each review was given a rating of either high, moderate, low, or critically low based upon the presence and number of critical or non-critical weaknesses (Shea et al., 2017, p. 358). Critical weaknesses were identified as a lack of registered protocol, inadequate literature search, no justification for exclusion of individual studies, no risk of bias assessment, inappropriate meta-analytical methods (if performed), lack of consideration of risk of bias when interpreting the results of the review, and a failure to assess the presence and likely impact of publication bias. A rating of 'high' was awarded if there were less than two non-critical weaknesses; 'moderate' if there were two or more non-critical weaknesses; 'low' if there was one critical weakness with or without non-critical weaknesses; and 'critically low' if there was more than one critical weakness.

3.2.2.6 Data extraction and analysis

Tables 2, 3, 4 and 5 present an overview of the systematic reviews of the literature that evaluated the use of blended learning in healthcare education. A meta-analysis was included in four of the reviews (Dunleavy et al., 2019, p. e12937; Liu et al., 2016, p. e2; Nagendrababu et al., 2019, p. 181; Viljoen, Millar, Engel, Shelton, & Burch, 2017, p. e018811). The data extracted from all nine reviews, including from those that performed a meta-analysis, are descriptively analysed.

3.2.3 Results

3.2.3.1 Review characteristics

The search identified 142 reviews, of which nine met the inclusion criteria for data extraction. The main reasons for exclusion were that reviews studied the intervention of e-learning alone rather than a blended approach, that blended learning was used as a comparator as opposed to an intervention, or that the population studied was not healthcare in nature. The reviews included quantitative, qualitative and mixed methodology studies with sample sizes ranging from 10 to 977 participants. A range of study designs were included in the reviews, including randomised trials, cohort studies, and qualitative analyses. A broad range of educational interventions were analysed, ranging from provision of CD-ROMs to fully interactive online programmes. The majority of studies included in the reviews were published after 2000, and this reflects the fact that the concept of blended learning was not described until this time.

Author & year of publication	Subjects	Countries	Research Question	Sources (years of search)	Number of included papers	Types of papers	Outcomes	Quality of evidence	Major findings
Liu 2016	All healthcare professional learners	44 developed and 12 developing	What is the impact of blended learning compared with no intervention, and compared with non-blended learning for all health professional learners	MEDLINE, CINAHL, Science Direct, EMBASE, Web of science, CENTRAL, ERIC Any language No date restriction	56 13 included in meta-analysis, n=2,238	Quantitative, qualitative, mixed methods Blended vs no intervention: I^2=94.8% Blended vs non-blended: I^2=94.6%	Knowledge	Blended vs no: moderate (downgraded for risk of bias, heterogeneity; upgraded for large effect) Blended vs non: low (downgraded for risk of bias, publication bias, heterogeneity; upgraded for large effect)	Meta-analyses performed Blended vs no intervention: SMD 1.4 (95% CI 1.04 to 1.77) Blended vs non-blended: SMD 0.81 (95% CI 0.57 to 1.05)
Dunleavy 2019	All healthcare professional learners	USA, China, Iran, Kenya, Turkey, Ethiopia	Effectiveness of mLearning interventions for delivering health professions education	MEDLINE, EMBASE, Cochrane, PsycINFO, ERIC, CINAHL, Web of Science Any language 1990 – 2017	29 n=3,175	RCT, cluster RCT Knowledge: I^2=88% Skills: I^2=93%	Knowledge Skills Satisfaction	High or unclear risk of bias	Meta-analyses performed Knowledge: SMD 0.20 (95% CI -0.47 to 0.86) Skills: SMD 1.06 (95% CI 0.09 to 2.03) Satisfaction: mixed results
George 2019	Doctors only	USA, Canada, Germany	Effectiveness of online digital education in improving doctors' knowledge, skills and attitudes	Cochrane, MEDLINE, EMBASE, PsychINFO, ERIC, CINAHL, Web of science Any language 1990 – 2017	93 17 for blended n=8,771	RCT, cluster RCT High heterogeneity	Knowledge Skills Satisfaction	Very low quality for knowledge Low quality for skills and satisfaction. Downgraded for unclear/high risk of bias, inconsistency, publication bias	Narrative Knowledge: 2 studies showed blended more effective and 5 studies showed it to be as effective Skills: 6 studies showed blended to be as effective Satisfaction: 3 studies with mixed results

Table 2: Summary of AMSTAR 2 High Quality Reviews

Author & year of publication	Subjects	Countries	Research Question	Sources (years of search)	Number of included papers	Types of papers	Outcomes	Quality of evidence	Major findings
Viljoen 2019	Medical students and residents only ECG training only	USA, China, Sweden	Efficacy of computer-assisted instruction compared with other methods of ECG instruction among medical students and residents	PubMed, Academic Search Premier, CINAHL, PsychINFO, ERIC, Africa-Wide Information, Teacher Reference Center, Scopus, Web of Science, Google Scholar Any language No date restriction	4 3 included in meta-analysis n=422	RCT, cohort I^2=50%	Knowledge	Good quality of evidence	Meta-analysis performed Knowledge of ECGs: SMD 0.84 (95% CI 0.54 to 1.14)

Table 3: Summary of AMSTAR 2 Moderate Quality Review

Author & year of publication	Subjects	Countries	Research Question	Sources (years of search)	Number of included papers	Types of papers	Outcomes	Quality of evidence	Major findings
McCutcheon 2015	Undergraduate nurses	8 countries (not specified)	Impact of both online and blended learning vs. face-to-face learning of clinical skills in undergraduate nursing students?	DARE, MEDLINE, CINAHL, BREI, ERIC, AUEI English only 1995 - 2013	19 2 included blended learning n=184	Quantitative, qualitative, mixed methods High heterogeneity	Skills Satisfaction	Weak evidence	Narrative Skills: Blended learning at least as effective Satisfaction: mixed results
Nagendrababu 2018	Undergraduate and postgraduate Dental Endodontic only	USA, Canada, Iran, Thailand, Netherlands	Does technology enhanced learning result in better educational outcomes compared to traditional learning in endodontics?	PubMed, Scopus English language only No date restriction	13 n=577	RCT I^2=62.7%	Knowledge Skills Satisfaction	3 low risk of bias, "some concerns' with remainder	Meta-analysis for knowledge; narrative for skills and satisfaction Knowledge: SMD 0.14 (95% CI -0.10 to 0.39) Skills: No difference Satisfaction: mixed results

Table 4: Summary of AMSTAR 2 Low Quality Reviews

Author & year of publication	Subjects	Countries	Research Question	Sources (years of search)	Number of included papers	Types of papers	Outcomes	Quality of evidence	Major findings
Rowe 2012	All healthcare professional learners	USA, Canada, UK, Australia, South Korea	Impact of a blended learning approach on healthcare students' clinical competencies	Academic Search Premier, CINAHL, Medline. English only 2000 - 2010	7 n=521	Quantitative, qualitative, mixed methods High heterogeneity	Skills	Not stated	Narrative Skills: possible benefits
Milanese 2014	Allied healthcare professionals	USA, Canada, UK, Taiwan, Denmark, Turkey, Germany	What is the effect on learning of a blended learning model of training delivery method for allied health clinicians?	AMED, AARP, Ageline, CINAHL, Cochrane, EMBASE, ERIC, MEDLINE, PubMed, PsycARTICLES, Science Direct, Scopus, SPORTDiscus, Web of knowledge, Web of Science English only No date restriction	5 4 SRs of 331 studies and 1 RCT (n=101) 11 primary studies on blended learning from SRs used	Systematic reviews, RCT High heterogeneity	Knowledge Satisfaction	High quality stated for SRs and RCT	Narrative Knowledge: some benefit Satisfaction: some benefit
River 2016	Higher education healthcare professionals Team-based learning only	USA, Canada, Colombia	What is the effectiveness of blending technology with team-based learning?	MEDLINE, CINAHL, ERIC, EMBASE English only No date restriction	9 n=2,094	Quantitative, and qualitative High heterogeneity	Knowledge Satisfaction	Not stated	Narrative Unable to make any meaningful conclusion

Table 5: Summary of AMSTAR 2 Critically Low Quality Reviews

The included reviews represent studies from a wide range of countries, with the largest review presenting data from 44 developed and 12 developing countries (Liu et al., 2016, p. e2). Five of the reviews limited their search to studies produced in the English language only (McCutcheon, Lohan, Traynor, & Martin, 2015, p. 255; Milanese, Grimmer-Somers, Souvlis, Innes-Walker, & Chipchase, 2014, p. 86; Nagendrababu et al., 2019, p. 181; River et al., 2016, p. 185; Rowe et al., 2012, p. e216), and these reviews focussed predominantly on practice in the UK and North America. Five of the reviews restricted their focus to specific healthcare groups (George et al., 2019, p. e13269; McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; Viljoen et al., 2017, p. e018811), whilst the remainder had no such restriction.

3.2.3.2 Quality of reviews

The AMSTAR-2 tool was used to appraise the quality of the review papers. The review of reviews identified a broad range of quality, with three high quality reviews (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; Liu et al., 2016, p. e2), one moderate quality review (Viljoen et al., 2017, p. e018811), two low quality reviews (McCutcheon et al., 2015, p. 255; Nagendrababu et al., 2019, p. 181), and three critically low quality reviews (Milanese et al., 2014, p. 86; River et al., 2016, p. 185; Rowe et al., 2012, p. e216). The higher quality studies adhered to PRISMA guidelines for reporting data and had significantly larger pooled sample sizes (2,238 to 8,771) compared with the other studies (101 to 2,094). All of the reviews that restricted their search strategies to English language only were ranked as either low or critically low quality (McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; River et al., 2016, p. 185; Rowe et al., 2012, p. e216).

3.2.3.3 Major findings of reviews

The reviews highlighted three main categories of study outcome: knowledge acquisition, skills acquisition, and participant satisfaction.

Most of the reviews reported outcomes relating to knowledge acquisition, with four studies presenting a meta-analysis for this outcome (Dunleavy et al., 2019, p. e12937; Liu et al., 2016, p. e2; Nagendrababu et al., 2019, p. 181; Viljoen et al., 2017, p. e018811). Blended learning was found to be better than no intervention for knowledge acquisition in 13 studies including 2 RCTs (SMD 1.4, 95% CI

1.04 to 1.77), and also no worse than non-blended learning in 44 studies including 31 RCTs (SMD 0.81, 95% CI 0.57 to 1.05) (Liu et al., 2016, p. e2). This high quality review covered all learners from all health professions and provided a much broader scope of review than other reviews, however it was limited by the large heterogeneity of the studies ($I^2 \geq 93.3$). The authors postulated that blended learning was more effective as students could review electronic materials as often as necessary at their own pace, whilst avoiding the negative feelings of social isolation. They identified publication bias in the non-blended comparison group, so their recommendation was weaker for that comparison. In a high quality review of six studies comparing blended learning with traditional learning for all healthcare professional learners, blended learning was found to be no different in terms of postintervention knowledge scores (SMD 0.20, 95% CI -0.47 to 0.86) (Dunleavy et al., 2019, p. e12937). There was a high degree of heterogeneity between these studies (I^2=88%), with a range of interventions studied including pre-recorded lectures, online programmes, and smartphone apps with multimedia content. A smaller moderate quality review looking specifically at knowledge acquisition from a blended learning approach to electrocardiogram (ECG) training amongst medical students and residents showed a positive effect for blended learning (SMD 0.84, 95% CI 0.54 to 1.14) (Viljoen et al., 2017, p. e018811). Whilst this review only identified three studies, it had a sample size of 422 participants with only a moderate level of heterogeneity between the studies (I^2 = 50%). The quality of evidence for each of the selected studies was rated as good, with some risk of bias in one study for selection (there was no baseline knowledge test to compare groups) and performance (it was not specified if both groups were taught the same curriculum). Finally, a low quality review looking specifically at knowledge acquisition for endodontics in undergraduate and postgraduate dental students analysed eleven studies (Nagendrababu et al., 2019, p. 181). Eight of these studies presented data that could be included in a meta-analysis, which showed no difference between technology-enhanced learning and traditional learning (SMD 0.14, 95% CI -0.10 to 0.39). As with the other reviews, significant heterogeneity was found between the studies (I^2=62.7%). The remaining systematic reviews that reported outcomes relating to knowledge acquisition were able to provide a narrative statement in the absence of a meta-analysis either supporting the concept of a blended learning approach as being at least as effective as traditional approaches (George et al., 2019, p. e13269; Milanese et al., 2014, p. 86), or declaring an inability to make any meaningful conclusion (River et al., 2016, p. 185).

The second outcome that was assessed was the impact of a blended learning approach for clinical skills training. There was a limited amount of evidence available with only five reviews presenting data (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; McCutcheon et al., 2015, p. 255; Nagendrababu et al., 2019, p. 181; Rowe et al., 2012, p. e216). Only one review presented the results of a meta-analysis (Dunleavy et al., 2019, p. e12937). This high quality review of all healthcare professional learners included data from eight studies showing a pooled estimate in favour of blended learning for skills acquisition (SMD 1.06, 95% CI 0.09 to 2.03). There was a very high level of heterogeneity between the studies (I^2=93%), and the evidence was rated as very low quality. Another high quality review could only provide a narrative statement following a review of six studies and stated that a blended learning approach "may be as effective as self-directed or face-to-face training in improving physician's skills" (George et al., 2019, p. e13269). A low quality review analysing the impact of a blended learning approach for endodontic education in undergraduate and postgraduate dental students was similarly unable to perform a meta-analysis due to the high levels of heterogeneity in the studies analysed (Nagendrababu et al., 2019, p. 181). It concluded that a blended learning approach produced no difference in skills performance. Another low quality review stated that the studies addressing a blended learning approach to teaching clinical skills in undergraduate nurse education "showed promise", but that the evidence lacked both quantity and quality (McCutcheon et al., 2015, p. 255). Finally, a critically low quality review stated that "results showed some measure of improvement in clinical skills", although it was later stated that broad claims of improvement were difficult to make (Rowe et al., 2012, p. 185). It did conclude however that a blended learning approach increased the ability to bridge the gap between theory and practice for students.

The final outcome that was assessed was participant satisfaction, and the six reviews addressing this outcome presented mixed results (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; River et al., 2016, p. 185). A common theme in all of these reviews was that some participants preferred online learning whereas some preferred didactic tuition. In some studies, participants undertaking an online component without access to face-to-face felt "disadvantaged" compared with their peers (McCutcheon et al., 2015, p. 255). Those that preferred the face-to-face element felt that this provided a "crutch" to their learning that they were unwilling to give up (River et al., 2016, p. 185). The remainder of the reviews stated that there were "mixed" findings for participant satisfaction (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181).

3.2.3.4 Quality of evidence in the reviews

A common theme throughout all of the reviews is that the level of evidence is of very low quality. A clear statement about level of evidence is presented in seven of the reviews (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; Liu et al., 2016, p. e2; McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; Viljoen et al., 2017, p. e018811), with most analyses declaring an unclear or high risk of bias, high levels of inconsistency, and publication bias. In the remaining reviews, there is sufficient information presented to infer that the evidence is very low quality due to differing educational approaches and other confounding factors such as the means of analysis of the different outcomes. Whilst this is a considerable weakness, the reviews are still able to provide an indication of a treatment effect for a blended learning approach. This is valuable as it provides encouragement for further development and research to occur.

3.2.3.5 Recommendations of reviews

Two reviews (one high quality and one moderate quality) with a combined sample size of 2,660 concluded that blended learning was superior to no or non-blended learning (Liu et al., 2016, p. e2; Viljoen et al., 2017, p. e018811), and one high quality review with a sample size of 8,771 concluded that blended learning was at least as effective as non-blended learning for knowledge acquisition (George et al., 2019, p. e13269). Two reviews (one high quality and one low quality) with a combined sample size of 3,752 concluded that there was no difference between blended and non-blended learning for knowledge acquisition (Dunleavy et al., 2019, p. e12937; Nagendrababu et al., 2019, p. 181). No reviews concluded that blended learning has an adverse effect on knowledge acquisition.

One high quality review with a sample size of 3,175 concluded that blended learning was superior to traditional learning (Dunleavy et al., 2019, p. e12937), and one high quality review with a sample size of 8,771 concluded that blended learning was at least as effective as non-blended learning for skills acquisition (George et al., 2019, p. e13269). One low quality review with a sample size of 577 showed no difference between blended learning and non-blended learning for skills acquisition (Nagendrababu et al., 2019, p. 181). No reviews concluded that blended learning has an adverse effect on skills acquisition.

Six reviews (two high quality, two low quality, and two critically low quality) concluded that there were mixed results for user satisfaction with regard to blended learning in a range of healthcare settings (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; River et al., 2016, p. 185).

3.2.4 Discussion

Blended learning is the combination of electronic and traditional learning, and as such it covers a wide variation of individualised educational formats. The systematic reviews presented in Tables 2 to 5 detail international research conducted in both high and low resource settings that describes the impact of blended learning on a broad range of healthcare professional groups. Blended learning is an approach that is used to address the complexity of learning (Rowe et al., 2012, p. e216) and it is used to support and develop students (McCutcheon et al., 2015, p. 255). It has the ability to increase the convenience and effectiveness for individualised and collaborative learning whilst transcending time and space boundaries (Liu et al., 2016, p. e2), and can therefore accommodate diverse student needs (River et al., 2016, p. 185). There is a demand for flexible, tailored and timely methods of teaching (Milanese et al., 2014, p. 86) which are also efficient and cost-effective (Dunleavy et al., 2019, p. e12937). Students benefit from the ability to learn anywhere, anytime and at their own pace (George et al., 2019, p. e13269) and it is therefore important that this approach to learning is studied with regard to educational outcomes as well as participant satisfaction. The drivers for its development are therefore, in essence, the potential benefits outlined in section 3.2.1.

The main limitation of these reviews is that they are based upon very low quality evidence due mainly to a high level of heterogeneity in the literature. The wide variation in interventions, course design and formats meant that it was difficult to provide a clear comparison between studies. The included studies describe a broad range of interventions including (but not limited to) web-based e-learning, online lectures, video case scenarios, blogging groups, use of Twitter, CD-ROM and video conferences. These interventions have a diverse ability to provide interactivity and engagement with learners, and this impacts upon their individual potential efficacy. Some of the interventions were fixed in time (e.g. video conferences) whilst others provided greater flexibility for learners to access them at their convenience. The technology used in some studies was quite basic (e.g. CD-ROM) as opposed to other studies that used more contemporary online learning packages. The use of blogging groups and similar social interventions may have conferred an additional benefit of reducing social isolation for learners when compared with other interventions. The only review with a moderate level of heterogeneity (I^2=50%) analysed the impact of blended learning on a focussed topic, namely the acquisition of ECG knowledge (Viljoen et al., 2017, p. e018811). The reviews that had a less focussed research question, displayed higher levels of heterogeneity.

Five of the reviews limited their search to studies produced in the English language only (McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; River et al., 2016, p. 185; Rowe et al., 2012, p. e216). As a result, the data presented was mainly from practice in the UK and North America. Whilst the results of these reviews are more likely to be applicable to UK practice, their narrower scope means that valuable evidence from other non-English speaking parts of the world may have been omitted.

Five of the reviews restricted their focus to specific healthcare groups (George et al., 2019, p. e13269; McCutcheon et al., 2015, p. 255; Milanese et al., 2014, p. 86; Nagendrababu et al., 2019, p. 181; Viljoen et al., 2017, p. e018811). Whilst there are some advantages of reviewing one specific approach to healthcare professional education, there is a risk that the broader benefits of multi-professional education are not captured in such an analysis. The main disadvantage of this approach is that the availability of published data for healthcare professional education in general is already limited. Analysing a sub-group of healthcare education is therefore unlikely to provide enough data to reach a definitive conclusion.

The paucity of published evidence prior to 2000 means that the earlier systematic reviews are unable to provide any clear recommendations about the benefits of a blended learning approach (McCutcheon et al., 2015, p. 255; Milanese et al., p. 86, 2014; Rowe et al., 2012, p. e216). These reviews suggested that a blended learning approach may be better than face-to-face or online learning alone, but there was limited evidence to make a conclusive opinion. This inability to provide a definitive statement is also seen in one systematic review that chose to focus on specific aspects of a blended learning approach, namely blending technology with team-based learning (River et al., 2016, p. 185). A meta-analysis was not performed in this review owing to the small number of heterogenous studies identified. This demonstrates a need for further research into the application of blended learning in specific areas where there is a lack of current evidence.

The outcome with the most conclusive evidence is knowledge acquisition. This is not surprising, as it is relatively easy to report objective outcomes such as MCQ scores that can then be combined for a meta-analysis. The general conclusion from these reviews was that a blended learning approach is at least as good and potentially better than a non-blended approach for knowledge acquisition. One of the strengths of a blended learning approach is that it enables the participant to prepare for the face-to-face element at a time of their choice, and also that they can repeat online learning as often as they wish. The use of an online learning element is particularly useful for factual information and it is therefore understandable that this approach is beneficial for knowledge acquisition when compared with a non-blended approach.

The benefits of a blended learning approach are less certain for the acquisition of skills, according to this review. Whilst the inference is that blended learning may have a positive effect for clinical skills education, the evidence is currently insufficient to support a recommendation. E-learning can be used to present video demonstrations of skills to enable participants to understand the approach in its correct context, but most clinical skills also require hands-on training to achieve competency. This may explain why a blended learning approach may not offer any significant benefit as the majority of the learning will take place during the face-to-face element of the course. In contrast, the evidence from the reviews does not infer that a blended learning approach has any detrimental effect on learning. This is a domain that therefore requires further research and evidence, as clinical skills are an important healthcare competency.

The results for the final outcome, participant satisfaction, are mixed. It is clear from many of the reviews that a blended learning approach is not necessarily suitable for every learner or every educational situation. It is important therefore that its use is carefully planned and evaluated rather than just assumed to be the best approach. This conclusion is supported by others who state that blended learning is highly context dependent and may not be suitable in all situations (Nortvig et al., 2018, p. 46; Valentina et al., 2019, p. 17).

3.2.4.1 Limitations of the review of reviews

The search was purposefully performed in healthcare databases only, with a focus on healthcare professional education. The reason for this was that this holds the greatest relevance to ALS training, which is designed as a postgraduate healthcare course. There is a possibility that searching non-healthcare databases may have identified additional reviews, including more reviews involving undergraduate students. Reviews were only included if they were published in the English language. As with the similar limitation described for the reviews themselves, this has the potential to exclude data from non-English speaking parts of the world. In addition, the data from primary studies not included in any of the reviews (including those where a blended learning approach was not immediately obvious from the title) was not descriptively analysed. Finally, there is the possibility that the principles of blended learning may have been described in reviews published prior to 2000, albeit before the concept had been formally described.

3.2.5 Conclusion

In summary, it appears that a blended learning approach has numerous advantages over a traditional non-blended approach, and it has been successfully used in a variety of healthcare situations. The evidence from a review of systematic reviews shows that there is a positive effect for a blended learning approach in terms of knowledge acquisition. There is a paucity of evidence from systematic reviews for its use for clinical skills training, although the limited evidence available does not infer any negative effect. Finally, there is conflicting evidence about the impact of blended learning on participant satisfaction. The findings from this review of reviews, and their relevance to the e-ALS course, will be discussed further in Chapter 5.

3.3 Alignment with educational theory

It is important that educational theories are taken into consideration when designing new courses, as they provide the basis for choice of instructional strategies (Khalil & Elkhider, 2016, p. 147). In this section, I will describe how blended learning aligns with the commonly described educational theories. Technological advances in education have helped to change the theoretical approach to teaching and it has been stated that they have helped to facilitate the use of instructional methods by shifting the style of learning towards the constructivist approach (Cook et al., 2008, p. 1181). This represents a different learning environment to that which existed prior to this era.

Medical education in the late 20th century aligned predominantly with the behaviourist approach (Skinner, 1990, p. 1). Skinner believed that behaviour could be shaped by rewarding good behaviour (positive reinforcement) and not rewarding undesirable behaviour (negative reinforcement). In this model of learning, the role of the teacher was pivotal such that they would be in total control of the educational experience dictating what was right and what was wrong with little opportunity for student reflection. Students would be regarded as a 'blank slate' and would be the recipient of learning with no recognition of any prior experience or learning. Didactic teaching sessions involving lectures to mass audiences, tutor-led tutorials, and negatively marked MCQs all contributed to this style of approach (Nunes & McPherson, 2003, p. 1). An example of this approach that continues to be used in healthcare education is the use of simulation for skills training. Students benefit from the 'trial and error' manikin approach to training without the fear that they will cause actual harm. They learn from positive results, but also from a situation where the simulation has a negative conclusion (Aliakbari, Parvin, Heidari, & Haghani, 2015, p. 2). The use of simulation in this way within advanced life support courses has been shown to have a positive effect on skills retention after the course (Kelly et al., 2019, p. 284).

In contrast, the constructivist theory (Bruner, 1966, p. 1; Piaget, 1953, p. 1) describes how students construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences. Students compare new information and experiences with their prior held beliefs and actively change behaviour or disregard the learning based upon their analysis of the material. The theory that nothing is learnt from scratch and that learners build upon the platform of experience in order to introduce new concepts has also been described as social constructivism (Vygotsky, 1980, p. 1). It has been stated that constructivism and behaviourism are not two distinct entities but lie at either end of a continuum (Jonassen, 1992, p. 137). The constructivist approach has also been described as an amalgamation between the behaviourist and cognitive approach (Amineh & Asl, 2015, p. 9), the latter of which focuses on the processes involved in learning including the process of integrating new information into existing knowledge.

Healthcare is a practical specialty and cannot be replaced entirely with e-learning (Valentina et al., 2019, p. 17). There is a need for interaction with experts to develop higher level thinking skills such as the synthesis or evaluation of knowledge (Morton et al., 2016, p. 195). Underpinning this is the importance of social interaction and the social processes in learning and this is consistent with the social learning theory (Bandura & Walters, 1963, p. 1). This theory describes a situation where learners flourish by observing and imitating others, thus placing their learning in a social context. It recognises that we interact and learn from others in the same environment and this can also include learning from observing positive and negative reinforcement in other learners. The face-to-face interaction with peers also improves motivation (Markett, Sánchez, Weber, & Tangney, 2006, p. 280; Westerlaken et al., 2019, p. 289) and enables students to bond and realise the importance of team working (Shorey, Siew, & Ang, 2018, p. 77). The term ‘situated learning’ has been used to describe the process of learning through participation in collaborative activities with other professionals. It has also been described as a theory of communities of practice (Lave & Wenger, 1991, p. 1). This version of situated cognition suggests that learning occurs when embedded within activity, context, and culture. It is usually unintentional rather than deliberate, and this has been described by the same authors as “legitimate peripheral participation”. The aim is to move learners towards full participation by allowing newcomers to learn through observation. It has been further described as “groups of people who share a concern or passion for something they do and learn how to do it better as they interact regularly” (Graven, 2003,

p. 185). Integral to this is the concept known as the 'Zone of Proximal Development' which is defined as the difference between what a learner can do without help and what they can do with help. This zone is defined as an area of learning that is assisted by a teacher or peer with a skill set that is higher than the learner. A key principle with situated learning is the element of social interaction and, as such, a blended learning approach ensures that this component is not omitted as is it would be with a pure e-learning approach.

With the introduction of the internet, social media, blogs and online discussion forums, the approach to learning theory has further radically changed. Traditional theories like behaviourism and constructivism are based upon classroom-based learning. Learning can no longer be regarded as an individual trait as there are now networks, resources, and opportunities available that were previously unimaginable. This has led to the development of the theory of connectivity (Downes, 2010, p. 27; Siemens, 2004, p. 1). The principle behind connectivism is that learning is dependent on a diversity of opinions and multiple sources of opinion. The ability to learn in this context is influenced by the diversity of the network and also the strength of the bonds between the information sources and may also utilise 'non-human appliances' in the form of virtual and augmented reality. The process of identifying these sources is itself part of the learning process and can enable the learner to gain a greater comprehension of the subject. As such, the use of technology with the flexibility and interactivity that it provides has been described as leading to an enhanced constructivist learning environment (Kok, 2009, p. 3). One of the key strengths of connectivism is that it enables flexible learning time (Şahin, 2012, p. 437). If a student feels like learning, they can do so at that moment and not be reliant upon formal and organised programmes that may conflict with work, family commitments, or location difficulties. Another strength of connectivism is that it has the potential to expose the learner to a vast range of information. This in itself is also a potential weakness if that information is inaccurate and from an unreliable source. Another weakness of this approach is that it may place those with a lack of digital literacy skills at a disadvantage. There are also concerns about the potential harmful effects of an addiction to technology and the social isolation that this may foster (Şahin, 2012, p. 437). In contrast, if the online elements of a learning programme are appropriately designed, these virtual communities of practice (Henri & Pudelko, 2003, p. 474; Kimble, Hildreth, & Wright, 2001, p. 216) can open up further opportunity within the blended learning approach for social inclusion.

The reality is that over many years, multiple theories have been proposed for the purpose, application, and interpretation of education and learning in general. Understanding educational theory is important as it enables us to understand, evaluate and improve the methods of teaching (Albert, Hodges, & Regehr, 2007, p. 103; Rees & Monrouxe, 2010, p. 334). By looking through the lens of different frameworks, alternative ways of teaching can be highlighted that may benefit the diversity of students attending the courses. The impact of e-learning and blended learning, and the changing theoretical approaches to education can all be reflected by the evolution of the ALS course. Whilst there are many similarities and differences between the various theories, they represent learning in context with different stages and situations of learning (Badyal & Singh, 2017, p. S1). This will be discussed in more detail in the next section.

3.4 Relevance to ALS training

In this section, I will outline how the RC(UK) ALS course has developed in line with contemporary educational theory, as well as discussing how the e-ALS course aligns with the benefits of a blended learning approach.

The educational delivery of the ALS course has evolved over the years since its inception from an instructor led approach to an approach that utilises technology and promotes self-directed learning. The earlier iterations of the ALS course strongly reflected the behaviourist approach that was commonly used at that time with a significant proportion of the teaching being delivered by a series of sixteen lectures. This approach was prone to cognitive overload, lower cognitive engagement, and therefore had a lesser motivational impact. There was also an emphasis on rote learning and repeated practice to achieve perfection. The use of simulation training with manikins has already been cited as an example of this approach, but another example is the preferred format of feedback that was used until the last decade. 'Pendleton's Rules' (Pendleton, 1984, p. 1) provided a rigid feedback structure centred around a discussion about what went well followed by what could be improved. Candidates were asked for their understanding of each concept first, followed by the views offered by the instructor. This provided the positive and negative reinforcement that underpins the behaviourist approach.

Over the years, the emphasis of the ALS course has moved away from didactic lectures to a more participative focus involving group work. ALS candidates come from a variety of backgrounds, professions and levels of expertise. This prior knowledge is valued, and they are encouraged to share that expertise with their colleagues. All of the teaching components of the ALS course require active participation by each candidate. The majority of the workshops are based upon problem-based learning and the simulations require candidates to manage realistic case scenarios in collaborative activities with other professionals. Individuals share their expertise with each other, and the intention is that they will bond as a group through this situated learning experience. A risk of this approach, however, is that such group work could also lead to a negative experience if there is a disruptive element in the group. As part of the debriefing, they are expected to reflect on their experiences in a safe educational environment and they subsequently participate in action planning to improve. Finally, candidates build upon their prior experience and either the new learning will resonate with what they already know, replace what they thought was correct, or can be ignored. It can be demonstrated therefore that the course has moved along the spectrum towards a more constructivist approach.

The constructivist approach is not necessarily beneficial for all candidates as there are some learners who do actually benefit from a more direct and didactic approach. The value of the group approach can also be challenged as it can potentially mask the important minority viewpoint. In its purest sense, constructivism avoids direct instruction and relies on the instructor guiding the students to discovering knowledge on their own. Within the time frame of an ALS course, this is not always feasible, and some direct instruction is still required. The standard course programme therefore still contains five lectures enabling didactic reinforcement of core facts. Whilst the workshops are designed to facilitate discussion, there is also a clear set of learning objectives for each session and instructors will inevitably guide students towards the things they need to know. This formal structure for the sessions contradicts the approach that constructivists may promote as there may not be sufficient time for self-learners to attain the outcomes needed. In addition, some candidates prefer highly structured learning environments to excel.

An aspect of the ALS course that has remained constant since its inception has been the scenario teaching sessions, where candidates learn how to manage a patient in cardiac arrest in a simulated environment. This form of situated learning enables candidates to learn as a team in the same context that they will be putting the skills into practice in real life. In addition, the principles of the theory of communities of practice resonate with the structured approach to skills teaching for the ALS course. The ‘four-stage approach’ enables learners to become actively more engaged, moving from the periphery to the centre of the learning experience to gain expertise (Bullock, 2000, p. 139; Peyton, 1998, p. 13). The four stages comprise a real time demonstration of the skill by the instructor, a repeat but this time with an expert description of the components of the skill, repeated once again with the trainee now describing components of the skill, and finally trainee practice with supervision. This approach builds upon the ‘Advance Organiser’ theory (Ausubel, Novak, & Hanesian, p. 1) which states that candidates find it easier to learn if they have already been presented with information that enables them to orient themselves to the topic. This underpins the first part of the four-stage technique where candidates watch and listen to a real-time run through of the skill to be learnt. They subsequently have in their mind a vision of how it should be done before the second stage when the skill is slowed down and explained in more detail. After a period allowing for questions, the student then talks the instructor through the process of the skill in the third stage before performing the skill themselves in the fourth stage. The concept therefore means that they have witnessed the skill being performed at least three times before they actually get to perform it themselves, allowing them to progress along the spectrum from novice towards mastery. Whilst commonly used as a technique on life support courses, there have been challenges to its validity with some feeling that not all four stages are necessary. Two studies (Greif, Egger, Basciani, Lockey, & Vogt, 2010, p. 1692; Orde, Celenza, & Pinder, 2010, p. 1687) showed no difference in outcomes between two-stage, three-stage and four-stage teaching methodologies. Despite this, the four-stage technique continues to be used as it is not felt that either of these studies had robust enough methodology to lead to any recommendations for change (Barelli & Scapigliati, 2010, p. 1607). More recently, a study looking at a comparison between a two-stage and four-stage approach to complex skills training (BLS/AED) showed no difference between the two approaches (Bjørnshave et al., 2018, p. 18). Another study that looked at 3-month retention of basic life support skills also found no difference between a two-stage and a four-stage approach to skills training (Bomholt et al., 2019, p. 1). The emerging evidence therefore that an educational strategy may exist that takes less time to execute and results in equivalent immediate and three-month skills performance could now lead to a revision of the decision to retain the four-stage approach.

The theory of connectivity introduces new opportunities for the delivery of resuscitation education. An exciting element of this theory is the acknowledgment of non-human appliances, including the use of artificial intelligence and virtual environments. An example from resuscitation training of this approach is the development of the RC(UK) Lifesaver (www.lifesaver.org.uk) and Lifesaver VR (www.lifesavervr.org.uk) apps for CPR training. Lifesaver is an immersive interactive game that is free to download and can be played online, on smartphones, and on tablets. Through a series of real life 'game in film' scenarios, the user can resuscitate victims of cardiac arrest and choking. It presents real-time consequences of decisions with the ability to revisit incorrect decisions so that the learner is always presented with the correct way to manage the scenario. The innovative element is the use of the accelerometer in the smart device to give live feedback and tuition to the player on the depth and rate of their simulated chest compressions. The fidelity of this is further amplified in the virtual reality version, where the use of simple cardboard goggles and a cushion on the floor transforms the experience. The effectiveness of Lifesaver was evaluated in a randomised controlled trial of three groups of school children (Yeung et al., 2017, p. S71). The study concluded that the use of Lifesaver by school children, compared to face-to-face training alone, can lead to comparable learning outcomes. It was proposed that its use can be considered where resources or time do not permit formal face-to-face training sessions. The true benefits for Lifesaver were realised when it was used alongside face-to face training as a blended learning approach. More contemporary technology has led to the utilisation of augmented reality for educational benefit. This describes the ability to superimpose computer generated imagery on the user's views of their surroundings. A feasibility study involved the delivery of CPR training utilising an augmented reality package to a convenience sample of 51 healthcare providers (Balian, McGovern, Abella, Blewer, & Leary, 2019, p. e02205). The participants were able to deliver chest compressions following training that complied with recommendations for compression rate, depth and percentage achievement of complete recoil. Both virtual and augmented reality therefore offer exciting future possibilities for key elements of resuscitation training.

The ALS course is a successful combination of numerous theoretical approaches. Learners use a constructivist approach to problem solve and build upon their baseline knowledge, and they do this within a social learning context. Embedded in this approach are some behaviourist aspects of learning whereby they learn discrete knowledge and skills via positive and negative reinforcement. The further development of a blended learning approach to ALS education aligns in particular with the theory of connectivity, with its utilisation of an online community of learning. The format of the e-ALS course delivers the benefits of blended learning that have previously been articulated in section 3.2.1. In particular, it allows candidates the ability to tailor their learning experience of the theoretical elements of ALS to a time and place of their convenience. It also allows them to revisit elements of the e-learning content if necessary, to further deepen their understanding of the subject matter. Whilst candidates on a conventional ALS course have the same ability with pre-course reading from the course manual, the e-learning modules deliver a greater degree of interactivity to capture the interest of the e-ALS candidate. There are also clearer links between the e-learning modules and the face-to-face elements of the course, including an online video of a typical cardiac arrest simulation. This helps to prepare the candidates for their face-to-face experience in a way that the manual cannot achieve. By maintaining a face-to-face element to the course, candidates are still able to benefit from peer and instructor led learning, as well as learning skills in a simulated environment that closely resembles the situation that they are being trained for. One of the main benefits of this blended approach is that it enables the face-to-face element to be reduced to one day thus reducing the study leave time and course costs for the candidate, as well as reducing the time needed for faculty to teach. As will be discussed in further detail in Chapters 4 and 5, the blended learning approach is not suitable for all age groups or learning styles and therefore the e-ALS course has not been designed to replace the c-ALS course. The two variants will continue to be delivered as long as demand for both courses continues to exist. The concept of a blended learning approach to advanced life support training therefore seemed to make sense but it was essential that this was formally evaluated. The research presented in Chapter 4, and the discussion in Chapter 5, will describe the process of the piloting, evaluation, improvement, and re-evaluation of the e-ALS course in greater detail.

Chapter 4: Published Research

In this chapter, I will present a narrative summary of the five publications that comprise the primary portfolio, along with a description of their strengths and weaknesses. The 2010 ILCOR EIT process concluded that "any method of pre-course preparation that is aimed at improving knowledge and skills or reducing instructor-to-learner face-to-face time should be formally assessed to ensure equivalent or improved learning outcomes compared with standard instructor-led courses" (Soar et al., 2010, p. e288). The following papers, that are presented in this research portfolio, are therefore of importance as they address that need for formal assessment as well as proving a positive association between course participation and patient survival.

Paper 1: Lockey, A., Lin, J., & Cheng, A. (2018). Impact of adult advanced cardiac life support course participation on patient outcomes – a systematic review and meta-analysis. *Resuscitation* 129:48-54

Paper 2: Perkins, G. D., Kimani, P. K., Bullock, I., Clutton-Brock, T., Davies, R. P., Gale, M., Lam, J., Lockey, A., & Stallard, N. (2012). Improving the efficiency of advanced life support training. *Annals of Internal Medicine* 157:19-28

Paper 3: Lockey, A. S., Dyal, L., Kimani, P. K., Lam, J., Bullock, I., Buck, D., Davies, R. P. & Perkins, G. D. (2015). Electronic learning in advanced resuscitation training: the perspective of the candidate. *Resuscitation* 97:48-54

Paper 4: Thorne, C. J., Lockey, A. S., Bullock, I. Hampshire, S., Begum-Ali, S., Perkins, G. D., on behalf of the Advanced Life Support Subcommittee of the Resuscitation Council (UK). (2015). e-learning in advanced life support – an evaluation by the Resuscitation Council (UK). *Resuscitation* 90:79-84

Paper 5: Thorne, C. J., Lockey, A. S., Kimani, P. K., Bullock, I., Hampshire, S., Begum-Ali, S., on behalf of the Advanced Life Support Subcommittee of the Resuscitation Council (UK). (2017). e-Learning in Advanced Life Support – what factors influence assessment outcome? *Resuscitation* 114:83-91

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Review

Impact of adult advanced cardiac life support course participation on patient outcomes—A systematic review and meta-analysis

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ABSTRACT

Objectives: The objective of this study was to evaluate the impact of the prior participation of one or more members of the adult resuscitation team in an accredited advanced life support course on patient outcomes (return of spontaneous circulation, survival to discharge, survival to 30 days, and survival to 1 year).

Methods: A systematic search of Medline, CINAHL, Embase, ERIC, and Cochrane databases was conducted through 6 March 2018. We included randomised and observational studies in any language. Reviewers independently extracted data on study design and outcomes. The GRADE approach was used to evaluate the overall quality of evidence for each outcome.

Results: Nine hundred and ninety-two articles were identified of which eight observational studies were included. No randomised controlled trials were identified. Meta-analysis showed an association between participation of healthcare personnel in an advanced life support course and return of spontaneous circulation [odds ratio (OR) 1.64; 95% CI 1.12–2.41, risk difference (RD) 0.10 (95% CI 0.03–0.17)]. Life support training showed a significant absolute effect on patient survival to discharge [RD 0.10, 95% CI 0.01–0.18], but non-significant relative effect [OR 2.12; 95% CI 0.98–4.57]. Data from one study showed an association with survival to 30 days [OR 7.15; 95% CI 1.61–31.69, RD 0.18 (95% CI 0.08–0.27)].

Conclusion: The inference of this review is that the advanced life support courses have a positive impact upon return of spontaneous circulation and survival to hospital discharge. The data also implies a positive impact upon survival to 30 days of adult cardiac arrest patients.

Introduction

The Advanced Cardiac Life Support (ACLS) course was first developed by the American Heart Association (AHA) in 1979 following their third national conference on cardiopulmonary resuscitation (CPR). The aim at that time was to develop and disseminate a standardised approach to the management of adult patients in cardiac arrest. In the early 1980's, a series of experts from the United Kingdom visited various courses and conferences in the United States (USA). The imported anglicised versions of ACLS were unified by the Resuscitation Council (UK) and became the course known today in the UK as the Advanced Life Support (ALS) course. This course was subsequently used as the basis for the European Resuscitation Council (ERC) and Australian Resuscitation Council (ARC) ALS courses.

Both courses are targeted at healthcare professionals who play an active role in the management of adult patients suffering from cardiac arrest. Suitable candidates include doctors, nurses, nurse practitioners, paramedics, outreach clinicians, and resuscitation officers/trainees. They learn the knowledge and skills needed to recognise and treat the deteriorating patient, deliver high quality CPR to adults, manage a cardiac arrest by working with a multidisciplinary team in an emergency situation, and utilise non-technical skills to facilitate strong team leadership and effective team membership. Over the years since their inception, both courses have evolved in a similar fashion from a didactic lecture-based format to versions incorporating e-learning and a greater emphasis on video-based learning, repetitive practice, simulation-based training [1,2] and debriefing [3]. In parallel with developments in educational delivery, the courses have also been continually updated to reflect contemporary international resuscitation guidelines.

The courses are cumulatively accessed throughout the world by over 1.3 million candidates every year (1,270,000 ACLS and 41,500 ALS). Despite these courses being the gold-standard for resuscitation education, the key question for stakeholders is whether attendance of healthcare personnel on such courses has an impact on patient

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outcomes. This is particularly important since evidence suggests that skills of many providers tend to decay within months of taking resuscitation courses [1,4]. We aimed to conduct a systematic review and meta-analysis of the published literature to determine if participation of one or more members of the resuscitation team in an accredited advanced life support course improves patient outcomes.

Methods

The review was planned, conducted and reported in adherence with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards of quality for reporting meta-analyses [5]. The study was registered with Prospero on 17 November 2017 (registration number CRD42017081667).

PICO question

We structured our question according to the PICO format – Population/Patient, Intervention, Comparator, and Outcome [6]. We asked, "In adult patients who have a cardiac arrest (P), does prior participation of one or more members of the resuscitation team in an accredited advanced life support course (I) as opposed to no such participation (C) affect the following patient outcomes – return of spontaneous circulation (ROSC), survival to hospital discharge, survival to 30 days, or survival to one year (O)?"

Study eligibility

Studies of any language were included that specifically looked at the impact upon adult patient outcomes of attendance at an accredited advanced cardiac life support course, including the AHA ACLS, RC(UK), ERC or ARC ALS course, by one or more of the healthcare personnel attending a patient in cardiac arrest. Studies looking at other types of life support courses (e.g. trauma, paediatric, neonatal, basic life support) were excluded. Studies that only looked at the impact of individual components of the course (e.g. defibrillation, airway management, drug therapy) were also excluded. We included both randomized trials and observational studies in the systematic review.

Data sources

We searched Medline, CINAHL, Embase, ERIC, and Cochrane with the last search date of 6 March 2018. The search strategy included terms "advanced cardiac life support", "cardiopulmonary resuscitation", "health personnel", "medical staff" and "nursing staff". The complete search strategy is described in Appendix 1 in Supplementary material. We also searched OpenGrey, EThOS and MedNar for reports presented at symposia, conferences, workshop and meetings.

Study selection

The titles of all potentially eligible studies were screened for inclusion with 100% agreement by two reviewers (AL, AC). Any articles that were included were also scrutinised for additional citations that may be relevant to the PICO. Any disagreements between the reviewers were resolved by discussion.

Data collection

Data from each paper was independently extracted by each reviewer and any conflicts were resolved by discussion to reach consensus. Data was collated separately for each outcome, namely return of spontaneous circulation (ROSC), survival to hospital discharge, survival to 30 days, and survival to 1 year. These outcomes were prioritised separately by two authors (A.L. and A.C.) as 'critical' with a consensus agreement on this in view of the impact upon patient as opposed to educational outcomes.

Analysis and GRADE approach

We used both quantitative and qualitative syntheses of evidence. Considering the clinical and content heterogeneity of included studies, we used a random effects model for meta-analysis. Data was entered into Review Manager (RevMan5, The Cochrane Collaboration, Oxford, UK) to calculate the odds ratio (OR) and risk difference (RD), 95% confidence intervals and statistical heterogeneity. Heterogeneity between studies was assessed by reviewing the methodology in each study, as well as visually inspecting the forest plots, which were statistically assessed using the chi-squared test. The extent of heterogeneity among studies was expressed with I^2, with I^2 values > 50% indicating large inconsistency or heterogeneity [7]. We conducted sensitivity analyses for ROSC and survival to hospital discharge by pooling results of studies with the same study designs.

The GRADE (Grades of Recommendation, Assessment, Development and Evaluation) approach was used to evaluate the overall quality of evidence with respect to five different domains of quality [8]: (1) limitation of study design and execution; (2) inconsistency; (3) indirectness; (4) imprecision; and (5) publication bias across all included trials. An evidence profile was created with one row dedicated to each outcome. Rating was conducted independently by two raters (A.L. and A.C.). Where there was disagreement, consensus was reached by discussion.

Results

Study selection

The search identified 992 articles. Of these, 974 articles were excluded leaving 18 full text articles to be screened for eligibility (see Appendix 2 in Supplementary material). Ten papers were excluded as they were either: literature reviews that contained no additional data, studies of the wrong population (not a formal advanced life support course as an intervention), editorials, simulation-based research (i.e. with no clinical outcomes), or examining only individual advanced life support interventions. In total, eight observational studies were identified for inclusion from the initial search. No additional studies of relevance were found by searching the grey literature.

Study characteristics

The study design and participant characteristics of included studies detailing any population differences are summarised in Table 1. All of the studies related to in-hospital cardiac arrest, with no studies referring to out-of-hospital cardiac arrest. The studies were conducted between 1986 and 2011. One study [9] related to the RC(UK) ALS course, whilst the remainder related to the AHA ACLS course delivered in a range of locations (USA, Brazil and India). Five studies were retrospective pre- and post-intervention cohort analyses [9–13]. One study was a retrospective cohort study [14] and two were prospective cohort studies [15,16]. In total, there were 1732 participants. Six studies (n = 1461) analysed the return of spontaneous circulation. Seven studies (n = 1507) analysed survival to hospital discharge. One study (n = 156) analysed survival to 30 days. Two studies (n = 455) analysed survival to 1 year. We were unable to formally evaluate the publication bias due to limited number of studies for each meta-analysis. It should be noted however that published outcomes were variable.

Risk of bias within studies

The risk of bias assessment is summarised in Table 2. There were two main issues identified relating to eligibility criteria and presence of confounding issues. Only four studies [10,13,14,16] contained

Table 1
Summary of included studies.

Study	Design	Setting	Number of patients	Outcome measures	Results
Lowenstein (1986) [10]	Retrospective cohort study, pre- and post-AHA ACLS	379 bed urban teaching hospital, Boston USA	90–37 pre ACLS (68% male; Age 68yr +/−1.8); 53 post ACLS (48% male; Age 65yr +/−2.1)	ROSC; Survival to hospital discharge	- 1st rhythm: Pre ACLS (VF 39%, Asystole 48%); Post ACLS (VF 25%, Asystole 56%) - ROSC increased from 32% to 60% (p = 0.009) - Survival to hospital discharge increased from 13% to 23% (p = NS)
Sanders (1994) [11]	Retrospective cohort study, pre- and post-AHA ACLS	Emergency Department in 42 bed rural community hospital, Arizona USA	64–29 pre ACLS (66% male; Age 60.7 yr +/−23.6); 35 post ACLS (51% male; Age 69.6yr+/−17.3)	ROSC; Survival to hospital discharge	- 1 st rhythm: Pre ACLS (VF 36%, Asystole 40%); Post ACLS (VF 44%, Asystole 29%) - No significant difference in ROSC (2/29 vs 7/35) and survival to discharge (1 vs 2)
Makker (1995) [15]	Parallel, prospective, consecutive sample of patients resuscitated by AHA ACLS certified medical residents, ACLS certified Emergency Physicians, and non-certified physicians	437 bed community teaching hospital, New Jersey USA	225–180 ACLS: 76 medical residents and 104 ED residents; 45 non—ACLS; 60.9% male; Age 63.4yr+/−17.6	ROSC	- 1 st rhythm: VF/VT 26.2%, Asystole 15% - ROSC ACLS certified medical 48.7% vs certified ED 29.8% (p = 0.010); All ACLS certified 37.8% vs non-ACLS certified 46.7% (p = NS)
Camp (1997) [12]	Retrospective cohort study, pre- and post-AHA ACLS	119 bed rural community hospital, Georgia USA	236–42 pre; 179 post ACLS; no data on age range or sex	Survival to hospital discharge	- No data on 1[st] rhythm - Pre-intervention 35.7% survivors vs - Post-intervention 29.1% survivors - (p > 0.3)
Pottle (2000) [9]	Retrospective cohort study, pre- and post-RC(UK) ALS	181 bed specialist cardiothoracic hospital, Harefield UK	299–139 pre; 160 post ALS; 68.1% male; Age 72 yr (range 21–88)	ROSC; Survival to hospital discharge; Survival to 1 year	- 1 st rhythm: VF/VT 58.3%, Asystole 21.7% - Increase in ROSC (71.94% to 80%) and Survival to discharge (32.8% to 41.9%) - Similar numbers surviving to 1 year (22.3% vs 20.6%) - No p values available (authors contacted)
Dane (2000) [14]	Parallel, cohort case comparison (nurse trained vs untrained in AHA ACLS)	550 bed tertiary centre, Georgia USA	117–29 non-ACLS; 88 ACLS	Survival to hospital discharge	- Survival rate 37.5% in ACLS trained group vs 10.3% in in-ACLS trained group (p < 0.02)
Moretti (2007) [16]	Parallel, multi-centre prospective cohort study (at least one member of team trained in AHA ACLS vs no trained member of team)	7 hospitals in Brazil	156–54 not trained; 102 trained; no data on age range or sex	ROSC; Survival to hospital discharge; Survival to 30 days; Survival to 1 year	- 1 st rhythm: VF 21.6%, Asystole 15.8% - Significant increase in ROSC (p = 0.04), survival to 30 days (p < 0.02) and survival to 1 year (p < 0.002) for ACLS group - Increased survival to discharge for ACLS group (p = 0.23)
Sodhi (2011) [13]	Retrospective cohort study, pre- and post-AHA ACLS	250 bed tertiary care hospital, India	627–284 pre ACLS (57% male; Age 58.8yr+/−8.2); 343 post ACLS (54.8% male; Age 55.1yr+/−6.9)	ROSC; Survival to hospital discharge	- No data on 1[st] rhythm - Increase in ROSC from 18.3% to 28.3% (p < 0.005) - Increase in survival to discharge 23.1% to 69.1% (p < 0.001)

Table 2
Risk of bias assessment.

Study	Year	Design	Total Patients	Population	Industry Funding	Non-RCT bias assessment			
						Eligibility Criteria	Exposure/Outcome	Confounding	Follow Up
Lowenstein	1986	Non-RCT	90	AHA ACLS	No	Low	Low	Low	Low
Sanders	1994	Non-RCT	64	AHA ACLS	No	High[b]	Low	Low	Low
Makker	1995	Non-RCT	225	AHA ACLS	No	Unclear[c]	Low	High[d]	Low
Camp	1997	Non-RCT	236	AHA ACLS	No	High[e]	Low	High[d]	Low
Pottle	2000	Non-RCT	299	RC(UK) ALS	No	High[f]	Low	High[d]	Low
Dane	2000	Non-RCT	117	AHA ACLS	Partial[a]	Low	Low	High[d]	Low
Moretti	2007	Non-RCT	156	AHA ACLS	No	Low	Low	Low	Low
Sodhi	2011	Non-RCT	627	AHA ACLS	No	Low	Low	High[d]	Low

[a] Portions of the research were funded by a Teaching Methods Grant from AHA to the first author.
[b] Did not elaborate on exclusion criteria for cardiac arrest patients.
[c] All incidents analysed but not clear how identified.
[d] Prognostic factors not adjusted for in statistical analysis of most studies; considered low if they reported characteristics of patients in one group vs another and described p values.
[e] Differing and unclear eligibility criteria for three periods of study.
[f] Only those with completed audit form (86.5%) included.

sufficient detail about eligibility criteria for inclusion, including clear exclusion criteria. In one study [12], there were differing eligibility criteria for the three periods of study. In another [9], only those with a completed audit form were included. Only three studies [10,11,16] were assessed to be low risk for confounding issues. The remaining studies did not report characteristics in the different groups and therefore could not demonstrate that prognostic factors had been adjusted for in the statistical analysis. All of the studies were assessed to be low risk for exposure, outcome and follow up.

Results

The results are summarised in Table 3.

Return of spontaneous circulation

For the critical outcome of return of spontaneous circulation, we identified six studies [9–11,13,15,16] (n = 1461; very low quality evidence downgraded for risk of bias, inconsistency, indirectness and imprecision) with data ranging from 1979 to 2010. The data showed an association between course participation and return of spontaneous circulation, with a pooled odds ratio of 1.64 (95% CI 1.12–2.41; Fig. 1)

Table 3
Summary of findings. **Question:** ALS compared to no ALS for health problem or population.

Certainty assessment							No of patients		Effect		Certainty	Importance
Noof studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	ALS	no ALS	Odds Ratio (95% CI)	Risk Difference (95% CI)		
ROSC												
6	observational studies	serious[a]	serious[b]	serious[c]	serious[d]	none	378/873 (43.3%)	203/588 (34.5%)	**OR 1.64** (1.12 to 2.41)	**RD 0.10** (0.03 to 0.17)	⊕○○○ VERY LOW	CRITICAL
Survival to Discharge												
7	observational studies	serious[a]	serious[b]	serious[c]	serious[d]	none	259/893 (29.0%)	100/614 (16.3%)	**OR 2.12** (0.98 to 4.57)	**RD 0.10** (0.01 to 0.18)	⊕○○○ VERY LOW	CRITICAL
30 day survival												
1	observational studies	not serious	not serious	not serious	serious[d]	none	22/102 (21.6%)	2/54 (3.7%)	**OR 7.15** (1.61 to 31.69)	**RD 0.18** (0.08 to 0.27)	⊕○○○ VERY LOW	CRITICAL
1 year survival												
2	observational studies	serious[a]	serious[b]	not serious	serious[d]	none	51/262 (19.5%)	31/193 (16.1%)	**OR 3.61** (0.11 to 119.42)	**RD 0.08** (0.13 to 0.30)	⊕○○○ VERY LOW	CRITICAL

CI: Confidence interval; **OR:** Odds ratio; **RD:** Risk difference.
Explanations.
[a] Mixture of serious and low risk of bias studies.
[b] Some studies showed significant improvement, and some showed no improvement.
[c] Differences in patient type, hospital type, provider type and team composition, and nature of intervention.
[d] Absence of confidence intervals.

Study or Subgroup	A(C)LS Events	A(C)LS Total	No A(C)LS Events	No A(C)LS Total	Weight	Odds Ratio M-H, Random, 95% CI
Makker 1995	68	180	21	45	17.7%	0.69 [0.36, 1.34]
Pottle 2000	128	160	100	139	21.5%	1.56 [0.91, 2.67]
Sodhi 2011	97	343	52	284	27.0%	1.76 [1.20, 2.58]
Moretti 2007	46	102	16	54	16.5%	1.95 [0.97, 3.94]
Lowenstein 1986	32	53	12	37	12.6%	3.17 [1.32, 7.66]
Sanders 1994	7	35	2	29	4.7%	3.38 [0.64, 17.71]
Total (95% CI)		**873**		**588**	**100.0%**	**1.64 [1.12, 2.41]**
Total events	378		203			

Heterogeneity: $Tau^2 = 0.10$; $Chi^2 = 9.83$, df = 5 (P = 0.08); $I^2 = 49\%$
Test for overall effect: Z = 2.53 (P = 0.01)

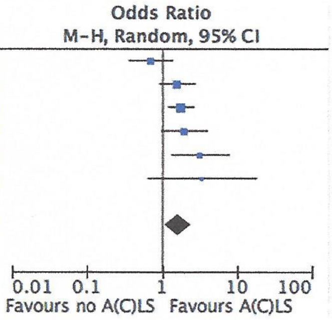


Fig. 1. Return of spontaneous circulation.

and a pooled risk difference of 0.10 (95% CI 0.03–0.17). Statistical heterogeneity was moderate ($I^2 = 49\%$, $p = 0.08$).

Within studies evaluating ROSC, Moretti et al [16] showed that increased numbers of ACLS-certified staff in the resuscitation team was associated with a higher rate of ROSC (OR 2.07, $p = 0.037$) in the logistic regression model.

Survival to hospital discharge

For the critical outcome of survival to hospital discharge, we identified seven studies [9–14,16] (n = 1507; very low quality evidence downgraded for risk of bias, inconsistency, indirectness and imprecision) with data ranging from 1979 to 2010. The data showed a significant absolute effect on patient survival to hospital discharge, with a pooled risk difference of 0.10 (95% CI 0.01–0.18; Fig. 2B), but a non-significant relative effect with a pooled odds ratio of 2.12 (95% CI 0.98–4.57; Fig. 2A). Statistical heterogeneity was high ($I^2 = 82\%$, $p < 0.001$).

Dane et al [14] reported the effect of ACLS training (adjusted OR 1.97, $p = 0.04$) on survival to hospital discharge, adjusting for initial rhythm. The effect size is much smaller compared to unadjusted OR, indicating that the initial rhythm is an important factor associated with survival.

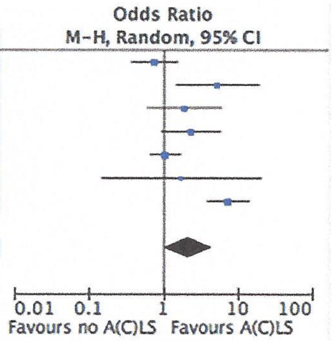
Survival to 30 days

For the critical outcome of survival to 30 days, we identified one study [16] (n = 156; very low quality evidence downgraded for imprecision) with data ranging from 1998 to 2001. The data showed an association between course participation and patient survival to 30 days with an odds ratio of 7.15 (95% CI 1.61–31.69) and risk difference of 0.18 (95% CI 0.08–0.27). As the 95% confidence limits are wide, these results should be interpreted with caution.

A

Study or Subgroup	A(C)LS Events	A(C)LS Total	No A(C)LS Events	No A(C)LS Total	Weight	Odds Ratio M-H, Random, 95% CI
Camp 1997	52	179	15	42	16.7%	0.74 [0.36, 1.50]
Dane 2000	33	88	3	29	12.7%	5.20 [1.46, 18.53]
Lowenstein 1986	12	53	5	37	13.6%	1.87 [0.60, 5.86]
Moretti 2007	26	102	7	54	15.3%	2.30 [0.92, 5.71]
Pottle 2000	67	160	57	139	18.1%	1.04 [0.65, 1.64]
Sanders 1994	2	35	1	29	6.5%	1.70 [0.15, 19.72]
Sodhi 2011	67	276	12	284	17.1%	7.27 [3.83, 13.78]
Total (95% CI)		**893**		**614**	**100.0%**	**2.12 [0.98, 4.57]**
Total events	259		100			

Heterogeneity: $Tau^2 = 0.79$; $Chi^2 = 33.39$, df = 6 (P < 0.00001); $I^2 = 82\%$
Test for overall effect: Z = 1.91 (P = 0.06)



B

Study or Subgroup	A(C)LS Events	A(C)LS Total	No A(C)LS Events	No A(C)LS Total	Weight	Risk Difference M-H, Random, 95% CI
Camp 1997	52	179	15	42	12.0%	-0.07 [-0.23, 0.09]
Dane 2000	33	88	3	29	12.5%	0.27 [0.12, 0.42]
Lowenstein 1986	12	53	5	37	12.1%	0.09 [-0.07, 0.25]
Moretti 2007	26	102	7	54	14.3%	0.13 [0.00, 0.25]
Pottle 2000	67	160	57	139	15.0%	0.01 [-0.10, 0.12]
Sanders 1994	2	35	1	29	15.7%	0.02 [-0.08, 0.12]
Sodhi 2011	67	276	12	284	18.5%	0.20 [0.14, 0.26]
Total (95% CI)		**893**		**614**	**100.0%**	**0.10 [0.01, 0.18]**
Total events	259		100			

Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 25.03$, df = 6 (P = 0.0003); $I^2 = 76\%$
Test for overall effect: Z = 2.18 (P = 0.03)

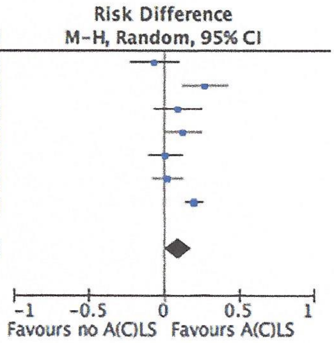


Fig. 2. Survival to hospital discharge.

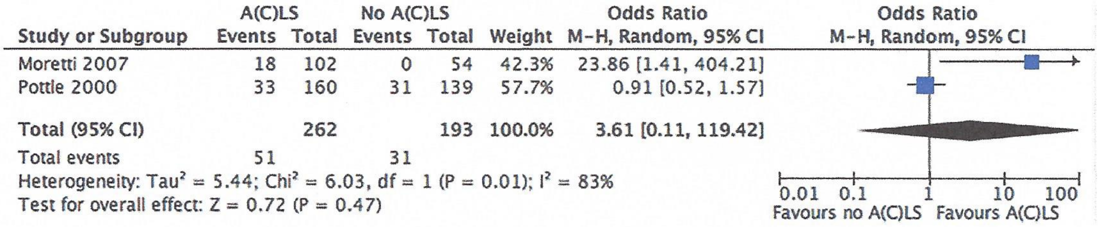


Fig. 3. Survival to 1 year.

Survival to 1 year

For the critical outcome of survival to one year, we identified two studies [9,16] (n = 455; very low quality evidence downgraded for risk of bias, inconsistency, and imprecision) with data ranging from 1993 to 2001. The data showed non-significant association between course participation and patient survival to 1 year with a pooled odds ratio of 3.61 (95% CI 0.11–119.42; Fig. 3) and risk difference of 0.08 (95% CI -0.13–0.30). Statistical heterogeneity was high (I^2 = 83%, p = 0.01).

Sensitivity analysis

We conducted sensitivity analyses by pooling results with the same study designs. We found an association between course participation and ROSC in pre- and post- cohort studies; however, the association is not significant in studies with parallel control. For long term survival outcome (i.e. survival to hospital discharge and survival to one year), studies with rigorous designs showed significant results (Table 4).

Discussion

Limitations and strengths

Analysing the outcomes from non-randomised studies can be challenging as there is a high risk of selection bias, due to differences between populations in the various intervention groups. Only three of the studies [10,11,16] included a detailed description of the separate group characteristics. Only one study adjusted for the initial rhythm of the patient [14] and one study adjusted for the number of ACLS certified staff in the resuscitation team [16].

Advanced life support training is not the only factor that can influence patient outcomes. Despite this, we feel that it is reasonable to combine the studies in the analysis as the intervention (ALS training) and the outcome measures are objective and standardised. To strengthen the analysis, we performed a sensitivity analysis by pooling results with the same study designs.

International Guidelines are reviewed and updated every five years, meaning that papers studying the effects of the course prior to 2015 are no longer as applicable. The algorithms for managing patients in cardiac arrest have changed significantly over the years, and the instructional design of how the courses are taught have also been updated in line with educational research [1].

A limitation is that there was no standardisation between studies with regard to the number of advanced life support trained members of the resuscitation team. It could be argued that the collective knowledge, clinical skills and non-technical skill performance of a team where many or all members are advanced life support trained may produce better outcomes than a team with only one trained member.

Whilst the target audience remains similar, some of the interventions taught on the course have varied over the years. One of the largest studies to study the importance of advanced airway management and drug therapy was the OPALS study from Ontario [17] which included 5638 patients enrolled from 17 cities in a system already optimised to deliver rapid defibrillation. There were significant differences to return of spontaneous circulation and survival to hospital, but no significant difference however for longer term outcomes (i.e. survival to discharge, survival with cerebral performance category level 1 to one year). These findings support the argument that advanced airway management and drug therapy are of lesser importance in the management of patients in cardiac arrest. On both the AHA ACLS and RC(UK) ALS courses, advanced airway management has been de-emphasised.

Over the years, there has been increasing emphasis on the team approach to resuscitation, with inclusion of new content in the form of videos, lectures and inclusion in the debriefing component of simulation-based education. Multiple reviews of the team training literature support the use of simulation-based team training for improving the process of resuscitative care, both in the simulated and clinical environments [18–22]. While this potentially adds benefit for patient outcomes, it does introduce a potential confounder as these elements were not emphasized in most advanced life support courses until 2010 [23,24]. Emphasis is now given to key crisis resource management principles, including teamwork, leadership, resource allocation, communication and situational awareness [1,25,26]. The RC(UK) ALS course includes the use of an adapted version of the TEAM tool [27] to guide an informal assessment of use of these skills during the teaching scenarios.

It would seem therefore that the benefits of the course outweigh the individual components taught. It is well documented that individual skills decay rapidly after tuition [1,4], but many other factors contribute to determining the outcome of the patient. This is alluded to by Pepe, Abramson and Brown [28] who challenge the efficacy of the components of ACLS yet state that "it would appear that something about the 'ACLS' worked".

Integration with prior work

Williams et al [29] concluded that some evidence is available that advanced life support interventions can improve outcome for patients suffering cardiac arrest in hospital. Their review included studies analysing the outcome from simulation assessments as well as actual patient outcomes. Only one study relating to our review [16] was identified as their review was limited to studies published between 2005

Table 4
sensitivity analyses.

Outcome	Design	Number of studies	Effect size (95% CI)	P -value	I^2
ROSC	Historical control	4	1.85 (1.38, 2.46)	< 0.001	0%
	Parallel control	2	1.15 (0.42, 3.18)	0.78	77%
Survival to hospital discharge	Historical control	5	1.78 (0.66, 4.81)	0.26	87%
	Parallel control	2	3.05 (1.42, 6.57)	0.004	0.6%
Survival to one year	Historical control	1	0.91 (0.52, 1.57)	0.72	N/A
	Parallel control	1	23.86 (1.41, 404.21)	0.03	N/A

and 2010. We believe that our review is the first to identify all studies relating exclusively to actual patient outcomes.

Implications and recommendations

The studies included in this review contain data ranging from 1979 to 2010. During this time, the content and delivery of the course has changed significantly. In the earlier papers, the authors have truly been able to look at outcomes before and after introduction of the course. The course from those early days, however, bears no resemblance to contemporary versions and the clinical science behind cardiac resuscitation has advanced significantly since then. The latter studies therefore benefit from representing an era more closely aligned with current practice. The drawback however is that it is more difficult to guarantee that those in the control cohorts have not had some sort of previous advanced life support instruction. The difference between the early and latter studies partly explains the large heterogeneity of the meta-analyses.

One theme that has emerged from some of the papers is that the introduction of advanced life support courses to hospitals may impact upon clinical practice and actually increase the number of resuscitation attempts made [10,12]. This has an effect in particular on the comparison of outcomes in pre- and post-intervention studies as the population studied is then different. Conversely, the number of patients who previously had an inappropriate resuscitation attempt may decrease as well. Clearly both these factors may be a positive consequence of the course and may contribute to an increased survival rate from the implementation of the course.

The advanced life support courses have a cost and resource implication for candidates, faculties, and organisations. They have evolved over the years in terms of course length and availability of e-learning in recognition of the increasing time pressures on healthcare professionals. It is appropriate to analyse if attendance at such a course produces any tangible benefit to patient outcomes given the resource that is invested in these courses. Within the limit of available studies, we feel that there is a desirable effect in terms of patient outcome albeit from very low quality evidence. The organisations that administer and govern these courses should continue to explore opportunities to deliver the training in the most educationally efficient way possible whilst being mindful of the resource implications. This approach is feasible and should continue to be acceptable to all stakeholders.

Conclusions

When looking at the analysis of pooled data, the inference is that the advanced life support courses have a positive impact upon return of spontaneous circulation and survival to hospital discharge. The data also implies a positive impact upon survival to 30 days. Future research should explore the impact of the courses on patient outcomes in the context of fully trained resuscitation teams.

Conflict of interest statement

Andrew Lockey is a Trustee of the Resuscitation Council (UK), which administers the Advanced Life Support course in the UK. None of the other authors have any conflicts of interest.

Acknowledgement

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2018.05.034.

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Paper 1 is a systematic review and meta-analysis using GRADE methodology (Schünemann, 2013, p. 1) of eight observational studies (Lockey, Lin, & Cheng, 2018, p. 48). The review was planned, conducted and reported in adherence with PRISMA standards of quality for reporting meta-analyses and was registered with Prospero on 17 November 2017 (registration number CRD42017081667). My contribution to this paper included conception and design, analysis and interpretation of the data, drafting of the article, and final approval of the article. The systematic review addressed a specific research question according to the PICO (**P**opulation, **I**ntervention, **C**ontrol, **O**utcomes) format. The question asked was: In adult patients who have a cardiac arrest (P), does prior participation of one, or more, members of the resuscitation team in an accredited advanced life support course (I) as opposed to no such participation (C) affect the following patient outcomes – return of spontaneous circulation (ROSC), survival to hospital discharge, survival to 30 days, or survival to one year (O)? A total of 992 articles were identified by the initial literature search in March 2018, of which eighteen full text articles were screened for eligibility. No randomised controlled trials were identified. This systematic review identified eight observational studies which were designed as either historical control (Camp, Parish, & Andrews, 1997, p. 529; Lowenstein, Sabyan, Lassen, & Kern, 1986, p. 512; Pottle & Brant, 2000, p. 46; Sanders et al., 1994, p. 56; Sodhi, Singla, & Shrivastava, 2011, p. 209) or parallel control (Dane, Russell-Lindgren, Parish, Durham, & Brown Jr, 2000, p. 83; Makker, Gray-Siracusa, & Evers, 1995, p. 116; Moretti et al., 2007, p. 458). Meta-analyses were performed for the outcomes that were reported in the identified papers; namely ROSC, survival to hospital discharge, survival to thirty days, and survival to one year. For ROSC, very low quality evidence was identified (downgraded for risk of bias, inconsistency, indirectness and imprecision) from six observational studies (Lowenstein et al., 1986, p. 512; Makker et al., 1995, p. 116; Moretti et al., 2007, p. 458; Pottle & Brant, 2000, p. 46; Sanders et al., 1994, p. 56; Sodhi et al., 2011, p. 209) enrolling 1,461 patients showing benefit for advanced cardiac life support training (OR 1.64, 95% CI 1.12 to 2.41). For survival to hospital discharge, very low quality evidence was identified (downgraded for risk of bias, inconsistency, indirectness and imprecision) from seven observational studies (Camp et al., 1997, p. 529; Dane et al., 2000, p. 83; Lowenstein et al., 1986, p. 512; Moretti et al., 2007, p. 458; Pottle & Brant, 2000, p. 46; Sanders et al., 1994, p. 56; Sodhi et al., 2011, p. 209) enrolling 1,507 patients showing possible benefit for advanced cardiac life support training (OR 2.12 95%, CI 0.98 to 4.57; RD 0.10, 95% CI 0.01 to 0.18). For survival to thirty days, very low quality evidence was identified (downgraded for imprecision) from one observational study (Moretti et al., 2007, p. 458) enrolling 156 patients showing benefit for advanced cardiac life support training (OR 7.15, 95% CI 1.61 to 31.69). Finally, for survival to one year, very low quality evidence was identified (downgraded for risk of bias, inconsistency, and imprecision) from two observational studies (Moretti et al., 2007, p. 458; Pottle & Brant, 2000, p. 46) enrolling 455 patients showing no benefit for advanced life support training (OR 3.61, 95% CI 0.11 to 119.42). The review concluded that prior attendance of at least one cardiac arrest team member on an advanced life support course may have a positive impact upon ROSC and survival to hospital discharge. Data from one study suggested an association with survival to thirty days as well. There was no impact upon survival to one year.

One of the strengths of this systematic review is that it was conducted using GRADE methodology (Schünemann, 2013, p. 1). This process has been adopted by over 100 organisations worldwide, including the National Institute for Health Care and Excellence (NICE) and the World Health Organisation (Guyatt et al., 2008, p. 924). The Grading of Recommendations Assessment, Development and Evaluation (GRADE) process considers the magnitude of effect and the quality of evidence at an individual outcome level. So, for example, a single paper may produce evidence of differing levels of quality for multiple outcomes, and the purpose of GRADE is to ensure that there is no overarching conclusion from a paper that either upgrades or downgrades evidence inappropriately. Each topic for a GRADE review is structured using the PICO format (**P**opulation, **I**ntervention, **C**ontrol, **O**utcomes). The quality of evidence is split into four levels; namely high, moderate, low and very low. High levels of evidence are generally seen in randomised controlled trials where there is confidence that the true effect is close to that of the estimate of the effect. Low levels of evidence are usually seen in observational studies, and the true effect is likely to be different to the estimate of effect in very low levels of evidence. Five factors impact upon the quality of evidence and these are risk of bias, inconsistency, indirectness, imprecision, and publication bias. They each need to be assessed at an outcome level and all can lower the quality of evidence. If the majority of studies for each of these five domains show a low risk for that domain then no downgrading of evidence is recommended. If there is a moderate or high risk in any domain, then downgrading of evidence up to two levels of evidence is recommended. On the basis of the review, a level of quality of evidence is then formulated for each outcome (high, moderate, low or very low). Paper 1 utilised the GRADE approach as it is an approach that considers the specific effect of an intervention at outcome level, which was consistent with the design of the papers identified. An alternative format could have been a scoping review, which is an approach that is typically used to present an overview of a large and often heterogenous body of literature. Scoping reviews are particularly useful if the studies included have a range of methodologies and study designs. They are used to provide a descriptive overview, as opposed to a statistical synthesis of evidence, and are often used in the preliminary phase to identify if a systematic review is feasible or not. As there is no assessment of bias in a scoping review, the output cannot be used to generate treatment recommendations. The GRADE approach was chosen for Paper 1 as it was felt that the heterogeneity in the studies was mitigated as the structure of the intervention studied was standardised as were the outcomes. To further strengthen the analysis, sensitivity analyses of the two designs of study were included for each outcome. This confirmed an association between course participation and ROSC in historical control studies but not in parallel control studies. The association for longer term outcomes were significant for parallel control studies, which was important as they represented a more robust methodological approach.

A potential limitation of this paper is that the studies included in this systematic review covered a period of time that spanned over twenty years. This limitation was mitigated to some extent as only one study (Sodhi et al., 2011, p. 209) presented data from courses that were run following the first set of international guidelines in 2000. The papers studied in the review were of variable quality with only three studies including specific descriptions of the groups analysed (Lowenstein et al., 1986, p. 512; Moretti et al., 2007, p. 458; Sanders et al., 1994, p. 56). The remaining studies were at risk of exhibiting selection bias as it is unclear if the populations studied were similar. Finally, there was no standardisation between studies with regard to the number of members of the resuscitation team who were advanced life support trained. There is a potential that teams with more than one trained member may have better results due to the benefits of team working, but this was not accounted for in the review. Despite these declared limitations, Paper 1 provides evidence using a systematic and transparent process for evidence evaluation that the participation of one, or more, members on an adult in-hospital cardiac arrest team may lead to improved patient survival outcomes. This places in context the importance of the remaining papers in this programme of research as the conventional advanced life support courses are an educational intervention that save lives. Any variation of that intervention would therefore need to be properly developed, piloted, and evaluated to ensure that this benefit is not lost.

Annals of Internal Medicine | Original Research

Improving the Efficiency of Advanced Life Support Training

A Randomized, Controlled Trial

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Background: Each year, more than 1.5 million health care professionals receive advanced life support (ALS) training.

Objective: To determine whether a blended approach to ALS training that includes electronic learning (e-learning) produces outcomes similar to those of conventional, instructor-led ALS training.

Design: Open-label, noninferiority, randomized trial. Randomization, stratified by site, was generated by Sealed Envelope (Sealed Envelope, London, United Kingdom). (International Standardized Randomized Controlled Trial Number Register: ISCRTN86380392)

Setting: 31 ALS centers in the United Kingdom and Australia.

Participants: 3732 health care professionals recruited between December 2008 and October 2010.

Intervention: A 1-day course supplemented with e-learning versus a conventional 2-day course.

Measurements: The primary outcome was performance in a cardiac arrest simulation test at the end of the course. Secondary outcomes comprised knowledge- and skill-based assessments, repeated assessment after remediation training, and resource use.

Results: 440 of the 1843 participants randomly assigned to the blended course and 444 of the 1889 participants randomly assigned to conventional training did not attend the courses. Performance in the cardiac arrest simulation test after course attendance was lower in the electronic advanced life support (e-ALS) group compared with the conventional advanced life support (c-ALS) group; 1033 persons (74.5%) in the e-ALS group and 1146 persons (80.2%) in the c-ALS group passed (mean difference, −5.7% [95% CI, −8.8% to −2.7%]). Knowledge- and skill-based assessments were similar between groups, as was the final pass rate after remedial teaching, which was 94.2% in the e-ALS group and 96.7% in the c-ALS group (mean difference, −2.6% [CI, −4.1% to 1.2%]). Faculty, catering, and facility costs were $438 per participant for electronic ALS training and $935 for conventional ALS training.

Limitations: Many professionals (24%) did not attend the courses. The effect on patient outcomes was not evaluated.

Conclusion: Compared with conventional ALS training, an approach that included e-learning led to a slightly lower pass rate for cardiac arrest simulation tests, similar scores on a knowledge test, and reduced costs.

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Ann Intern Med. 2012;157:19-28. www.annals.org
For author affiliations, see end of text.
* For a list of the Electronic Advanced Life Support Collaborators, see the **Appendix** (available an www.annals.org).

Competency in advanced life support (ALS) is a core component of undergraduate (1, 2) and postgraduate (3, 4) medical curricula. Each year, more than 1.5 million health care professionals around the world attend advanced resuscitation courses. With pressure on budgets across health care systems (5), there is a need for more cost-effective solutions for training.

The growth of the Internet and the increased popularity of using computers at work and at home during the past decade have provided opportunities for innovation and new approaches to health care education (6, 7). Alternatives to the traditional model of instructor-delivered training, such as DVD (8, 9) or electronic learning (e-learning) solutions (10), are proven to be effective options for training laypersons in cardiopulmonary resuscitation (CPR). However, the spectrum and complexity of advanced resuscitation skills are greater, and whether components of the ALS curriculum can be effectively delivered through e-learning is uncertain (11, 12). Our study aims to determine whether a blended solution to advanced resuscitation training, comprising a combination of e-learning and face-to-face instructor training, produces outcomes similar to those of conventional, instructor-led training.

Methods

Design Overview

Our study was an open-label, noninferiority, randomized, controlled trial. Participants were enrolled between December 2008 and October 2010, when target recruitment was achieved. Follow-up was completed in January 2011. The study was approved by a national research ethics committee from the West Midlands, United Kingdom (UK), on behalf of all U.K. centers and the human research ethics committee of the University of Western Australia. Institutional approvals were obtained at participating centers.

Heart of England National Health Service Foundation Trust acted as the coordinating center and sponsor. The trial was conducted in accordance with the principles of good clinical practice and has been reported in accordance with the Consolidated Standards of Reporting Trials recommendations (13, 14). Participants provided written in-

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Context

Advanced life support (ALS) training is required for many health care providers.

Contribution

This trial, involving 3732 health care professionals, compared a conventional 2-day on-site ALS course with a 1-day course supplemented with electronic learning (e-learning). More participants in the conventional group (80%) than in the e-learning group (75%) passed a cardiac arrest simulation test. Other skill and knowledge tests were similar between the groups. Costs were higher for conventional training.

Caution

Many eligible participants (24%) did not attend the courses.

Implication

An ALS course supplemented with e-learning was less expensive but had lower pass rates on cardiac arrest simulation tests than did conventional training.

—*The Editors*

formed consent through a central online consent service hosted by the Resuscitation Council (UK).

Setting and Participants

Participants were recruited from 31 study centers located in England (n = 25), Wales (n = 1), Scotland (n = 2), Northern Ireland (n = 1), and Australia (n = 2). Study centers advertised courses locally through newsletters, Web sites, and word of mouth and nationally through the Resuscitation Council (UK) course list (www.resus.org.uk/pages/courses.htm) and Australian Resuscitation Council Web site (www.resus.org.au/als_ils/default.htm).

Course centers assessed eligibility before randomization. Included participants were health care professionals, either registered or in training, who held a current clinical (or training) appointment. Participants were expected to apply advanced resuscitation skills as part of their clinical duties. Exclusion criteria were refusal to provide informed consent, lack of space for a participant to attend the course at the chosen center, and enrollment less than 4 weeks before the course began.

Randomization and Interventions

Secure electronic randomization was provided by Sealed Envelope (Sealed Envelope, London, United Kingdom; www.sealedenvelope.com). Randomization (1:1 allocation to a conventional vs. blended learning course) was stratified by course center by using random, permuted blocks of 6. The course administrator at each center randomly assigned participants.

Conventional ALS Course

The ALS course is a 2-day (20-hour) advanced interprofessional resuscitation training program (15). The course teaches the knowledge, attitudes, and skills to both lead and participate as a member of a resuscitation team. A multiprofessional faculty of trained instructors teaches the courses. The instructor–candidate ratio is no more than 1:3.

The course comprises 4 lectures, 6 interactive workshops, 2 skill stations (covering airway management, initial assessment, CPR, and defibrillation), and 12 structured cardiac arrest simulation sessions. Participants work in groups of 4 to 6 during the cardiac arrest simulations and are presented with a simulated cardiac arrest by using medium-fidelity resuscitation mannequins (16). This approach enables the team to practice implementing resuscitation algorithms and develop technical and team leadership skills. Participants were given a hard-copy manual 4 weeks before the course.

E-Learning Blended Course

The e-learning material was prepared by using Articulate, version 5.4 (Articulate, New York, New York), and hosted on a customized learning management system. It comprised the same 4 e-lectures as the face-to-face course delivered with a voiceover plus 6 interactive workshops. The workshops used the same case-based learning material as the face-to-face course and were combined with interactive activities and formative tests.

The total playing time was 158 minutes, which excluded time taken to read the material and respond to interactive questions. A sample of the e-learning content is available at www.resus.org.uk/eALSsamp/player.htm. The time spent by each user logged into the e-learning system (maximum time, 24 hours) was recorded automatically.

After completing the e-learning material, participants attended a 1-day (10-hour) face-to-face course that comprised the 2 skill stations and 12 structured cardiac arrest simulation sessions from the conventional course plus a cardioversion and pacing workshop. Participants received a hard copy of the manual and had access to the e-learning material 4 weeks before the face-to-face element of the course.

Outcomes and Follow-up

The primary outcome was performance during a standardized simulated cardiac arrest, known as the cardiac arrest simulation test (CASTest), taken immediately after the face-to-face course. Secondary outcomes were knowledge (measured by pre- and postcourse multiple-choice question [MCQ] tests), technical skills assessment (patient assessment, defibrillation, CPR, and airway management), CASTest domain scores, overall course pass rate, the proportion of candidates identified with exceptional performance and invited for instructor training, and the costs of training.

The primary outcome assessment, the CASTest, presented a structured simulation of a patient at risk for cardiac arrest who then had a cardiac arrest. This test was selected as the primary outcome because it provided the best single outcome measure for testing applied knowledge and technical and human factor skills (17). Participants had a resuscitation team for the simulation at their disposal; the team comprised members of the teaching faculty.

Performance was measured by 2 instructors by using a validated rating scale of 24 criteria (18). Each criterion was marked by using an ordinal scale (range, 1 to 4; with 1 indicating unacceptable and 4 indicating excellent). The performance criteria covered 4 domains: periarrest management (5 criteria), management of nonshockable rhythms (7 criteria), shockable rhythms (11 criteria), and postresuscitation care (1 criterion).

At the end of the CASTest, instructors compared scores and agreed on a single score for each domain. The instructors then assigned a pass or fail decision on the basis of a global assessment of the candidates' overall performance. A rate of 1 (unacceptable) in 1 or more domains was a failing grade. If the instructors could not agree on scores or the final outcome, the course director was consulted and made the final decision.

The precourse MCQ test was taken without supervision immediately before the face-to-face course. In the conventional ALS (c-ALS) group, the test was taken after participants had access to the course manual for 4 weeks. In the electronic ALS (e-ALS) group, it was taken after participants had access to the course manual and e-learning material for 4 weeks. The postcourse MCQ test was supervised and completed at the end of the face-to-face course.

Individual questions were grouped into blocks of 4 with a common stem. The pass mark was 75%. The internal consistency reliability measures for the MCQ test (Kuder–Richardson Formula 20) were 0.857 for the precourse MCQs and 0.958 for the postcourse MCQs (data on file). Technical skills in airway management and initial assessment and resuscitation (comprising structured assessment of critically ill patients, basic CPR skills, and defibrillation) were assessed by 2 instructors using an outcome-based assessment template that defines acceptable levels of performance.

At the end of each course, assessors met to identify outstanding performers for consideration for training as future instructors, a classification known as instructor potential. Performance during the course was evaluated by using a standardized, structured scoring sheet that considered the results of the MCQ test, communication, enthusiasm, ability to critique oneself and other participants, interactivity, supportiveness, ability to work cohesively with other members of the team, and credibility.

Participants who were unsuccessful in the initial CASTest were allowed 1 opportunity to repeat the CASTest during the course and one after the course. Participants who were unsuccessful in the postcourse MCQ test were allowed 1 further attempt. All reassessments had to be done within 3 months of the course, at which point the final course outcome was recorded.

The costs of training were the expenses of hiring a room, catering for each course center, and the cost of teaching faculty (for centers in the United Kingdom). Teaching faculty costs were based on the time spent attending the course multiplied by standard tariffs (19) according to clinician profession and grade. Remedial training and reassessment were nominally charged at 2 hours of instructor time per candidate. Calculations were done in British pound sterling and converted to U.S. dollars at an exchange rate of £1.00 to $1.60.

Statistical Analysis

The sample size was calculated on the basis of a test of a noninferiority hypothesis for the primary end point of the pass rate of the initial CASTest. From background data (20, 21), we assumed that the pass rate for the c-ALS group was 74% and judged that the e-ALS group would be concluded noninferior if the pass rate for the e-ALS group was higher than 69% (that is, a noninferiority margin of a 5% absolute difference in pass rates).

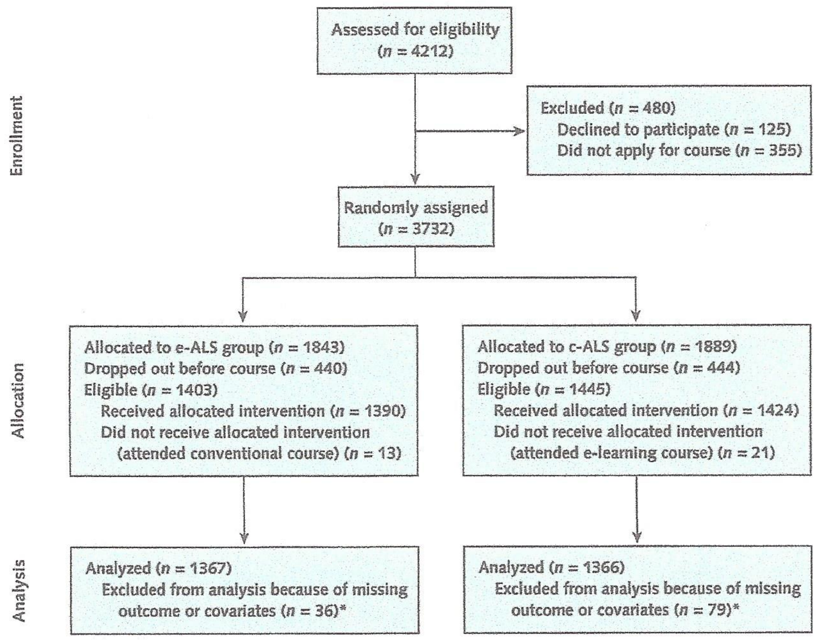
The noninferiority margin was set a priori by an expert group tasked to define the minimal important difference in outcomes. Noninferiority would therefore be demonstrated if a 95% CI for the difference between the e-ALS and c-ALS pass rates was always greater than −5%. The sample size was determined to ensure an 80% power of achieving this when the pass rates in the e-ALS and c-ALS groups were equal.

Assuming a normal approximation to the binomial distribution, a total of 2510 participants (1255 in each group) was required. We included contingency for a 10% dropout rate after randomization because of difficulty with candidates attending the randomly allocated course dates, giving a total target sample size of 2788 (1394 in each group). Recruitment was continued until outcome data were available for this target sample size.

The pass rate for the CASTest was analyzed by using sample survey techniques (21, 22) to obtain estimates for the difference in pass rates for the e-ALS and c-ALS groups and to account for the clustering of participants in courses and centers. The comparison of the e-ALS and c-ALS training was stratified by center and allowed for clustering by course and was adjusted for age and profession. Predictive margins (23) were found and presented as adjusted CASTest pass rates. This analysis was conducted by using version 3.28 of the survey package (http://cran.r-project.org/web/packages/survey) in R, version 2.14.1 (R Foundation for Statistical Computing, Vienna, Austria).

Bootstrap resampling (resampling at the course level) was performed to obtain a 95% CI for the difference between the pass rates. Noninferiority was claimed if all values included in the 95% CI for the difference between e-ALS and c-ALS exceeded −5 (5% margin). A total of 115 trainees (approximately 4% of the trainees who started the courses) had missing values for the CASTest, age, or

Figure 1. **Study flow diagram.**



c-ALS = conventional advanced life support; e-ALS = electronic advanced life support.
* More data are missing for the conventional group because of a computer system error that occurred during the first 3 courses (1 e-learning and 2 conventional courses).

profession. Complete case analysis was performed to avoid including these cases in the analysis.

The binary secondary outcomes were analyzed by using the survey analysis technique in the same way as the primary end point. The MCQ test scores, CASTest scores, and candidate evaluation scores were analyzed by using multilevel linear regression models in SAS, version 9.2 (SAS Institute, Cary, North Carolina). The multilevel regression models included random effects for center and course and were adjusted for age and profession. The scores were assessed for normality and homogeneity of variance.

The analyses of secondary end points yielded adjusted estimates and CIs for the difference in e-ALS versus c-ALS mean scores or pass rates. For secondary outcomes expressed as pass rates, noninferiority was again assessed by using the noninferiority margin of 5%. The study was analyzed on an intention-to-treat basis. In addition, a per-protocol analysis according to the actual course attended was conducted.

Role of the Funding Source

The study was funded with a grant from the Resuscitation Council (UK). The funding source played no role in the study design, statistical analysis, manuscript preparation, or decision to submit the manuscript for publication. It assisted with data collection, but randomization and outcome data were stored and analyzed externally. The National Institute of Health Research provided support for data collection at sites.

RESULTS

A total of 4212 participants was assessed for eligibility; 3732 of these persons gave informed consent and were randomly assigned (**Figure 1**); of this group, 1843 were randomly assigned to the e-ALS group and 1889 to the c-ALS group. A total of 440 participants in the e-ALS group and 444 in the c-ALS group withdrew after randomization but before attending the course. E-mail follow-up of nonresponders indicated that most people withdrew because they were unable to secure leave for the assigned course dates. Thirteen participants randomly assigned to the e-ALS group attended the conventional course; 21 participants allocated to the c-ALS group attended the e-learning course. No participants were lost to follow-up.

As mentioned, both an intention-to-treat analysis and a per-protocol analysis according to the actual course attended were done. Results are presented here for the intention-to-treat analysis. The per-protocol analysis led to similar conclusions.

Table 1 summarizes baseline participant characteristics. Most participants were junior physicians within the first 2 years of graduation. The groups were well-matched with respect to age, profession, specialty, and grade. Baseline characteristics for a few participants were not recorded.

Overall performance on the initial CASTest was lower in the e-ALS group (**Figure 2**). A total of 1033 participants (adjusted estimate of pass rate, 74.5%) passed the assessment in the e-ALS group compared with 1146 (adjusted estimate of pass rate, 80.2%) in the c-ALS group (mean difference, −5.7% [95% CI, −8.8% to −2.7%]). Within the performance criteria scores for the periarrest management domain, the e-ALS group score was higher than that of the c-ALS group (mean difference, 0.79 [CI, 0.44 to 1.15]; $P < 0.001$).

In **Figure 3**, visual inspection of the scores by domain suggests that the difference was most pronounced in the initial assessment of the simulated patient (Airway, Breathing, Circulation, Disability, Exposure approach). By contrast, the score of the e-ALS group for management of nonshockable rhythms was lower than that of the score of the c-ALS group (mean difference, −0.45 [CI, −0.89 to 0.00]; $P < 0.001$). Visual inspection of the domain scores did not identify any specific items as different. There was no significant difference in the cardiac arrest management score for shockable rhythms (mean difference, −0.58 [CI, −1.33 to 0.16]; $P = 0.13$).

Performance in the precourse MCQ test (taken immediately before the face-to-face course) was marginally better in the e-ALS group (mean score, 92.44% for the e-ALS group vs. 88.27% for the c-ALS group). The adjusted difference is 4.19% (CI, 3.71% to 4.67%; $P < 0.001$). There was no significant difference in the end-of-course MCQ test scores (88.96% for e-ALS vs. 89.54% for c-ALS). The adjusted difference was 0.55% (CI, −1.11% to 0.02%; $P = 0.054$). Performances in the initial assessment and resuscitation (pass rate, 99.4% for e-ALS vs. 99.5% for c-ALS) and airway skill assessments (100% pass rate for both groups) were similar.

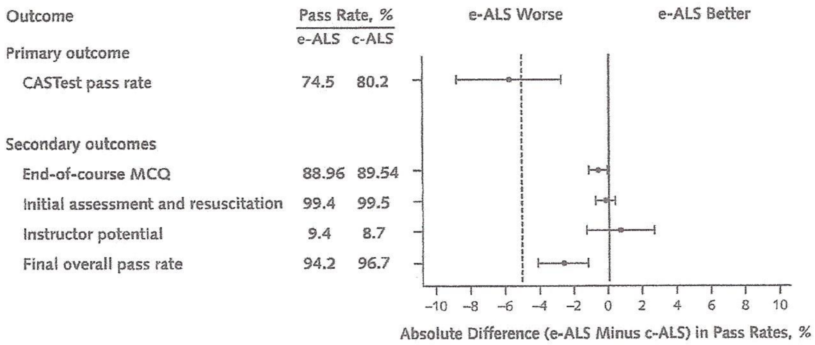
Table 1. **Baseline Participant Characteristics**

Characteristic	e-ALS Group (n = 1403)	c-ALS Group (n = 1445)
Mean age (SD), y	31.3 (7.70)	31.5 (7.85)
Age category, n (%)		
20–29 y	730 (52.0)	704 (48.7)
30–39 y	457 (32.6)	483 (33.4)
40–49 y	161 (11.5)	155 (10.7)
50–59 y	40 (2.9)	40 (2.8)
60–69 y	2 (0.1)	5 (0.3)
≥70 y	1 (0.1)	3 (0.2)
Missing	12 (0.9)	55 (3.9)
Profession, n (%)		
F1 physician	179 (12.8)	195 (13.5)
F2 physician	390 (27.8)	367 (25.4)
Middle-grade/senior physician	455 (32.4)	484 (33.5)
Junior nurse	72 (5.1)	61 (4.2)
Senior nurse	166 (11.8)	173 (12.0)
Operating department practitioner	14 (1.0)	11 (0.8)
Ambulance staff	7 (0.5)	6 (0.4)
Medical student	103 (7.3)	98 (6.8)
Missing	17 (1.2)	50 (3.5)
Specialty, n (%)		
Medicine	333 (23.7)	337 (23.3)
Critical care/anesthesia	229 (16.3)	197 (13.6)
Emergency medicine	162 (11.5)	179 (12.4)
Medical specialty	148 (10.5)	178 (12.3)
Surgery/theaters	191 (13.6)	184 (12.7)
Cardiology	83 (5.9)	85 (5.9)
Prehospital care	14 (1.0)	14 (1.0)
Psychiatry	31 (2.2)	20 (1.4)
Other	205 (14.6)	212 (14.8)
Missing	7 (0.5)	39 (2.7)

c-ALS = conventional advanced life support; e-ALS = electronic advanced life support; F1 = foundation year 1; F2 = foundation year 2.

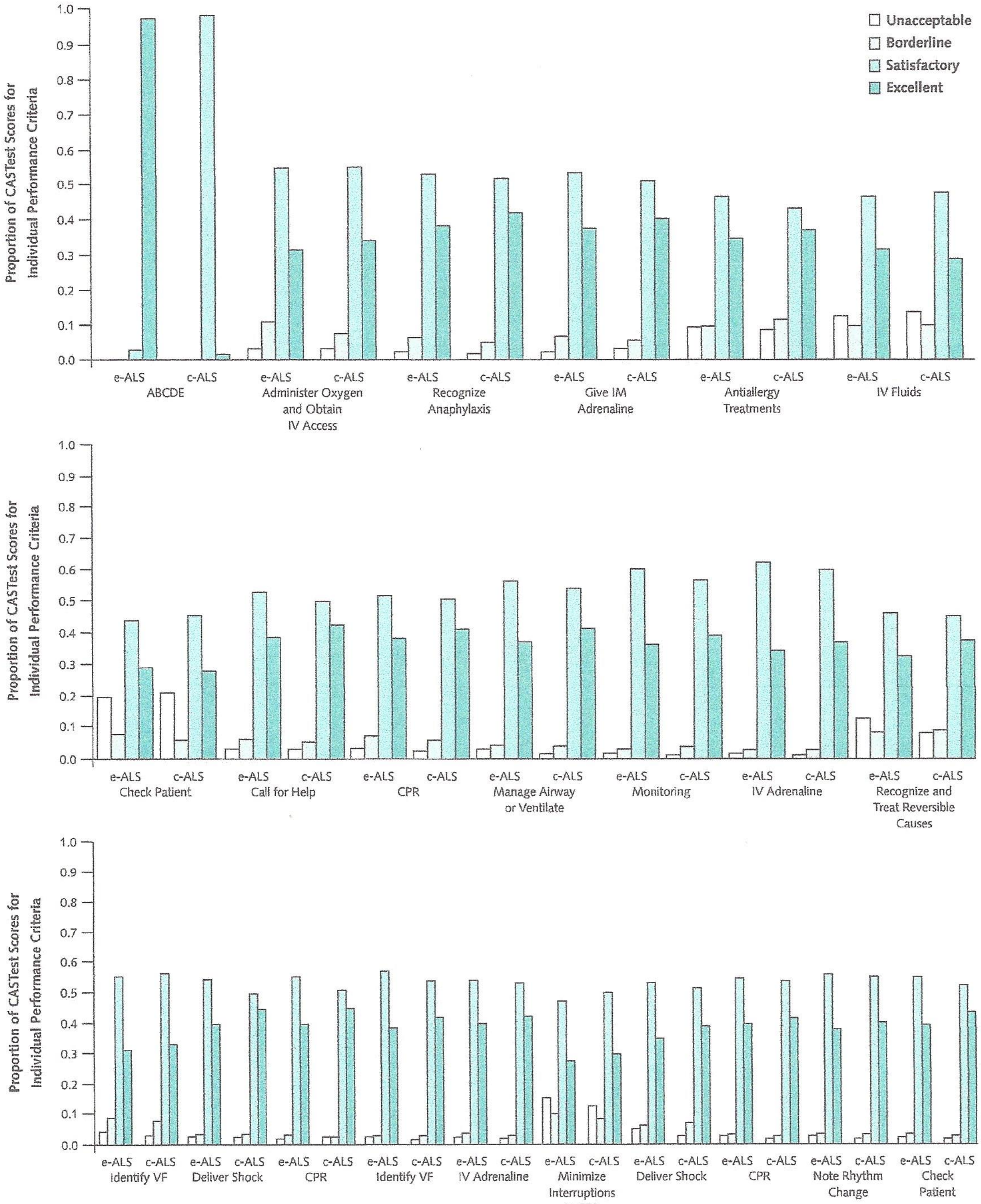
To pass the overall course, participants had to pass all assessments (postcourse MCQ test, overall pass for CASTest, and skill assessments). Those who initially failed the CASTest were provided with a short period of revision or

Figure 2. **Differences (95% CIs) in pass rates for the CASTest and other outcomes.**



The pass rates are predictive margins that account for clustering within courses, stratification by center, and adjustment for age and profession. If all values in the 95% CI are greater than −5% (*dashed line*), e-ALS training is considered noninferior to c-ALS training. For the CASTest results, the 95% CI crosses the 5% margin and is inconclusive. For the overall pass rate, initial assessment and resuscitation test, and instructor potential, e-ALS training is noninferior to c-ALS training. c-ALS = conventional advanced life support; CASTest = cardiac arrest simulation test; e-ALS = electronic advanced life support; MCQ = multiple-choice question.

Figure 3. **CASTest domain scores.**



Data shown are the proportion of scores for individual performance criteria grouped by the 3 domains: initial assessment and resuscitation, management of pulseless electrical activity, and management of a shockable rhythm. ABCDE = Airway, Breathing, Circulation, Disability, Exposure approach; c-ALS = conventional advanced life support; CASTest = cardiac arrest simulation test; CPR = cardiopulmonary resuscitation; e-ALS = electronic advanced life support; IM = intramuscular; IV = intravenous; VF = ventricular fibrillation.

remedial support, after which they were retested. Participants who were unsuccessful at this point were given up to 90 days for reassessment of the MCQ test or CASTest. At the end of this process, 94.2% in the e-ALS group and 96.7% in the c-ALS group (mean difference, −2.6% [CI, −4.1% to −1.2%]; $P = 0.002$) passed.

Post hoc analysis of health professional groups showed variation across the professional groups based on profession and seniority (**Table 2**). Medical students in the e-ALS group had a higher pass rate in the initial CASTest than those in the c-ALS group (mean pass rate difference, 9.0% [CI, −0.9% to 19.2%]), whereas foundation-year physicians in the e-ALS group had a lower pass rate than those in the c-ALS group.

Senior nurses, junior nurses, and operating department practitioners in the e-ALS group had a slightly lower pass rate than those in the c-ALS group. Except for medical students, noninferiority could not be concluded.

For participants in the e-learning group, the median time spent logged into the e-learning system was 6.88 hours (413 minutes) (interquartile range, 4.43 hours [266 minutes] to 10.22 hours [613 minutes]). There were no significant effects of time spent logged into the e-learning system and various test outcomes. Only 53% of participants received protected study time from their employers before the face-to-face course.

A total of 426 days of faculty time was used to deliver the e-learning course at a cost of $553 136 compared with 964 days at a cost of $1 232 486 for the conventional ALS course. Retest costs were $18 944 for the e-learning course compared with $13 568 for the conventional course, because more persons underwent retesting in the e-ALS group. Catering costs were available from 23 centers (average daily cost, $846). Seven of the 23 centers were charged for room hire at an average daily rate of $864 (range, $400 to $2400). Taken together, these costs equal $438 per candidate for e-ALS training and $935 for conventional ALS training.

Discussion

In this large, open-label, noninferiority, randomized, controlled trial, a blended approach to resuscitation training was compared with a standard 2-day, face-to-face, instructor-led course. Compared with our definition of noninferiority (5% difference), the e-learning course was noninferior for theoretical knowledge and technical skill acquisition. By contrast, the CI for the primary outcome—performance during the CASTest—was −8.8% to −2.7%, which included a possible 5% difference. As such, the result was inconclusive and could not be claimed to be noninferior (14).

Table 2. **Results, by Professional Group**

Variable	Participants, *n*	e-ALS Group, %	c-ALS Group, %	Difference (95% CI), %
Initial CASTest pass rate*†				
Operating department practitioner	24	69.69	72.28	−2.59 (−15.84 to 5.44)
Junior nurse	123	72.94	74.76	−1.82 (−12.55 to 8.06)
Senior nurse	332	70.26	71.53	−1.27 (−8.44 to 6.37)
Medical student	197	88.44	79.48	8.96 (−0.92 to 19.21)
F1 physician	366	71.22	80.66	−9.44 (−16.95 to −2.39)
F2 physician	742	73.17	83.50	−10.33 (−15.74 to −5.09)
Other physician	918	76.32	81.67	−5.35 (−9.91 to −0.45)
Overall course pass rate†				
Operating department practitioner	24	69.69	81.62	−11.93 (−27.05 to −1.12)
Junior nurse	122	86.46	90.78	−4.32 (−9.36 to 0.73)
Senior nurse	330	91.90	92.24	−0.34 (−4.01 to 3.53)
Medical student	198	97.95	100	−2.05 (−5.08 to 0.00)
F1 physician	365	93.46	97.12	−3.66 (−7.34 to 0.06)
F2 physician	741	96.89	99.71	−2.83 (−4.48 to −1.28)
Other physician	916	94.33	96.33	−2.00 (−4.54 to 0.44)
Identification of instructor potential				
Operating department practitioner	24	8.03	8.66	−0.63 (−17.28 to 16.02)
Junior nurse	126	9.60	3.35	6.25 (0.73 to 11.61)
Senior nurse	334	10.19	10.90	−0.71 (−4.78 to 3.55)
Medical student	198	0.00	0.00	–
F1 physician	367	1.70	4.24	−2.54 (−5.13 to 0.05)
F2 physician	742	4.92	4.57	0.35 (−2.21 to 3.04)
Other physician	930	18.06	15.27	2.79 (−1.26 to 6.87)

c-ALS = conventional advanced life support; CASTest = cardiac arrest simulation test; e-ALS = electronic advanced life support; F1 = foundation year 1; F2 = foundation year 2.
* Primary outcome.
† Estimated pass rates are predictive margins that account for clustering within courses, stratification by center, and adjustment for age and profession. Pass rates for ambulance staff were not computed because this group was too small to make reasonable computation.

The overall course outcome (after remediation and repeated tests) was 2.5% lower overall in the e-ALS group (CI, −4.1% to −1.2%), which we declared noninferior. The effect of the e-learning approach can be expressed as 1 additional person failing to successfully complete the course for every 39 people (CI, 24 to 86 people) enrolled in a course.

A MEDLINE search of the literature for English-language articles identified that e-learning is now widespread in undergraduate and postgraduate health care programs (24). Electronic learning provides standardization of content and allows learners to progress through material at their own pace and at a time and location that meets their personal and professional needs (25). A systematic review and meta-analysis of 201 studies found that, compared with no intervention, e-learning improved knowledge, skill, and behavior outcomes. The effects were smaller and more heterogeneous when compared with traditional instructional methods (26). This could at least be partially explained by wide variation in context, types of instructional methods, and presentation formats used as part of e-learning courses (27).

Use of e-learning during basic life support and automated external defibrillation training was evaluated by the International Liaison Committee of Resuscitation in 2010 (12, 28). Most studies identified in their review used video self-instruction ($n = 15$) or computer-based e-learning ($n = 5$) as alternatives to instructor-led training. The studies focused on knowledge- and skill-based outcomes. Ten of the studies supported video or e-learning, 7 were equivocal, and 3 suggested that the specific video or e-learning approach was inferior to face-to-face, instructor-led training. These data informed the committee's recommendation to consider video- or computer-based learning as an alternative to instructor-delivered basic life support and automated external defibrillation training (12).

The skills required for advanced resuscitation are more complex than those for basic life support and automated external defibrillation. We identified 3 randomized, controlled trials that evaluated e-learning before (21) or after (29, 30) standard face-to-face ALS training. Two of these studies found that the e-learning intervention had no effect on knowledge- or skill-based learning outcomes, whereas the third found small increases in knowledge domains in the e-ALS group (29). A brief Internet search identified several providers of online training for ALS. Given the uncertain efficacy of e-learning and its growth as a training method, we considered it timely to undertake a large-scale evaluation.

Our study showed that the e-learning course was noninferior for knowledge and technical skills. By contrast, participants in the e-ALS group scored lower in the CASTest than those randomly assigned to the conventional training course. Detailed analysis of specific elements of the test identified reduced performance in the nonshockable algorithm. This part of the test combines technical skills (advanced patient assessment, airway management, rhythm recognition, differential diagnosis, and drug administration) with nontechnical skills (for example, teamwork) (31, 32).

A possible explanation may be that the reduced face-to-face training in the e-ALS group limits time for social interaction and testing effective teamwork strategies within groups. Whether this could be influenced by adding social interactivity, such as forums or virtual chat rooms, Wikis (databases of online content that users can create and edit), or social networking in the context of advanced resuscitation training, is worthy of future study (30, 33).

To our knowledge, this is the first large-scale, pragmatic, randomized, controlled trial to compare the effectiveness of a hybrid e-learning course with a traditional approach to ALS training. Our study demonstrates the feasibility of applying robust clinical trial methodology to educational research. The study is strengthened by embedding the evaluation within existing training schemes and including more than 30 centers from 4 countries.

The study has limitations. Approximately 25% of randomly assigned participants withdrew before receiving the intervention, which could have a large effect in a noninferiority trial. The proportions were similar in both groups (23% in the e-ALS group and 22% in the c-ALS group). This finding suggests that these withdrawals were nondifferential, which was confirmed by e-mail follow-up.

The study was open-label; as a result, the assessors could not be blinded to the participant's course. The potential bias that this may have introduced was limited by using standardized and validated outcome-based performance criteria; using a broad instructor base from multiple centers and countries; using 2 assessors for all skill or simulation-based tests; and including blinded, computerized evaluation of knowledge-based outcomes.

Electronic learning approaches do not suit all practitioners because of the differences in learning style, age, access to computers, and computer literacy (34). The persons who consented to participate in this study expressed their willingness to consider either an e-learning or a conventional approach to training. Introducing free choice or removing choice (if conventional programs were withdrawn in favor of the blended approach) would require close monitoring. Finally, although moderate evidence links advanced resuscitation training to process and patient outcomes (35–37), this study was limited to assessing educational outcomes. The effect on patient outcomes was not determined.

A blended approach to ALS training that included e-learning reduced the duration and costs of face-to-face training by one half. The blended and conventional approaches had similar outcomes for knowledge- and skill-based domains. However, success rates in the CASTest were 6% lower in the e-ALS group than in the c-ALS group, which resulted in 1 additional participant who did not successfully complete the course for every 39 course participants.

From the University of Warwick, Warwick Medical School, Coventry; Heart of England NHS Foundation Trust, Birmingham; National Clinical Guideline Centre, Royal College of Physicians and Resuscitation Council (UK), London; University of Birmingham, Birmingham Medical School, Birmingham; and Calderdale Royal Hospital, Salterhebble, Halifax, United Kingdom, and Australian Resuscitation Council, Melbourne, Australia.

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Reproducible Research Statement: *Study protocol:* Available at www.resus.org.uk/consent/eALSprcl.pdf. *Statistical code:* Available at https://files.warwick.ac.uk/nstallard/browse/e-ALS. *Data set:* Not available.

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In 2008, the RC(UK) introduced a pilot version of the e-ALS course in 31 course centres. Paper 2 is an open-label non-inferiority (NI) randomised trial that analysed the educational outcomes from healthcare professionals attending this pilot e-ALS course as opposed to the conventional face-to-face course (c-ALS) (Perkins et al., 2012, p. 19). It was the first large scale randomised controlled trial in this field. My contribution to this paper included conception and design, critical revision of the article for important intellectual content, and final approval of the article. Due to the fact that I was the Chairman of the RC(UK) ALS Sub-committee and that I had instigated this project, I did not have any involvement in the analysis and interpretation of the data or with drafting the article.

The null hypothesis was that e-ALS would be inferior to c-ALS in terms of the primary outcome (performance at the initial cardiac arrest simulation test, known as the CasTest). Secondary outcomes analysed included knowledge and skill-based assessments, overall course pass rate, proportion of participants recommended for instructor status, and resource use.

A total of 4,212 participants were assessed for eligibility over a range of 31 ALS course centres (25 in England, 1 in Wales, 2 in Scotland, 1 in Northern Ireland, and 2 in Australia) between December 2008 and October 2010. Of these, 3,732 consented to participate. They were randomly assigned in blocks of six at course centre level to a course using sealed opaque envelopes. The numbers of participants who dropped out of the study were 440 in e-ALS and 444 in c-ALS. Crossover numbers included 13 allocated to e-ALS and 21 allocated to c-ALS who attended the alternative course. In total, 1,367 participants were analysed in the e-ALS group and 1,366 participants were analysed in the c-ALS group. The data presented in the paper followed the Intention to Treat (ITT) model, although Per Protocol (PP) analysis was also undertaken to further validate the results. ITT includes in the analysis all subjects who have been randomised, regardless of whether they adhered to the protocol. This is generally used in superiority RCTs as it reflects reality, but it can lead to increased Type I errors (false acceptance of the inferior new treatment). PP excludes participants who deviated from the protocol and is therefore sometimes referred to as an analysis of optimal conditions (i.e. every participant that completed that arm of the protocol only is included). This can lead to attrition bias, if the remaining groups no longer have similar characteristics. It is generally recommended that both methods are used for NI trials to increase validity. There was no difference in outcome between the two analyses.

With regard to the primary outcome, the study showed that performance in the first CasTest was lower in e-ALS participants than it was in c-ALS participants. The number who passed the first CasTest on the e-ALS course was 1,033 (74.5%), whereas the number who passed it one the c-ALS course was 1,146 (80.2%). The mean difference was -5.7% (95% CI -8.8% to -2.7%). Knowledge and skill-based assessments were similar in both groups, with an adjusted difference in MCQ scores of 0.55% (95% CI -1.11 to 0.02, p=0.054) and near identical pass rates for the 'Initial Assessment and Resuscitation' and airway skills assessments. The final course pass rate was 94.2% for e-ALS and 96.7% for c-ALS (mean difference -2.6%; 95% CI -4.1% to 1.2%). Faculty, catering and facility costs were estimated to be $438 per individual for e-ALS as opposed to $935 for c-ALS. The confidence limits for the primary outcome overlapped the NI margin (-5%), so it was deemed to be inconclusive. The confidence limits for the overall pass rate were within the NI margin and also overlapped zero risk difference.

Paper 2 is the first large scale randomised controlled trial analysing the educational impact of a blended learning approach to life support education, and this constitutes its major strength. Another strength of this paper is that it used the non-inferiority (NI) approach. This is used when the researcher plans to show that a new treatment or intervention is not inferior to a standard accepted intervention. NI may be defined as being as efficacious or worse than an amount less than a prespecified NI margin. The impact of advanced life support courses on patient outcomes have been studied several times over the years, and a systematic review of the literature has already been presented in this chapter as Paper 1 (Lockey, Lin, & Cheng, 2018, p. 48). This confirms that advanced life support training is well established and worthy of being benchmarked against. In order for a new intervention to be valid in an NI trial, it should be as similar as possible to the standard intervention. This was certainly the case for the e-ALS course in terms of participant profiles, inclusion and exclusion criteria, and outcome measures. The sample size for a NI trial is calculated after setting an NI margin prior to the study, which is the smallest clinically meaningful difference between the two interventions. The NI margin for this study was set at 5% absolute difference in pass rates. This was set *a priori* by an expert group based upon the minimal important difference in outcomes. The sample size (2,510) was subsequently calculated to ensure 80% power of achieving this margin. A 10% contingency was factored in for dropouts.

An alternative option would have been to undertake a superiority randomised controlled trial. The NI approach was used as it was felt that the incremental benefits of the e-ALS course would be marginal and that the numbers needed for a superiority randomised trial would be unfeasible. It was also anticipated that there may be collateral benefits to the new approach other than the outcomes measured that may sway stakeholders towards e-ALS. It was for this reason that a brief assessment of cost-effectiveness was also undertaken. The consideration of collateral benefits may also be regarded as a potential limitation as the investigators' interpretation of these factors may lead to undue focus or bias in the conclusions, thus adversely influencing the interpretation by the reader. This has been described as 'spin' (Boutron, Dutton, Ravaud, & Altman, 2010, p. 2058) and can include focusing on statistically significant results, interpreting negative results as equivalence, and claiming NI when it doesn't exist. The potential implication of this with regard to Paper 2 will be discussed in Chapter 5.

An element of the study design that constitutes both a strength and a weakness is the randomisation process. By assigning each participant to one limb of the study by randomisation, we were able to minimise selection bias. Whilst this process ensured comparable groups in terms of demographics, there was a potential that the spread of learning styles in each group may have presented a confounding effect. Subsequent studies that are presented within this programme of research have also identified that success in a blended learning approach to healthcare education is influenced by age and clinical background. Small differences in these demographics in the two groups may therefore have led to a more significant impact upon outcomes and ultimately the results for the primary outcome. The impact of this will be discussed further in Chapter 5. Another limitation of the paper was the sizeable number of dropouts, although the proportion was comparable between the two groups (23% in e-ALS and 22% in c-ALS). Each participant who dropped out was contacted by email to identify the reason for non-attendance. As each course centre now ran both types of course, the number of available local dates for each course type was effectively halved. Non-attending participants informed us that they had dropped out as they were unable to attend any of the reduced number of dates at their local course centre for their allocated course. We were therefore assured that these withdrawals were nondifferential. Finally, neither participants nor instructors were blinded to the type of course. This was mitigated by the fact that the validated outcome-based assessment strategies and tools were identical for both courses. In addition, each face-to-face assessment involved two accredited ALS instructors who assessed the candidates independently before making a final collaborative agreement of the outcome.

In summary, Paper 2 was a landmark trial that compared for the first time the impact of a blended learning approach as opposed to a traditional approach to advanced life support training on educational outcomes. The results were not as conclusive as anticipated and the impact of this will be discussed further in Chapter 5. It was therefore important that the opinions of the participants should be taken into account to guide future development of the course, and the evaluation of candidate perspectives is presented next as Paper 3.

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Simulation and education

Electronic learning in advanced resuscitation training: The perspective of the candidate☆

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ABSTRACT

Background: Studies have shown that blended approaches combining e-learning with face-to-face training reduces costs whilst maintaining similar learning outcomes. The preferences in learning approach for healthcare providers to this new style of learning have not been comprehensively studied. The aim of this study is to evaluate the acceptability of blended learning to advanced resuscitation training.
Methods: Participants taking part in the traditional and blended electronic advanced life support (e-ALS) courses were invited to complete a written evaluation of the course. Participants' views were captured on a 6-point Likert scale and in free text written comments covering the content, delivery and organisation of the course. Proportional-odds cumulative logit models were used to compare quantitative responses. Thematic analysis was used to synthesise qualitative feedback.
Results: 2848 participants from 31 course centres took part in the study (2008–2010). Candidates consistently scored content delivered face-to-face over the same content delivered over the e-learning platform. Candidates valued practical hands on training which included simulation highly. Within the e-ALS group, a common theme was a feeling of "time pressure" and they "preferred the face-to-face teaching". However, others felt that e-ALS "suited their learning style", was "good for those recertifying", and allowed candidates to "use the learning materials at their own pace".
Conclusions: The e-ALS course was well received by most, but not all participants. The majority felt the e-learning module was beneficial. There was universal agreement that the face-to-face training was invaluable. Individual learning styles of the candidates affected their reaction to the course materials.

Introduction

Electronic learning heralds a new approach for the provision of clinical learning in healthcare, including advanced resuscitation training.[1,2] With financial pressures facing health care, there is a demand to provide equivalent standards of education at lower costs. With regard to the Resuscitation Council (UK) Advanced Life Support (ALS) course, a multi-centre, randomised controlled, non-inferiority trial compared a blended approach of electronic learning resources (e-ALS) coupled with traditional face-to-face teaching.[3] The study found that although knowledge and skill based assessments were similar between the two groups, performance in the cardiac arrest simulation test (CASTest) was lower in the e-ALS group. After remedial teaching the final pass rates were similar. The blended approach (with e-learning and reduced face to face contact) was approximately half the cost of the traditional approach, which has the potential to lead to significant cost savings to the health system.

A subsequent study, analysing 27,170 candidates,[4] demonstrated slightly higher scores for e-ALS in all assessment modalities including first attempt CAS-test pass rate (84.6% vs 83.6%, $p = 0.035$). The overall pass rate was equivalent between both courses (96.6%, $p = 0.776$).

A key additional determinant of the success of an e-learning programme is the acceptability and reaction amongst the candidates attending the course. The opinion of healthcare providers regarding electronic learning in life support training has not been

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comprehensively studied. This study aims to evaluate the reactions of candidates attending the traditional two-day face-to-face (c-ALS) or the blended approach of electronic learning and a one-day face-to-face course (e-ALS).

Methods

Course description

The c-ALS is a 2-day, 20-h course. It consists of four face-to-face lectures, six interactive workshops (rhythm recognition, blood gases, tachycardia, bradycardia, special circumstances and ethics), two skill stations including airway management, initial assessment, CPR and defibrillation and 12 simulated cardiac arrest scenarios.

The e-ALS is a 1-day, 10-h, face-to-face course accompanied by 158 min of electronic learning material. The e-learning material includes e-lectures (with the same slides but accompanying commentary) and interactive learning material (with the same material as the face-to-face workshops but combined with interactive activities and formative tests). The face-to-face element delivers identical skill stations and cardiac arrest scenarios to the conventional course.

Study design

The primary study[3] was an open-label, non-inferiority, randomised controlled trial enrolling participants between December 2008 and October 2010. Participants were randomised between c-ALS and e-ALS with 1:1 randomisation. Data were collected for 31 study centres with 25 centres in England, two in Scotland, one in Wales and Northern Ireland and two participating in Australia. All candidates were healthcare providers or trainees.

We developed and pilot tested an evaluation form to capture candidate experience of learning in evaluating the c-ALS and e-ALS courses. The questionnaire captured professional background, course centre and course type. No personal identifiable data were collected. Respondents were invited to rate content and presentation of learning material using a 6 point Likert scale (1 = very poor, 6 = very good). The reported impact of the course content on personal development were also captured using a 6 point Likert scale (1 = strongly disagree, 6 = strongly agree). Binary (yes/no) preferences were sought on preferred learning style.

Free text feedback to the following open questions was also recorded.

a. What aspects of learning did you find most helpful in the course?
b. Please comment on how the course learning methods matched your preferred learning approaches.
c. Any other comments.

Ethical approval

The National Research Ethics Committee for the West Midlands granted ethical approval for UK courses. The University of Western Australia Human Research Ethics committee provided ethical approval for Australian courses. The Heart of England Foundation trust, UK (HEFT) provided sponsorship and acted as the coordinating centre. Participants gave informed consent via a central online consent service, run by the Resuscitation Council (UK).

Statistical analysis

The ratings, impacts and preferences for e-ALS and c-ALS were compared using odds ratios. The ratings and impacts responses are on 6 point Likert scales but because very few participants chose scores of 1, 2 or 3, in the analysis, we combined responses with scores 1, 2 and 3 into a single category. To account for the ordinal nature of the responses, the odds ratios were obtained by fitting proportional-odds cumulative logit models. We parameterised the models so that the odds ratios compare the odds of higher scores. Hence, for example, an odds ratio of 0.5 means that the odds for higher scores for e-ALS is half the odds for higher scores for c-ALS, and an odds ratio of 1.15 means that the odds for higher scores for e-ALS is 15% more than the odds for higher scores for c-ALS. We report the odds ratios (95% confidence intervals) and the p-values.

Thematic analysis

An inductive approach to the qualitative data was undertaken with thematic content analysis.[5] The free text comments covered a number of different themes. As more evaluation forms were analysed, a list of common themes developed. These themes were given a numerical label and were linked to original comments. All comments and thematic labels were recorded in an excel spreadsheet

Results

2733 candidates attended the courses between December 2008 and October 2010 and were issued evaluation forms. 2596 evaluation forms were received (95% response rate), with 137 forms lost to follow up. The remaining 2596 comprised 1294 in the c-ALS group and 1302 in the e-ALS group (Fig. 1).

The professional background of candidates included 1835 doctors, 431 nurses, 23 operating department practitioners, 19 paramedics, 6 resuscitation officers, 188 'other', and 94 unknown/not specified on evaluation form. The level of experience, seniority and speciality was not recorded for this evaluation, although in the main trial the groups were well matched with respect to age, profession, specialty and grade.

Reactions to lectures and workshops

The candidates' reactions to different styles of course content are summarised in Table 1. Candidates consistently preferred

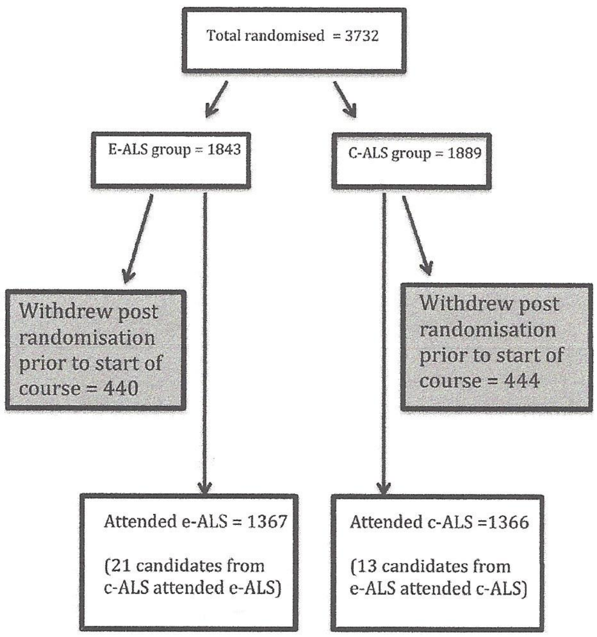

Fig. 1. Numbers involved in e-ALS and c-ALS groups.

Table 1
Comparing quality of lectures/workshops/e-learning materials, skills station, CAS demonstration and CAS teaching between conventional 2 days ALS (c-ALS) and electronic ALS (e-ALS).

Variable	c-ALS (n^* = 1294)							e-ALS (n^* = 1302)							OR (95% CI)	p-Value
	n^{**}	Response						n^{**}	Response							
		1†	2	3	4	5	6‡		1†	2	3	4	5	6‡		
Introduction – ALS in perspective	1270	0	0.1	1.0	18.2	48.1	32.6	1285	0.3	0.4	5.7	27.9	45.6	20.2	0.477 (0.412–0.553)	<0.001
Causes and prevention of cardiac arrest	1285	0	0.2	1.4	15.8	46.6	36.0	1282	0.3	0.5	4.4	24.3	49.0	21.5	0.486 (0.419–0.563)	<0.001
Acute coronary syndromes	1279	0	0.3	2.3	15.0	44.3	38.1	1275	0.3	0.4	3.1	23.8	48.2	24.2	0.541 (0.467–0.627)	<0.001
ALS treatment algorithm	1285	0	0.1	0.5	10.5	42.6	46.4	1282	0.3	0.6	1.7	15.9	47.1	34.3	0.584 (0.504–0.677)	<0.001
Post resuscitation care	1278	0	0.3	2.7	18.3	44.1	34.6	1282	0.5	0.7	4.7	25.7	47.2	21.2	0.542 (0.469–0.627)	<0.001
Rhythm recognition (monitoring, 12 lead ECG)	1285	0	0.2	2.1	12.0	40.2	45.4	1285	0.3	1.0	5.4	23.2	43.4	26.7	0.418 (0.361–0.484)	<0.001
Tachycardias, cardioversion and drugs	1273	0.1	0.2	1.2	12.3	41.8	44.5	1285	0.4	1.6	5.9	21.3	45.5	25.2	0.400 (0.345–0.464)	<0.001
Bradycardia, pacing and drugs	1273	0.2	0.4	1.3	12.1	41.7	44.4	1279	0.5	1.9	6.7	22.9	44.6	23.4	0.360 (0.310–0.418)	<0.001
Arterial blood gases	1275	0	0.6	2.9	15.9	38.9	41.6	1279	1.5	2.1	8.9	27.4	39.9	20.3	0.353 (0.304–0.409)	<0.001
Special circumstances	1265	0	0.5	2.4	15.3	43.2	38.7	1280	1.3	3.2	11.1	30.5	39.0	15.0	0.261 (0.224–0.303)	<0.001
Ethics/bereavement	1244	0.6	1.2	6.4	24.4	39.5	28.0	1271	0.8	2.4	10.1	33.8	36.8	16.1	0.530 (0.459–0.613)	<0.001
Airway management	1286	0	0.2	1.3	12.6	44.0	41.8	1290	0	0.2	1.5	10.5	44.6	43.3	1.092 (0.943–1.264)	0.240
Initial assessment and resuscitation	1279	0.1	0.1	0.2	7.9	42.9	48.8	1278	0	0.2	0.3	8.3	40.5	50.7	1.058 (0.911–1.229)	0.461
CASDemo	1274	0	0.1	0.8	8.8	38.1	52.3	1281	0	0.2	1.0	10.7	42.0	46.1	0.784 (0.675–0.910)	0.001
CASTeach 1–3	1271	0	0	0.4	6.2	37.8	55.6	1285	0.1	0	0.5	7.4	42.7	49.3	0.779 (0.669–0.906)	0.001
CASTeach 4–5	1264	0	0	0.2	6.0	37.1	56.7	1275	0	0	0.6	8.1	41.6	49.7	0.746 (0.640–0.868)	<0.001

CI, confidence interval.
Cells in the columns "response" give percentages for each response.
* Number of trainees randomly allocated.
** Number of trainees with no missing data.
† Very poor.
‡ Very good.

Table 2
Comparing helpfulness of course contents and methods of learning between c-ALS and e-ALS intervention groups.

Variable	c-ALS (n^* = 1294)			e-ALS (n^* = 1302)			OR (95% CI)	p-Value
	n^{**}	Response		n^{**}	Response			
		Yes	No		Yes	No		
Was the course content and methods of learning enjoyable?	1275	98.5	1.5	1274	93.9	6.1	0.232 (0.140–0.385)	<0.001
Did the course content and methods of learning develop knowledge and skills?	1273	99.5	0.5	1281	98.1	1.9	0.248 (0.101–0.609)	0.002
Did the course content and methods of learning help to prepare you to work in a team?	1273	98.9	1.1	1281	95.4	4.6	0.230 (0.128–0.415)	<0.001
Were you given study time by your employer to prepare prior to the face-to-face aspect of the course?	1248	42.8	57.2	1256	53.1	46.9	1.514 (1.293–1.773)	<0.001

CI, confidence interval.
Cells in the columns "response" give percentages for each response.
* Number of trainees randomly allocated.
** Number of trainees with no missing data.

face-to-face lectures to the identical lectures delivered as e-lectures (odds ratios [OR] 0.477–0.584). In the conventional course, face-to-face workshops evaluated more positively than lecture content whilst ratings were similar between e-lectures and the interactive e-learning material. Overall, face-to-face workshops rated more highly than interactive e-learning material (OR 0.261–0.4).

Reactions to skills stations and cardiac arrest scenarios

There was no difference in the preferences for airway (OR 1.09) or initial assessment and resuscitation (OR 1.058) between course types. By contrast cardiac arrest simulation teaching scored more highly in the conventional course than e-ALS (OR 0.746–0.784).

Learning style

Table 2 gives the candidates' evaluation of the c-ALS and e-ALS course content and methods of learning. The percentage of candidates in the e-ALS that were given time to prepare is larger than the percentage of candidates in the c-ALS (53.1 vs 42.8). For the remainder of the questions relating to course content and methods of learning, c-ALS candidates felt that the course experience was better than those attending the e-ALS.

Impact of course on personal development

Table 3 shows the candidates' views on the impact of the course content on personal development. Once again, the candidates on the c-ALS course rated their learning experience better than those on the e-ALS course.

Qualitative data

Comments were synthesised qualitatively into themes and recorded in an Excel spreadsheet. Of the 2596 evaluation forms, 276 completed forms (118 c-ALS and 156 e-ALS) were analysed looking at the free text comments.

After analysing 100 candidate forms no new themes were identified (saturation), however to maximise the information, and to ensure no themes were omitted, a further 176 forms were analysed. After the full analysis, 25 distinct thematic categories were found which were further condensed into 6 category headings.

Teaching

Candidates praised the opportunities for "*small group teaching*". It was highlighted that candidates were able to use "*practical scenario sessions to consolidate knowledge*" and they found "*working as a team*" with "*continuous assessment and feedback*" beneficial. The interaction with faculty was advantageous in clarifying points, with candidates "*meeting instructors and asking questions if unclear*". Candidates in both groups commented that there were many opportunities for "*feedback*" and to be "*critiqued*" and that this helped to develop their skills.

The lectures in the c-ALS group received mixed reviews with comments such as "*would prefer less lectures ... more around manikin based demonstration*". Others felt that the "*lectures and workshops were good*".

Resources

Generally candidates felt the course materials had information in a "*structured*", "*systematic*" and "*easy to grasp*" format that was "*thorough*" and included "*detailed information*". The "*e-learning material was very well written*", and was found to be "*very clear-could prepare for the face to face component*". Candidates also found the narrator of the e-learning "*stopped it being dry*" and "*feeling too much like a lecture*".

However, complaints included that they "*didn't like the online learning. Was slow, voice was dull and off-putting and I just read the slides*". Some candidates claimed that the "*e-learning kept stopping*", and "*slides kept freezing*".

One e-ALS candidate suggested, "*questions during the online activity could not be asked. If there was a forum online or before the course (a time where questions could be answered by course leaders) - this would be helpful*". Other suggestions included "*being able to access the online material after the course*".

Time

The e-learning component was praised by candidates as it enabled them to "*do work at their own rate*" and "*repeat any areas*" they needed to. Candidates on the e-ALS reported that it was "*easier to get study leave for just one day*" and they were able to do the online component when it was "*convenient*" for them. Some candidates liked the flexibility of the e-ALS, giving them the choice over how they used their time. "*E-learning meant I had to absorb the course content in my own time... e-learning allowed me to dedicate more time to those areas I wasn't as confident in*".

In the UK, doctors can apply for funded study leave time for essential courses. One e-ALS candidate explained that they would have preferred the two-day course, as "*I did not get study leave for the e-learning so only did it after work so it was broken up. I would have found it more useful if I could have completed the e-learning all in one day*". The ability to do e-learning in their own time was a positive for many but also negative for others. It seemed to relate to personal preferences and individual ways of learning.

Table 3
Comparing impact of course content on personal development between c-ALS and e-ALS intervention groups.

Variable	c-ALS (n^* = 1294)							e-ALS (n^* = 1302)							OR (95% CI)	*p*-Value
	n^{**}	Response						n^{**}	Response							
		1†	2	3	4	5	6‡		1†	2	3	4	5	6‡		
Delivery of course content enabled me to develop my practice knowledge and skills	1274	0.4	0.3	1.0	7.9	38.3	52.0	1274	0.4	0.7	2.4	17.0	44.6	34.9	0.475 (0.409–0.551)	<0.001
I enjoyed the blended learning approaches on the course	1272	0.5	0.2	1.5	9.8	39.2	48.8	1280	0.9	2.3	4.8	19.1	43.7	29.1	0.404 (0.348–0.469)	<0.001
I felt well prepared to meet the assessment criteria throughout the course	1272	0.2	1.0	3.8	17.6	43.7	33.6	1281	0.9	2.4	8.5	29.0	40.7	18.4	0.431 (0.373–0.499)	<0.001
The course learning methods facilitated my knowledge development	1267	0.5	0.6	1.5	8.8	44.6	44.0	1279	0.5	1.1	4.9	19.9	48.7	24.8	0.396 (0.341–0.461)	<0.001
The course reinforced my pre-course knowledge and skills	1267	0.5	0.2	0.8	7.5	41.0	50.0	1278	0.4	0.8	2.0	15.2	48.5	33.2	0.484 (0.416–0.562)	<0.001
The learning materials were of a high quality	1268	0.4	0.4	0.9	8.8	40.0	49.4	1279	0.5	1.8	2.8	17.1	46.4	31.4	0.451 (0.389–0.524)	<0.001
The course length is right in enabling me to develop knowledge and skills	1266	0.8	1.4	3.4	13.3	38.0	43.0	1268	1.7	3.9	8.0	19.4	42.0	25.1	0.450 (0.389–0.521)	<0.001

CI, confidence interval.
Cells in the columns "response" give percentages for each response.
* Number of trainees randomly allocated.
** Number of trainees with no missing data.
† Strongly disagree.
‡ Strongly agree.

Candidates reported that the e-learning took longer than predicted with claims it took "*at least twice as long as the predicted 7 hours*". There was also a sense that only one practical day on e-ALS felt "*rushed*", that "*there was not enough time to ask questions*" and it was a "*very intensive course to fit into one day*".

Skill acquisition

The practical element of both courses was useful for skill acquisition. Candidates reported that working in small groups throughout the scenarios and manikin-based teaching was useful for them to develop the skills of team leading and team working. Comments included "*Being a team leader and working as a team member*" was a useful learning experience and enabled them to get "*hands on*". This was reiterated by another candidate who found having "*lots of chances ... taking it in turns to lead and practice*" a positive experience.

Learning

Candidates seemed clear on their learning styles and how the course suited these. "*It matched my learning methods - hands on*" and "*I am an active learner, so I liked practicing on the dummies and with case scenarios*". Some e-ALS candidates found the "*self directed learning very good*" and "*liked the instant feedback on the pre-course multiple choice questionnaire (MCQ)*".

Others "*struggled with the lack of face to face learning time on e-ALS*". One candidate "*found the e-learning frustrating as I like to ask questions and challenge as part of my learning. I felt distracted doing e-learning at home with emails popping up and being disturbed by phone or children. I think I prefer lectures*". Another complained, "*I did not particularly enjoy the e-learning sections. I found it difficult to engage with a computer!*" and "*I feel that the best way to learn is through interactive, hands on teaching*". An e-ALS candidate explained they "*spent very little time on computer*", preferring to go through the "*manual and taking MCQs online*". Some candidates on e-ALS also remarked "*there is no way to ask questions*" however others felt that this was not a problem as "*any questions could be asked on the practical day*".

Some of the candidates felt that their level of experience prior to the course might affect their preference for e-ALS or c-ALS. One candidate felt that e-ALS "*is good but would be more appropriate for those re-certifying*" whilst those attending the course for the first time might need "*more time to pick up knowledge and skills*".

Administrative

Candidates felt that the one-day option with e-ALS makes it easier to "*fit in an ALS course*". However, as in previous comments, a candidate "*found it difficult to find the time to complete the e learning at home, but managed it late at night after my 2 children were in bed*". Another candidate stated "*7 Hours of e-learning was a lot to do in own time, quite boring and monotonous sitting in front of a computer for 7 hours!*".

The lack of study leave for the e-learning component was highlighted. Those attending the c-ALS course needed two days of study leave, whereas those attending e-ALS would have to fit in the online learning section in their own time. Candidates from e-ALS group remarked, "*I would have liked a study leave day from work to complete the online learning sections*" and "*I did not get study leave for e-learning component - had to give up my own time*".

Candidates also felt that as the course had been shortened to one day, then the course price should reflect this reduction in face-to-face teaching, with comments like "*if only one day course...it is too expensive*".

Discussion

The main findings from this study were that candidates consistently rated content delivered face-to-face more positively than content delivered via the e-learning platform. Candidates' written feedback indicated that they valued small group teaching with opportunities for interaction with instructors and other team members. Time pressure during the e-learning course including reduced time for peer support, problems with the functioning of the e-learning platform, and personal learning preferences seemed to be the main drivers behind less favourable evaluations for e-learning.

Studies into e-learning have shown some benefit for the candidate to gain knowledge and acquire skills either in comparison with a face-to-face style or as the sole educational tool.[6,7] In relation to resuscitation training, an approach including e-learning led to similar acquisition of knowledge and was provided with reduction in costs.[3] Other benefits of e learning are consistency of learning material, the ability of the learner to learn at their own pace, and repeating sections if required.[8] One multicentre trial found candidates who underwent an e-learning module prior to the standard ALS course had favourable user evaluation although no evidence of any improvement in course outcomes.[2]

The differences in feedback apparent in free text data appeared to be related to candidates' learning styles.[9] Brown (2008) found that the learning style of health science students could be used to a limited extent as a predictor of students' attitudes towards e-learning,[10] with others suggesting that students interested in e-learning are independent learners who prefer a more abstract way of thinking.[11] Other studies have shown that candidates with all learning styles have positive attitudes towards e-learning.[12] Previous studies suggest students with different learning styles have different preferences for support with some candidates preferring a high level of instructor input and others favouring a low instructor presence.[13]These findings fit with the data collected in this study. To our knowledge this is the first large-scale candidate evaluation of electronic learning in advanced resuscitation teaching.

The reduction in face-to-face course duration was driven by financial pressures on the healthcare system. Many candidates were clearly frustrated about the associated reduction in study leave despite the need to complete the e-learning material. This may explain in part why candidates favoured c-ALS.

There are a number of limitations that should be considered in relation to this study. The overall response rate to the survey was good; nevertheless the views of the 133 non-respondents may have differed from those that chose to respond. Not all of the domains were completed on the collected evaluation forms. Where data was missing, it was highlighted in the tables.

The demographic data did not include level of seniority, specialty or previous ALS course attendance. This may have affected candidates' outlook on an e-learning approach and also enable them to compare the c-ALS or e-ALS course to previous experiences. The qualitative data were analysed using a thematic approach. The analysis was performed until it had reached saturation culminating in 276 out of 2733 evaluation forms analysed, meaning there is a potential for missed themes and ideas.

A blended approach to ALS training may not suit all learning styles. The benefits of e-learning are well documented and it may be used successfully in particular for candidates re-certifying or with previous experience in resuscitation training. There needs to be more research into how different personalities and learning styles relate to successful e-learning. By identifying the type of learners struggling with e-learning, we may be able to redesign electronic components to help suit all learning styles. There may also be a need to develop the online social experience surrounding e-learning.

Conclusion

Candidates' quantitative feedback showed a preference towards the traditional ALS course. Other qualitative data showed universal satisfaction with the practical element of the course and most candidates undergoing the e-ALS found the e-learning component beneficial. There were however a number of candidates who struggled with the e-learning component and there were concerns about the reduction in study leave time available with e-ALS. The differences in reactions seemed to be based on the candidates' individual learning styles. Future research should focus on ensuring all learning styles can be incorporated in e-learning materials to ensure that it provides the same learning opportunities to all styles of learner.

Conflict of interest statement

AL, IB, RD and GP are all members of the ALS Sub-Committee of the Resuscitation Council (UK). No other conflicts of interest declared.

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Paper 3 was conducted in parallel with Paper 2 and captures the opinions and perspectives of 2,596 participants recruited from 31 centres in the UK and Australia attending both c-ALS and e-ALS course types during the pilot process (Lockey et al., 2015, p. 48). The mixed methodology approach included both quantitative and qualitative data analysis. My contribution to this paper included conception and design, drafting of the article, critical revision of the draft, and final approval of the article.

All participants of the pilot study were invited to complete a written evaluation of the course they attended. A total of 2,596 evaluation forms were returned (1,294 c-ALS and 1,302 e-ALS), representing a response rate of 95%. The participants were asked to rate content and presentation of the learning material using a 6-point Likert scale. They were also asked to rate the impact upon their personal development using the same scale and answer questions about their learning style using a binary scale. Finally, they were asked to provide free text responses to three questions: 1) what aspects of learning did you find most helpful to the course, 2) please comment on how the course learning methods matched your preferred learning approaches, and 3) any other comments.

The scores for the content and presentation of lecture materials were consistently rated lower for those attending the e-ALS course (OR 0.477 to 0.584) in comparison with the ratings for those undertaking the c-ALS lectures. There was a strong preference for face-to-face workshops over lecture content on c-ALS with little difference between e-lectures and e-learning workshop material on e-ALS. There was a lack of preference for e-learning material over face-to-face workshops (OR 0.261 to 0.4). Unsurprisingly, there was little difference in the rating for skills stations and simulation teaching sessions, which reflects the fact that these elements were identical for both courses. Overall, c-ALS participants rated their experience in terms of content and methods of learning, as well as learning experience, as higher than e-ALS participants. The only element that was rated higher by e-ALS participants was the amount of dedicated preparatory time that they were able to have prior to the course.

The qualitative data provided valuable insights into participant learning styles. There were six overarching themes identified relating to teaching, resources, time, skill acquisition, learning and administrative elements. Participants valued opportunities for small group teaching and, in particular, the interactivity and ability to receive feedback. There was specific feedback about the e-learning lectures, with some feeling that the delivery was slow and dull. Comment was also made that there was no ability to ask questions for clarification during e-learning as opposed to face-to-face lectures and there were some technical issues with e-learning modules freezing. In addition, comments were made about the strengths of e-ALS in terms of the flexibility of when to access it, the ability to repeat it, and the general convenience of this approach. It was felt that study leave was easier to achieve for one day face-to-face, although the lack of any dedicated study leave time for the e-learning component of e-ALS was also highlighted as an issue. Participants valued the face-to-face practical element of both courses, thus reinforcing the previous comments that they prefer this style of teaching and learning. It was felt by some that e-ALS may benefit those who are re-certifying rather than those taking the course for the first time as they may need less time to pick up the main concepts.

It is important to note that this data was obtained from participants included in a fully randomised study where they had no choice as to the limb of the study that they were allocated to. This is important as they may have attended the course that least suited their learning style. This is a potential limitation as it may have influenced the tone of their feedback. One of the other limitations of this study was that the demographics did not include the level of seniority or prior course experience and this could be seen as a missed opportunity. Further research was needed to analyse in more detail the profiles of participants who have better outcomes with the e-ALS approach. The findings from such a study could then be used to identify if any cohorts existed that should be guided towards e-ALS in preference to the c-ALS course. This formed the basis of Paper 5, which will be discussed later.

There was an impressive response rate of 95%, although not all participants completed all of the questions. There is a possibility that the 133 non-respondents may have had differing opinions, and this is a potential limitation. This limitation was mitigated however as the amount of missing data was small and random in nature. With regard to the qualitative element of the study, there was an assumed saturation of themes after 276 of 2,596 evaluation forms had been analysed. There is a potential that further themes may have been identified with analysis of the remaining responses and therefore this represents another potential limitation of the paper.

As stated previously, Paper 2 was the first study of its kind to analyse the educational outcomes of a blended learning advanced life support course as opposed to a conventional version. In parallel with this, there had been no large-scale analysis of the specific views of candidates on e-learning in advanced life support training. This analysis of 2,596 participants therefore places Paper 3 in a novel position within the body of knowledge. The findings from both Paper 2 and Paper 3 were used to develop a definitive version of the e-ALS course, with investment in a bespoke learning management system and a higher quality e-learning product. It was important that the educational outcomes of this updated version of the e-ALS course were evaluated and the results of this are presented in Paper 4.

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Simulation and education

e-Learning in advanced life support – An evaluation by the Resuscitation Council (UK)☆

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ABSTRACT

Aim: To descriptively analyse the outcomes following the national roll out of an e-Learning advanced life support course (e-ALS) compared to a conventional 2-day ALS course (c-ALS).

Method: Between 1st January 2013 and 30th June 2014, 27,170 candidates attended one of the 1350 Resuscitation Council (UK) ALS courses across the UK. 18,952 candidates were enrolled on a c-ALS course and 8218 on an e-ALS course. Candidates participating in the e-ALS course completed 6–8 h of online e-Learning prior to attending the 1 day modified face-to-face course. Candidates participating in the c-ALS course undertook the Resuscitation Council (UK) 2-day face-to-face course. All candidates were assessed by a pre- and post-course MCQ and a practical cardiac arrest simulation (CAS-test). Demographic data were collected in addition to assessment outcomes.

Results: Candidates on the e-ALS course had higher scores on the pre-course MCQ (83.7%, SD 7.3) compared to those on the c-ALS course (81.3%, SD 8.2, $P<0.001$). Similarly, they had slightly higher scores on the post-course MCQ (e-ALS 87.9%, SD 6.4 vs. c-ALS 87.4%, SD 6.5; $P<0.001$). The first attempt CAS-test pass rate on the e-ALS course was higher than the pass rate on the c-ALS course (84.6% vs. 83.6%; $P=0.035$). The overall pass rate was 96.6% on both the e-ALS and c-ALS courses ($P=0.776$).

Conclusion: The e-ALS course demonstrates equivalence to traditional face-to-face learning in equipping candidates with ALS skills when compared to the c-ALS course. Value is added when considering benefits such as increased candidate autonomy, cost-effectiveness, decreased instructor burden and improved standardisation of course material. Further dissemination of the e-ALS course should be encouraged.

1. Introduction

Advanced life support (ALS) courses, which include hands-on practice and simulation, are widely used in healthcare training to equip candidates with the knowledge, attitudes and technical and non-technical skills to effectively manage patients in cardiac arrest. Such courses are consistently well received by learners and have been shown in some settings to improve patient outcomes from cardiac arrest.[1–3] In the United Kingdom (UK), competency in ALS is a core requirement for healthcare professionals working in front-line acute care specialties. The Resuscitation Council (UK) introduced its first ALS course in 1992,[4] and since then there have been increasing numbers of candidates undertaking ALS courses nationwide. During 2013 alone, 19,082 candidates participated in an ALS course.[4,5]

In recent years there has been a global change in medical education, with academic institutes pioneering e-Learning as an alternative to more traditional delivery methods. The reasons for this shift are multi-factorial but include rapid medical advancements resulting in decreased time for academics to deliver formal teaching, the increasing accessibility of online material via the internet and making education more learner-centred rather than instructor-centred.[6] Several randomised controlled trials (RCTs)

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have demonstrated that e-Learning is superior to more traditional methods in higher education and corporate environments.[7,8] In the medical field, e-Learning courses are becoming exponentially more popular in both undergraduate and post-graduate education as candidates seek greater accessibility to pre-requisite material and a more personalised learning schedule. A large meta-analysis found that internet-based learning had comparable outcomes to conventional learning methods.[9] E-Learning has been shown to be effective in areas as diverse as reproductive health training,[10] ultrasound skills,[11] haematological disorders[12] and the management of epistaxis.[13]

The ability to deliver ALS course content by e-Learning was evaluated in a large, multi-centre, non-inferiority randomised controlled trial. The trial established equivalence in outcome when comparing learning methods (by finding no difference in overall pass rates) and was significantly cheaper to deliver.[14] Following the results of this trial the Resuscitation Council (UK) rolled out a national e-Learning ALS course (e-ALS). The course required an update in learning materials (to reflect emerging evidence) but remains conceptually the same as the course tested in the randomised controlled trial. The methods of candidate assessment remained identical.

The aim of this study is to descriptively analyse the outcomes following the national roll out of an e-Learning ALS course.

2. Methods

2.1. Setting and participants

Potential ALS candidates were invited to participate in ALS courses through one of the 181 national training centres. Course centres were able to select the balance of e-ALS and c-ALS courses that they offered. Participants were free to register for either course at any of the course centres, thus candidate choice was based on availability of ALS courses in the local area.

Each candidate was required to register on the Resuscitation Council (UK) learning management system (LMS) prior to attending the course. They also received the ALS course manual a minimum of 4 weeks before the course date. Those undertaking the e-ALS were asked to complete the electronic learning modules. Progress on the e-Learning content was monitored by the course centres and this information was available to the faculty at the start of the course. Candidates were free to choose to personalise their learning experience – undertaking as little or as much of the e-Learning preparation as they felt necessary.

2.2. c-ALS and e-ALS courses

The Resuscitation Council (UK) 2-day c-ALS course involves participation in three e-Learning modules plus face-to-face lectures, small group sessions and practical cardiac arrest simulation teaching (CAS-teach).

The e-ALS course comprises 6–8 h of e-Learning content which replaces a number of the face-to-face lectures that are present on the c-ALS course. The candidates then attend a 1-day face-to-face course, which has fewer lectures and consequently a proportionately greater amount of time devoted to small group teaching and simulation training (CAS-teach).

Prior to attending the face-to-face element of each course, participants undertook a pre-course MCQ, although the score did not contribute towards the final assessment. Candidates subsequently completed their respective e-ALS or c-ALS course. They then undertook a compulsory post-course MCQ and were assessed by means of a practical cardiac arrest management simulation test (CAS-test) where they assumed the role of team leader. In order to successfully become ALS providers it is compulsory for candidates to pass both the post-course MCQ and the CAS-test. Candidates were permitted two attempts at the MCQ and three attempts at the CAS-test. Both sets of MCQs consisted of 30 stem questions, selected from a question bank, with each having four true/false answers, thus the total number of items to answer was 120. The pass mark was 75%. The CAS-test simulations have been previously validated[15,16] and assess candidates' abilities in airway management, patient assessment, defibrillation and basic life support. Raw scores and pass/fail data were collected for both of these aspects of assessment.

Routinely collected demographic data were collected for each participant during online registration on the LMS. Data were then transferred to Microsoft Excel (*Microsoft Corporation, Redmond, USA*) and subject to statistical analysis using SPSS 22 (*IBM, Armonk, USA*). Descriptive statistics were extracted. Independent *t*-tests were utilised to determine differences between continuous variables, and the chi-squared test for the dichotomous variables. *P*-values of <0.05 were considered statistically significant.

3. Results

There were 1350 ALS courses carried out between 1st January 2013 and 30th June 2014. Nine hundred c-ALS courses were run by 181 ALS centres across the UK. The remaining 450 e-ALS courses were facilitated by 94 centres.

3.1. Demographics

A total of 18,952 (69.8%) candidates participated in a c-ALS course. The remaining 8218 (30.2%) candidates undertook an e-ALS course. Mean age on the e-ALS course was 32.0 years (SD 8.2) and on the c-ALS course 32.8 years (SD 8.7). Table 1 demonstrates participant demographics with regards to professional background and previous ALS/ILS experience (immediate life support). Candidates on both courses were highly comparable, in spite of statistically significant differences between the proportions on each course, which was mostly attributable due to the very large sample size in this study. On the c-ALS course 57 candidates started but did not complete the course and on the e-ALS course the corresponding number was 15. The remainder of missing data resulted from incomplete data entry by candidates or local course organisers on the LMS.

3.2. Candidate pass/failure rates

3.2.1. Multiple choice questions

Candidate pass/failure results are portrayed below in Table 2. The proportion of candidates completing the pre-course MCQ was 97.6% for the c-ALS course and 99.1% for the e-ALS course. The mean score of 83.7% (SD 7.3) on the e-ALS course was significantly higher than the mean score of 81.3% (SD 8.2) on the c-ALS course (average difference 2.4%, 95% CI 2.2–2.6%, $P < 0.001$).

The mean post-course MCQ score was slightly higher on the e-ALS course at 87.9% (SD 6.4), compared to 87.4% (SD 6.5) on the c-ALS course. The mean difference of 0.6% (95% CI 0.4–0.7%) was small, but statistically significant ($P < 0.001$). The corresponding pass rates for the post-course MCQ first attempt were therefore higher on the e-ALS course (97.5%) compared with the c-ALS course (96.7%).

3.2.2. CAS-test assessments

The first attempt CAS-test pass rate of 84.6% (95% CI 83.8–85.4%) on the e-ALS course was significantly higher than the pass rate of 83.6% (95% CI 83.1–84.1%) on the c-ALS course (Chi-square 4.44, $P = 0.035$). There were no difference in pass rates between the two courses in terms of 'Airway Management' (Chi-square 0.06, $P = 0.807$) or the 'Initial Assessment and Resuscitation' workshop (Chi-square 0.411, $P = 0.522$).

Table 1
Participant demographics on the c-ALS and e-ALS courses.

	c-ALS	e-ALS	P-value
Professional background			
Doctor	13,492 (71.2%)	6236 (75.9%)	<0.001
Nurse	3988 (21.0%)	1244 (15.1%)	<0.001
Medical student	573 (3.0%)	534 (6.5%)	<0.001
Operating department practitioner	226 (1.2%)	73 (0.9%)	0.025
Ambulance staff/paramedic	225 (1.2%)	40 (0.5%)	<0.001
Resuscitation officer	41 (0.2%)	15 (0.2%)	0.527
Other	319 (1.7%)	74 (0.9%)	<0.001
Not available	88	2	
Grade of training			
Medical student	577 (3.0%)	537 (6.5%)	<0.001
Foundation Year 1 doctor	3588 (18.9%)	1650 (20.1%)	0.041
Foundation Year 2 doctor	4005 (21.1%)	1663 (20.2%)	0.067
Junior grade doctor (ST1/ST2)	1724 (9.1%)	794 (9.7%)	0.169
Middle grade doctor[a]	2814 (14.8%)	1465 (17.8%)	<0.001
Senior grade doctor[b]	824 (4.3%)	488 (5.9%)	<0.001
Junior nurse (band 4–6)	3281 (17.3%)	1002 (12.2%)	<0.001
Senior nurse (band 7–9)	1162 (6.1%)	395 (4.8%)	<0.001
Other	896 (4.7%)	223 (2.7%)	<0.001
Not available	81	1	
Previous ALS experience			
Never	11,125 (58.7%)	4615 (56.2%)	<0.001
0–6 months	766 (4.0%)	209 (2.5%)	<0.001
7–12 months	564 (3.0%)	220 (2.7%)	0.157
18–24 months	287 (1.5%)	119 (1.4%)	0.646
2–4 years	2273 (12.0%)	1157 (14.1%)	<0.001
>4 years	3822 (20.2%)	1888 (23.0%)	<0.001
Not available	115	10	
Previous ILS[c] experience			
Never	5968 (31.5%)	2704 (32.9%)	0.021
0–6 months	2242 (11.8%)	1010 (12.4%)	0.282
7–12 months	4689 (24.7%)	1766 (21.5%)	<0.001
18–24 months	2686 (14.2%)	1126 (13.7%)	0.305
2–4 years	1075 (5.7%	505 (6.1%)	0.126
>4 years	2118 (11.2%)	1059 (12.9%)	<0.001
Not available	110	48	
Total	18,952	8218	

[a] Middle grade doctor – ST3 and above, registrar.
[b] Senior grade doctor – Consultant or Associate specialist.
[c] ILS – immediate life support.

3.2.3. *Overall pass/fail rate*

The overall pass rate, after re-sit attempts, of 96.6% was identical on both c-ALS (95% CI 96.3–96.8%) and e-ALS courses (95% CI 96.2–97.0%, Chi-square 0.081, $P = 0.776$).

3.2.4. *Candidate pass/failure rates by professional background*

Overall course pass rates were very similar when stratified by professional background and are displayed in Table 3. The best performing group was resuscitation officers who demonstrated a 100% pass rate on the e-ALS course and 97.6% on the c-ALS course. Medical students had the highest pass rate for the c-ALS course (98.6%) and the second highest for the e-ALS course (98.3%). Doctors were the third most successful profession and performed marginally better on the c-ALS course (98.2%) compared to the e-ALS course (97.8%). Other than operating department practitioners ($P = 0.024$) there were no statistically significant differences in pass rates between the two courses.

Table 2
Candidate pass/fail results for c-ALS and e-ALS courses.

	c-ALS	e-ALS	P-value
Mean pre-course MCQ mark (SD)	81.3 (8.2)	83.7 (7.3)	<0.001
Mean post-course MCQ mark (SD)	87.4 (6.5)	87.9 (6.4)	<0.001
Post-course MCQ first attempt pass	18,225 (96.7%)	7983 (97.5%)	
Post-course MCQ first attempt fail	621 (3.3%)	207 (2.5%)	
Results not available	106	28	
CAS-test first attempt pass	15,758 (83.6%)	6931 (84.6%)	0.035
CAS-test first attempt fail	3093 (16.4%)	1260 (15.4%)	
Results not available	101	27	
Course pass	18,244 (96.6%)	7926 (96.6%)	0.776
Course fail	651 (3.4%)	277 (3.4%)	
No show/results pending	57	15	
Total	18,952 (69.8%)	8218 (30.2%)	

Table 3
Overall candidate pass rate according to professional background.

Job role	c-ALS pass	c-ALS total	e-ALS pass	e-ALS total	P-value
Doctor	13,225 (98.2%)	13,471	6095 (97.8%)	6232	0.078
Nurse	3651 (92.1%)	3963	1122 (90.9%)	1235	0.153
Medical student	565 (98.6%)	573	525 (98.3%)	534	0.696
Operating department practitioner	183 (82.1%)	223	67 (93.1%)	72	0.024*
Ambulance staff/paramedic	219 (97.8%)	224	39 (97.5%)	40	1.000*
Resuscitation officer	40 (97.6%)	41	15 (100.0%)	15	1.000*
Other	294 (93.3%)	315	62 (84.9%)	73	0.019
Not documented	67 (78.8%)	85	1 (50.0%)	2	1.000*
Total	18,244 (96.6%)	18,895	7926 (96.6%)	8203	0.776
Results not available		57		15	
Overall participants		18,952		8218	

* Fisher's exact test.

4. Discussion

The average marks are slightly higher on the pre-course MCQ for the e-ALS course (83.7%) compared to the c-ALS course (81.3%), indicating that it has potential advantages in preparing candidates prior to attending the face-to-face aspect. This is perhaps unsurprising given that e-ALS candidates had access to 12 online modules and the ALS course manual, compared to the course manual alone for the c-ALS course. This small difference narrows by completion of the course and the results of the post-course MCQ demonstrate this equivalence (87.9% and 87.4% respectively). This 'catch-up' phenomenon could be explained by the fact that candidates on the c-ALS course have double the face-to-face time to consolidate their pre-requisite knowledge compared to those on the e-ALS course. These data reinforce the findings from a systematic review in 2010 by the International Liaison Committee on Resuscitation (ILCOR) that e-Learning prior to an ALS course (either from the internet or a CD) prepares candidates at least equally as well, or better than conventional learning for the theoretical aspects of the course.[17]

There is some concern in the literature that decreasing the face-to-face time of ALS courses may compromise candidates' practical capabilities and therefore potentially impact adversely on patient care.[3,18,19] A recent randomised controlled trial (RCT) by Perkins et al. demonstrated that candidates on e-ALS courses had lower CAS-test pass rates when compared to candidates randomised to a c-ALS course.[14] The pass rates were 74.5% and 80.2% respectively with an absolute difference of 5.7% (and after pre-defined remediation a differential pass rate of 2.6%). Two possible explanations have been postulated for this difference; firstly, a decreased time for social interaction between candidates and their instructor, preventing them from clarifying queries instantly via synchronistic discussion[3,14]; and secondly, the net duration of content on the e-ALS course is 3 h less than the c-ALS course, meaning that candidates have less time to process and retain the information.[18] In the study by Perkins et al. there was no difference in post-course MCQ scores between the groups, indicating that knowledge acquisition is comparable between the two types of course.[14]

Interestingly the findings by Perkins et al. are not replicated in our observational study. Whilst candidates were not randomly assigned to either course, those on the e-ALS course actually demonstrate marginally better performance in the CAS-test assessments than their c-ALS counterparts, with pass rates of 84.6% and 83.6%, respectively. The results from our study are consolidated by the fact that despite not randomising candidates, the baseline demographics for both the c-ALS course and the e-ALS course are similar. This is in spite of the slightly misleading, aforementioned statistically significant differences due to the very large sample size. An interesting observation to note however, is the higher proportion of doctors in the e-ALS group (75.9%) compared to the c-ALS group (71.2%) and the correspondingly lower proportion of nurses (e-ALS 15.1%, c-ALS 21.0%) and medical students (e-ALS 3.0%, c-ALS 6.5%). Given that doctors display a higher overall course pass rate on both courses (e-ALS 97.8%, c-ALS 98.2%) compared to nurses (e-ALS 90.9%, c-ALS 92.1%) this may have a small influence on the overall pass rates. Nevertheless, as nurses comprise a relatively small proportion of the total course candidates, the implication is likely to be minimal.

The overall 96.6% candidate pass rate for the e-ALS course was identical to the c-ALS course. This is a reassuring fact for resuscitation organisations, that, in spite of almost halving the face-to-face time of the ALS course by instigating the e-ALS approach, candidates' knowledge and more importantly candidates' abilities to lead a cardiac arrest scenario have not been compromised. The overall pass rate after re-sit attempts was similar to that found on previous ALS courses in the UK,[14] Australia[14] and Italy.[20] It is therefore reasonable to assume that the comparable pass rates between the two courses is due to the fact that the e-ALS course is as effective as the c-ALS course at preparing candidates for the post-course MCQ and the practical CAS-test simulation. This is reinforced by the data in Table 3 which demonstrate largely similar course pass rates for both c-ALS and e-ALS when stratified by professional background. As this is an extremely large observational data set, the interpretation of equivalence is purely data led.

The main advantage of the e-ALS course is that it renders learning more participant-centred as opposed to instructor-centred. This empowers candidates, providing them with greater autonomy to decide when they would like to learn and what they would like to learn. The fact that the majority of the e-Learning material is not compulsory means that candidates are not forced to participate in sessions that they may already be incredibly well versed in, as they would be on the c-ALS course. This personalised rather than 'one-size fits all' aspect of e-ALS course accounts for the fact that individuals may have vastly different learning requirements. These are just a few of the explanations for why student satisfaction is reportedly greater with e-Learning courses than traditional didactic courses.[17,21]

There are other practical benefits of the e-ALS course. By halving the face-to-face aspect the monetary cost of facilitating an ALS course is drastically reduced. Perkins et al. calculated that the cost per candidate trained on the e-ALS course was $438 (€330), less than half the cost of the $935 (€706) per candidate on the c-ALS course.[14] The burden on instructors is also decreased by the e-ALS course halving the face-to-face time. This means that, in theory, instructors could teach on twice as many e-ALS courses than c-ALS courses in the same time period. The fact that all of the content is online improves standardisation and allows changes to be disseminated promptly. The e-Learning section of the LMS routinely collects user data regarding access to online content. This allows the Resuscitation Council (UK) to constantly monitor, evaluate and improve the online material and enhance the platform interface.

With the advancement of e-Learning, in particular the financial savings associated with it, there is an increasing opportunity for its utilisation in ALS refresher training. Whilst it is well established that there is a significant amount of skill decline in the months following an ALS course,[22–24] there remains a lack of evidence as to whether candidates on c-ALS and e-ALS courses demonstrate differential rates of skill decay. e-Learning has been suggested as a possible method of preventing skill decline. A small RCT by Jensen et al. did not demonstrate any significant improvement in ALS skill retention following a 12-month e-Learning course.[25] This RCT was limited by the fact that 20% of candidates in the intervention group failed to access the e-Learning material at all and only 57% of candidates accessed the sufficient amount of pre-defined content in the study protocol.[25] This phenomenon of candidates not accessing the material has been witnessed in other studies[26,27] and may obscure any true difference in outcomes between the approaches. In reality, it likely represents a pattern that would be replicated in the 'real-world' setting should e-Learning continue to be disseminated. Further research is required into barriers to accessing e-Learning so that this can be addressed.

Previous research has indicated that candidates undertaking a course which comprises of purely e-Learning are likely to compromise their practical resuscitation capabilities.[19,28] The main strength of this hybrid e-ALS course is that it incorporates a blend of prior e-Learning, which is then consolidated by practical CAS-test simulations. As Perkins et al. highlighted in their rebuttal, candidates on the e-ALS course actually receive the same amount of skill-based simulation as those on the c-ALS course.[18] Whilst the dissemination of the Resuscitation Council (UK) e-ALS course has been highly successful, it remains difficult to determine the optimum proportions for e-Learning and face-to-face aspects and future research should seek to identify this.

The Resuscitation Council (UK) has noted a dramatic increase in demand for the e-ALS courses and a relative decrease in the number of c-ALS courses being facilitated (data on file). When the above results are combined with the other significant benefits of this educational approach, there is indeed a strong case for advocating further dissemination of e-Learning in ALS.

4.1. Limitations and further research

The LMS routinely collects data on whether candidates have accessed the e-Learning material prior to attending the course. Given that only two modules out of a total of 12 are compulsory it is likely that a significant proportion of those on the e-ALS course will not have accessed the material in its entirety. As previously mentioned, this may limit conclusions that can be drawn from such data. It is currently unclear whether accessing pre-requisite e-Learning modules can be a predictor for whether a candidate will successfully pass their subsequent ALS course. There is scope for further research to answer this specific question.

The results from the prior trial which demonstrated that candidates on the e-ALS course had significantly lower CAS-test pass rates when compared to the c-ALS were not replicated in our paper. However, a degree of caution must be used when drawing conclusions from our dataset, as they are from observational data alone and the participants were not randomised to either group. In spite of this, the large sample size and the demographic homogeneity of the candidates in both the e-ALS and c-ALS groups improve its reliability.

Whilst the results in our study demonstrated a statistically significant difference between the two courses, this is attributable to the large sample size and these results are unlikely to be clinically significant. Instead the substantive data reporting in this paper provides evidence of equivalence of c-ALS and e-ALS course outcomes rather than superiority. In the literature, there remains a paucity of evidence as to whether the shift towards e-Learning will demonstrate a clinically significant impact on patient care. Whilst this should be the ultimate goal for any advancement in medical education, the practical and ethical considerations surrounding the design of such a study render this difficult to ascertain.

5. Conclusion

The hybrid e-ALS course is as effective at equipping candidates with ALS skills when compared to the c-ALS course. When the additional benefits of the e-ALS course are taken into account such as increased autonomy for candidates, cost-effectiveness, decreased instructor burden and the means for standardisation and evaluation of online material by course organisers, it provides an altogether more sustainable ALS course. Further research is required to determine whether e-Learning has any clinical benefits over the conventional approach, but in the meantime it is reasonable to recommend that the dissemination of e-Learning ALS courses should be increased as a viable alternative to the conventional 2-day ALS course.

Conflict of interest statement

CJT is a Trainee Representative for the ALS Subcommittee for the Resuscitation Council (UK). ASL is Honorary Secretary of the Resuscitation Council (UK) and a member of the European Resuscitation Council ALS Course Committee. IB is Lead Educator for the Resuscitation Council (UK). SH is Director of Course Development and Training for the Resuscitation Council (UK). SB-A is Project and Development Manager for the Resuscitation Council (UK). GDP is Chair of the ALS Subcommittee for the Resuscitation Council (UK) and member of the European Resuscitation Council ALS Course Committee.

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Paper 4 is a descriptive analysis of the educational outcomes for 27,170 c-ALS and e-ALS course participants following the national roll out of the definitive RC(UK) e-ALS course (Thorne et al., 2015, p. 79). My contribution to this paper included conception and design, drafting of the article, critical revision of the draft, and final approval of the article.

Having analysed the conclusions from Paper 2 and Paper 3, the RC(UK) trustees committed to the investment needed to develop a definitive e-ALS course. The course material was updated in terms of content and a bespoke learning management system (LMS) was procured. The functionality of this LMS enabled a greater degree of interaction and a more varied presentation style than the pilot Articulate version. In all other aspects, the product remained conceptually the same and participants underwent an identical face-to-face element to the pilot course as well as an identical series of assessments to the conventional and pilot courses.

This paper descriptively analyses the educational outcomes for all 27,170 participants who registered for an e-ALS or c-ALS course between 1 January 2013 and 30 June 2014. Overall, 900 c-ALS courses were run across 181 course centres and 450 e-ALS courses were run across 94 course centres, giving a total of 1,350 courses. In total, 18,952 participants attended a c-ALS and 8,218 participants attended an e-ALS course. The study therefore represents the whole population during that time frame, as opposed to a sample population.

The mean age for participants was similar; for e-ALS it was 32.0 years (SD 8.2) and for c-ALS it was 32.8 years (SD 8.7). The breakdown of participants for each course in terms of profession and seniority was similar, although the statistical analysis shows significant differences due to the large sample size. The majority of participants on both courses were FY1 and FY2 doctors (first two years of post-graduation employment for UK doctors), which is to be expected given the Foundation School requirements for attendance of all Foundation doctors on an ALS course. This was followed by middle grade doctors and junior nurses, and most participants in both groups had no previous ALS experience. The RC(UK) also runs a one-day Immediate Life Support (ILS) course for healthcare professionals who may have to act as first responders and treat patients in cardiac arrest until the arrival of a cardiac arrest team. The results from Paper 4 showed that approximately a third of both groups had no previous ILS experience either. The number of participants who started but did not complete the course was 57 for c-ALS and 15 for e-ALS. There was missing data for MCQ results for 106 c-ALS and 28 e-ALS participants due to incomplete data entry by course centres and participants. Similarly, there was missing data for CasTest results from 101 c-ALS and 27 e-ALS participants. This missing data represents a very small proportion of the sample groups and was therefore not felt to be a source of bias particularly as it was random in nature. As this was a retrospective data analysis and not a prospective randomised controlled trial, there was no bias on the part of the instructors when they performed their assessments. No other potential sources of bias were identified.

The outcome measures that were used were the ones routinely used to assess candidates on an ALS course, and were the same ones that had been used for Paper 2. The MCQ papers had been previously validated with a Cronbach's Alpha score in excess of 0.8 indicating high validity (Lockey, 2017, p. 1), and the CasTest scenarios had also been validated as being of equal performance (Perkins et al., 2007, p. 484).

The main finding of Paper 4 was that the overall pass rate was identical for both courses (96.6%; p=0.776). This is particularly reassuring, given the uncertainty of the results from Paper 2 and presumably reflected the fact that participants were now attending their course of choice. Participants on the e-ALS outperformed participants on the c-ALS course on the pre-course MCQ (83.7%, SD 7.3 vs 81.3%, SD 8.2; p<0.001), post-course MCQ (87.9%, SD 6.4 vs 87.4%, SD 6.5; p<0.001), and first attempt at CasTest (84.6% vs 83.6%; p=0.035). There was no difference in terms of pass rates for airway management (Chi-square 0.06; p=0.807) or 'Initial Assessment and Resuscitation' (Chi-square 0.411; p=0.522). The improved pre-course MCQ marks for e-ALS compared with c-ALS (2.4%) reflect the fact that these participants had been exposed to more theoretical learning before the face-to-face course. This is because c-ALS participants only had access to their manual, whereas e-ALS participants had access to the e-learning modules as well as the manual. It is interesting to note that the e-ALS participants still scored higher on the post-course MCQ, although the difference in marks (0.5%), whilst statistically significant due to the large sample size, was virtually identical. As previously noted, e-ALS participants performed slightly better on the first CasTest. Whilst this is statistically significant, this may also be related to the large sample size and it was felt that there was no clinically significant difference.

The paper concluded that the e-ALS course demonstrates equivalence to traditional face-to-face learning in equipping participants with advanced life support skills when compared to the c-ALS course. The reduced cost of running e-ALS courses that had been highlighted in Paper 2 was further referenced as justification for this blended learning approach to training. A major strength of this paper was the ability to present an accurate descriptive analysis of such a large amount of data. Descriptive analyses enable the researcher to present raw data in a more meaningful way and are used to summarise and quantitatively describe a collection of information, rather than learn about information that a population sample is meant to represent. The data collected from the LMS was cross-sectional in nature and, as such, there was no randomisation. Whilst this is a limitation, it does allow insight into outcomes for the course of the participant's choice. These limitations were felt to be mitigated by the large sample size and the comparable demographics between the two groups. Another potential limitation of this study is that it didn't take into account the amount of time spent accessing the e-learning modules. It was unclear whether the time spent accessing the e-learning correlated with course outcomes, although it should be noted that candidates on the c-ALS course have a similar choice as to whether to access pre-course learning from the course manual. The final paper in this programme of research, Paper 5, will describe an analysis of this question, as well as an analysis of what key factors influence outcomes for candidates on an e-ALS course.

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EUROPEAN RESUSCITATION COUNCIL

Simulation and education

e-Learning in Advanced Life Support—What factors influence assessment outcome?☆

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ABSTRACT

Aim: To establish variables which are associated with favourable Advanced Life Support (ALS) course assessment outcomes, maximising learning effect.

Method: Between 1 January 2013 and 30 June 2014, 8218 individuals participated in a Resuscitation Council (UK) e-learning Advanced Life Support (e-ALS) course. Participants completed 5–8 h of online e-learning prior to attending a one day face-to-face course. e-Learning access data were collected through the Learning Management System (LMS). All participants were assessed by a multiple choice questionnaire (MCQ) before and after the face-to-face aspect alongside a practical cardiac arrest simulation (CAS-Test). Participant demographics and assessment outcomes were analysed.

Results: The mean post e-learning MCQ score was 83.7 (SD 7.3) and the mean post-course MCQ score was 87.7 (SD 7.9). The first attempt CAS-Test pass rate was 84.6% and overall pass rate 96.6%. Participants with previous ALS experience, ILS experience, or who were a core member of the resuscitation team performed better in the post-course MCQ, CAS-Test and overall assessment. Median time spent on the e-learning was 5.2 h (IQR 3.7–7.1). There was a large range in the degree of access to e-learning content. Increased time spent accessing e-learning had no effect on the overall result (OR 0.98, P = 0.367) on simulated learning outcome.

Conclusion: Clinical experience through membership of cardiac arrest teams and previous ILS or ALS training were independent predictors of performance on the ALS course whilst time spent accessing e-learning materials did not affect course outcomes. This supports the blended approach to e-ALS which allows participants to tailor their e-learning experience to their specific needs.

Introduction

The Formula for Survival[1] identifies three factors that influence survival from cardiac arrest: high-quality research, efficient education of patient caregivers and an effective chain of survival from the early recognition of cardiac arrest through to post resuscitation care.[2] Advanced Life Support (ALS) courses, which address both the second and third aspects of this formula, are used internationally to train healthcare personnel how to manage patients in cardiac arrest. Previous studies have linked participation on ALS courses to improved outcomes from cardiac arrest.[3–5] Courses use multimodal delivery methods to equip participants with background scientific knowledge, targeted clinical skills and non-technical skill development. This blended learning approach is from course manuals, online e-learning material, didactic lectures, hands-on skill stations and formative assessment. In the United Kingdom (UK) and many other countries, successful completion of an ALS course (or similar) is required for healthcare professionals who manage acutely unwell patients on a regular basis.

The Resuscitation Council (UK) has a 25 year history in delivering ALS courses.[6] A total of 20,268 individuals participated in an ALS course between January 2015 and December 2015.[6,7] In 2011,

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a strategic decision was taken to meet increasing demand, and to increase the flexibility of learning for participants. The Resuscitation Council (UK) launched a novel e-learning ALS course (e-ALS), as an alternative to the conventional two day face-to-face course (c-ALS), valuing this key educational approach of blended learning. This constitutes 5–8 h of pre-course online e-learning, followed by a condensed, focussed one day face-to-face element. A multi-centre randomised control trial (RCT) in 2012[8] and a large observational study of 27,170 participants in 2015[9] demonstrated almost identical assessment outcomes for participants enrolled upon either c-ALS or e-ALS. The findings of these two studies consolidated the emerging role of the Resuscitation Council (UK) e-ALS course. Whilst outcome data were comparable in the observational study,[9] it did not assess the extent to which those participants enrolled on the e-ALS course actually accessed the e-learning material, or its effect on assessment outcomes.

Previous studies investigating the utility of e-learning all display a common limitation, whereby participants often do not fully access the e-learning material.[10,11] Jensen et al. investigated e-learning as a means for retaining ALS competency but found that only 57.5% of candidates accessed all of the stipulated modules.[10] Similarly Perkins et al. found that only 64% of candidates accessed pre-course e-learning via a CD prior to attending an ALS course.[11] This limitation was acknowledged by the authors, who postulated that any true difference between the control and intervention groups may not have been detected because the intervention had not been implemented effectively. Secondly, it provides challenges for ALS course organisers to establish exactly what extent of e-learning has been undertaken by the participants prior to attending a face-to-face course. Whilst this allows personalisation of the learning experience, it also reduces the standardisation of content delivered to those on an ALS course. Consequently, it is unknown whether making e-learning non-compulsory adversely affects candidate outcome.

This study was designed to access the aforementioned observational study data set,[9] analysing the extent to which participants access pre-requisite e-learning material, establishing the effect on candidate ALS assessment outcome. In doing this, study authors intend to highlight independent predictors of successful ALS course outcome.

Methods

Setting and participants

ALS participants voluntarily enrolled on a one-day e-ALS course at one of 94 national training centres. Each candidate registered on the Resuscitation Council (UK) Learning Management System (LMS) prior to attending the course. Participants were from a wide range of healthcare professions and stages of training.

The e-ALS course

The e-ALS course consists of 5–8 h of e-learning content covering essential ALS topics. Each candidate is given access to the LMS 8 weeks prior to their course and is asked to complete the 12 electronic learning modules. Additionally, participants receive a physical copy of the ALS course manual at least four weeks before the course date. e-Learning progress is monitored by the course centres. Participants are free to choose to personalise their learning experience—undertaking as little or as much of the e-learning preparation as they feel necessary although there are three compulsory modules: ALS in perspective; Advanced Life Support algorithm; non-technical skills (progress data are not routinely collected on the LMS for this module as it was only introduced in 2013).

There are nine non-compulsory modules: causes and prevention of cardiac arrest; acute coronary syndromes; monitoring, rhythm recognition and 12 lead ECG; bradycardia, pacing and drugs; tachycardia, cardioversion and drugs; special circumstances; post resuscitation care; arterial blood gas analysis; and decisions relating to resuscitation.

On completion of the e-learning, participants undertake a compulsory multiple choice questionnaire (MCQ), although the results do not affect their post-course outcome. After completing the one-day face to face aspect, each candidate undertakes a post-course MCQ and a practical cardiac arrest management simulation test (CAS-Test). In order to achieve ALS competency, participants need to pass both of these aspects. Participants are permitted two attempts at the MCQ and three attempts at the CAS-Test. The pre and post-course MCQs comprise 30 different stem questions, with each having four true/false answers, creating a total of 120 questions. The pass mark is 75%. The CAS-Test simulations are criterion based and are well validated.[12,13] They assess participants' abilities in patient assessment, formulating a treatment plan and leadership of the cardiac arrest team. Overall scores and pass/fail data are recorded.

Statistical analysis

Demographic data were collected on the LMS. Anonymised data were transferred to Microsoft Excel *(Microsoft Corporation, Redmond, USA)* and analysed using SPSS 23 *(IBM, Armonk, USA)* and R statistical program Version 3.3.1.[14] Categorical baseline characteristics were summarised using counts and percentages while continuous baseline characteristics were summarised using mean, median (IQR, interquartile range) and ranges. Independent *t*-tests, one-way ANOVAs and linear regression models were utilised to determine differences between continuous variables. Logistic regression was used for dichotomous outcome variables.

A multivariable logistic regression model was fitted to assess which variables predict whether a trainee passes the CAS-Test on the first attempt. Trainees attending the same course session tend to have similar outcomes[8] and so the multivariable logistic regression model included a random effects term for course session. A similar model was fitted to assess which variables predict whether a trainee passes the overall test. Odds ratios (OR), 95% confidence intervals and p-values from the multivariable random effects logistic regression models were reported. To assess which variables predict the MCQ score of a trainee in the first attempt, MCQ scores were analysed by fitting a linear mixed model with a random effects term for course session. Mean difference in MCQ scores, 95% confidence intervals and p-values from the linear missed model were reported. An analysis of standard residuals was carried out and outliers removed. Co-linearity was assessed by independently entering each independent variable into a logistic regression with the remaining variables entered as dependent variables. Collinearity was present if the variance inflation factor (VIF) was >1. In all models, missing data were excluded from the complete case analysis by a listwise deletion. Statistical significance was set at P-values of <0.05.

Results

Demographics

8218 participants were enrolled on one of 450 e-ALS courses during the study period. Mean age was 32.0 years (SD 8.2). 15 participants started but failed to complete the course. 1.8% of the total

Table 1
Participant demographics on the e-ALS course and time spent on e-learning.

Characteristics/outcomes	n, (%)	Hours spent on compulsory modules	Hours spent on non-compulsory modules	Total hours spent on e-learning	Overall pass rate (%)
Healthcare background					
Doctor	6236 (75.9)				6095 (97.8)
Range		0–13.2	0–21.0	0–24.0	
Mean (SD)		1.1 (0.8)	4.1 (2.5)	5.3 (3.0)	
Median (IQR)		0.9 (0.7–1.4)	3.8 (2.6–5.3)	4.9 (3.4–6.7)	
Nurse	1244 (15.1)				1122 (90.9)
Range		0–8.9	0–17.2	0–24.0	
Mean (SD)		1.3 (0.9)	5.4 (3.4)	6.9 (3.9)	
Median (IQR)		1.1 (0.8–1.6)	4.8 (3.4–6.6)	6.2 (4.5–8.5)	
Medical student	534 (6.5)				525 (98.3)
Range		0–4.7	0–16.0	0–17.6	
Mean (SD)		1.1 (0.7)	4.4 (2.2)	5.6 (2.6)	
Median (IQR)		0.9 (0.7–1.3)	4.1 (2.9–5.6)	5.3 (4.0–6.9)	
Operating department practitioner	73 (0.9)				67 (93.1)
Range		0–6.9	0–11.5	0.2–21.4	
Mean (SD)		1.3 (1.1)	5.3 (2.7)	7.0 (3.7)	
Median (IQR)		1.0 (0.8–1.4)	5.2 (3.5–7.2)	6.4 (4.8–8.8)	
Ambulance staff/paramedic	40 (0.5)				39 (97.5)
Range		0–6.4	0–18.7	0–22.7	
Mean (SD)		1.3 (1.2)	4.7 (3.1)	6.5 (4.0)	
Median (IQR)		1.1 (0.7–1.9)	4.8 (3.3–5.7)	6.4 (4.4–8.0)	
Resuscitation officer	15 (0.2)				15 (100.0)
Range		0.6–3.0	4.3–9.5	5.1–10.4	
Mean (SD)		1.3 (0.7)	6.1 (1.5)	7.5 (1.7)	
Median (IQR)		1.0 (0.8–2.1)	6.1 (4.8–7.1)	7.5 (5.7–9.2)	
Other	74 (0.9)				62 (84.9)
Range		0–5.5	0–18.0	0–20.6	
Mean (SD)		1.4 (0.9)	6.0 (3.4)	7.8 (4.1)	
Median (IQR)		1.2 (0.9–1.5)	4.8 (3.7–7.5)	6.7 (5.0–9.7)	
Not available	2				
Stage of training					
Medical student	534 (6.5)				525 (98.3)
Range		0–4.7	0–16.0	0–17.6	
Mean (SD)		1.1 (0.7)	4.4 (2.2)	5.6 (2.6)	
Median (IQR)		0.9 (0.7–1.3)	4.1 (2.9–5.6)	5.3 (4.0–6.9)	
Foundation Year 1 doctor	1650 (20.1)				1624 (98.4)
Range		0–7.0	0–21.0	0–21.7	
Mean (SD)		1.1 (0.7)	4.0 (2.2)	5.2 (2.6)	
Median (IQR)		0.9 (0.7–1.3)	3.8 (2.7–5.2)	4.9 (3.6–6.5)	
Foundation Year 2 doctor	1663 (20.2)				1639 (98.6)
Range		0–10.0	0–18.4	0–20.8	
Mean (SD)		1.1 (0.8)	4.1 (2.3)	5.3 (2.8)	
Median (IQR)		0.9 (0.7–1.3)	3.9 (2.7–5.2)	5.0 (3.6–6.6)	
Junior grade doctor (ST1/ST2)	794 (9.7)				768 (96.8)
Range		0–9.4	0–20.6	0–24.0	
Mean (SD)		1.2 (0.8)	4.3 (2.7)	5.5 (3.3)	
Median (IQR)		1.0 (0.7–1.5)	3.7 (2.6–5.4)	4.9 (3.5–7.0)	
Middle grade doctor[b]	1465 (17.8)				1434 (97.9)
Range		0–13.2	0–20.8	0–23.5	
Mean (SD)		1.1 (0.8)	3.9 (2.5)	5.1 (2.9)	
Median (IQR)		0.9 (0.7–1.4)	3.5 (2.3–5.0)	4.7 (3.2–6.5)	
Senior grade doctor[c]	488 (5.9)				469 (96.1)
Range		0–5.1	0–17.7	0–21.2	
Mean (SD)		1.2 (0.9)	4.1 (2.7)	5.4 (3.4)	
Median (IQR)		1.0 (0.8–1.5)	3.7 (2.5–5.3)	4.9 (3.3–7.1)	
Junior nurse (band 4–6)	1002 (12.2)				886 (88.4)
Range		0–8.9	0–17.2	0–23.1	
Mean (SD)		1.3 (0.9)	5.0 (3.2)	7.1 (3.9)	
Median (IQR)		1.1 (0.8–1.6)	4.9 (3.5–6.7)	6.4 (4.7–8.7)	
Senior nurse (band 7–9)	395 (4.8)				378 (95.5)
Range		0–6.8	0–15.4	0–24.0	
Mean (SD)		1.3 (0.9)	5.0 (3.2)	6.6 (3.8)	
Median (IQR)		1.1 (0.8–1.6)	4.5 (3.1–6.5)	5.9 (4.2–8.1)	
Other	223 (2.7)				202 (90.2)
Range		0–8.3	0–18.7	0–22.7	
Mean (SD)		1.6 (1.2)	5.9 (3.3)	7.6 (4.2)	
Median (IQR)		1.2 (0.9–1.9)	5.3 (3.5–7.7)	6.9 (4.9–9.5)	
Not available	1				
Previous ALS experience					
No	4615 (56.2)				4411 (95.6)

Table 1 (*Continued*)

Characteristics/outcomes	n, (%)	Hours spent on compulsory modules	Hours spent on non-compulsory modules	Total hours spent on e-learning	Overall pass rate (%)
Range		0–10.0	0–21.0	0–24.0	
Mean (SD)		1.2 (0.8)	4.5 (2.7)	5.8 (3.2)	
Median (IQR)		1.0 (0.7–1.4)	4.1 (3.9–7.2)	5.3 (3.8–7.2)	
Yes	3593 (43.8)				3515 (98.0)
Range		0–13.2	0–21.0	0–24.0	
Mean (SD)		1.2 (0.8)	4.1 (2.6)	5.4 (3.2)	
Median (IQR)		1.0 (0.7–1.4)	3.8 (2.5–5.3)	5.3 (3.9–7.2)	
Not available	10				
Previous ILS experience[a]					
No	2704 (32.9)				2624 (95.5)
Range		0–8.3	0–21.0	0–24.0	
Mean (SD)		1.2 (0.9)	4.5 (2.8)	5.8 (3.4)	
Median (IQR)		1.0 (0.8–1.5)	4.1 (2.7–5.8)	5.3 (3.7–7.4)	
Yes	5466 (67.1)				5302 (97.2)
Range		0–13.2	0–20.9	0–24.0	
Mean (SD)		1.1 (0.8)	4.3 (2.6)	5.5 (3.1)	
Median (IQR)		1.0 (0.7–1.4)	4.2 (2.9–5.7)	5.4 (3.8–7.3)	
Not available	48				
Core member of resuscitation team					
No	4373 (53.8)				4173 (95.7)
Range		0–9.4	0–21.0	0–23.5	
Mean (SD)		1.2 (0.8)	4.5 (2.7)	5.8 (3.2)	
Median (IQR)		1.0 (0.8–1.5)	4.2 (2.9–5.7)	5.4 (3.9–7.3)	
Yes	3759 (46.2)				3668 (97.7)
Range		0–13.2	0–21.0	0–24.0	
Mean (SD)		1.1 (0.8)	4.1 (2.6)	4.9 (3.1)	
Median (IQR)		0.9 (0.7–1.4)	3.8 (2.6–5.3)	4.9 (3.5–6.8)	
Not available	86				
Total	8218				7926 (96.6%)
Range		0–13.2	0–21.0	0–24.0	
Mean (SD)		1.2 (2.8)	4.3 (2.7)	5.6 (3.2)	
Median (IQR)		1.0 (0.74–1.4)	4.0 (2.7–5.5)	5.2 (3.7–7.1)	

[a] Immediate Life Support.
[b] ST3+, middle grade equivalent.
[c] Consultant or associate specialist.

participants had a degree of missing data and these were excluded from the analysis. Any missing data occurred due to incomplete data entry by participants or local course facilitators on the LMS. Stratified participant demographics are displayed in Table 1 in addition to time spent accessing the e-learning and corresponding pass rates.

Assessment outcomes

Assessment outcome data are displayed in Table 2. 99.1% of participants completed the post e-learning MCQ, with a mean score of 83.7 (SD 7.3). The mean post-course MCQ score was 87.7 (SD 7.9). Resuscitation officers had the highest mean score in the post-course MCQ (90.5, SD 5.5), with operating department practitioners (ODP) the lowest (79.2, SD 17.0). Those participants who had previous ALS experience or were a core member of the resuscitation team performed better in the post-course MCQ ($P < 0.001$, $P < 0.001$ respectively), as did the more senior doctors and nurses. Participants with previous ILS experience performed worse in the post-course MCQ ($P < 0.001$).

The first attempt pass rate for CAS-Test was 84.6%. Univariate analysis found that paramedic and resuscitation officer pass rates were similar to physicians whilst nurses, medical students and those in the 'other' category had lower pass rates. Those participants with previous ALS experience were 1.97 times more likely to pass the CAS-Test assessment on the first attempt (OR 1.97 (95% CI 1.73–2.24), $P < 0.001$) compared to those with no previous ALS experience. Those who were core members of the resuscitation team were 1.67 times more likely to pass the CAS-Test scenario, compared with those who were not core members (95% CI 1.48–1.90), $P < 0.001$). Middle grade doctors were 1.75 times more likely to pass the CAS-Test compared to Foundation Year 2 doctors. (95% CI 1.40–2.17, $P < 0.001$).

The overall course pass rate was 96.6%. Resuscitation officers demonstrated the highest pass rate at 100%. Junior nurses had the lowest pass rate of 88.4%. When compared to doctors in the univariate analysis; nurses (OR 0.22, 95% CI 0.17–0.29, $P < 0.001$), ODPs (OR 0.30, 95% CI 0.12–0.76, $P = 0.011$) and participants from the 'other' category (OR 0.12, 95% CI 0.06–0.24, $P < 0.001$) had significantly lower overall pass rates. Participants were more likely to pass if they had previously undertaken ALS training (OR 2.27, 95% CI 1.73–2.98, $P < 0.001$), ILS training (OR 1.64, 95% CI 1.29–2.09, $P < 0.001$) or were a core member of the resuscitation team (OR 1.91, 95% CI 1.48–2.47, $P < 0.001$).

The significant independent variables from the univariate analyses were assessed for co-linearity. Grade of training was removed due to co-linearity with healthcare background. The remaining independent variables were entered into multivariate analyses. Figs. 1–3 present the findings from the multivariate analyses, with full data in supplementary material. Previous ILS and ALS experience and being a core member of a resuscitation team were independent predictors of CAS-Test performance, post course MCQ score and overall success rates. Increasing age was associated with worse post course MCQ score, CAS-Test outcome and overall result.

Time spent accessing e-learning

Median time spent on the e-learning was 5.2 h (IQR 3.7–7.1). Resuscitation officers spent the longest time (median 7.5 h, IQR 5.7–9.2). Doctors spent the least amount of time (median 4.9 h, IQR 3.4–6.7). In general, those doctors with more clinical experience spent less time accessing the e-learning material. This is

Table 2
Univariate predictors of assessment outcomes.

Independent variables	Mean post e-learning MCQ score	Mean post-course MCQ score	P-value	CAS-Test pass (%)	Odds ratio (95% CI)	P-value	Overall course pass (%)	Odds ratio (95% CI)	P-value
Healthcare profession									
Doctor (comparision)	84.7	88.7	<0.001[b]	5352 (86.0)			6095 (97.8)		
Nurse	79.7	80		1005 (81.3)	0.71 (0.60–0.83)	<0.001	1122 (90.9)	0.22 (0.17–0.29)	<0.001
Medical student	83.4	86.5		425 (79.6)	0.64 (0.51–0.79)	<0.001	525 (98.3)	1.31 (0.66–2.59)	0.435
Operating department practitioner	73.0	79.2		51 (70.8)	0.40 (0.24–0.66)	<0.001	67 (93.1)	0.30 (0.12–0.76)	0.011
Ambulance staff/ paramedic	81.4	85.4		37 (92.5)	2.00 (0.62–6.62)	0.247	39 (97.5)	0.88 (0.12–6.43)	0.897
Resuscitation officer	86.6	90.5		13 (86.7)	1.06 (0.24–4.69)	0.941	15 (100.0)	3.6×10^6	<0.001
Other	79.9	83.6		46 (66.7)	0.33 (0.20–0.54)	<0.001	62 (84.9)	0.12 (0.06–0.24)	<0.001
Stage of training									
Medical student	83.3	86.4	<0.001[b]	426 (79.5)	0.72 (0.56–0.92)	0.010	526 (98.0)	0.70 (0.34–1.44)	0.332
Foundation Year 1 doctor	83.0	86.6		1394 (84.7)	1.03 (0.85–1.24)	0.754	1624 (98.4)	0.92 (0.52–1.60)	0.754
Foundation Year 2 doctor (comparision)	83.2	87.7		1401 (84.3)			1639 (98.6)		
Junior grade doctor (ST1/ST2)	85.2	89.1		667 (85.6)	1.11 (0.87–1.40)	0.406	768 (96.8)	0.45 (0.26–0.79)	0.006
Middle grade doctor[d]	87.0	91.1		1322 (90.4)	1.75 (1.40–2.17)	<0.001	1434 (97.9)	0.70 (0.41–1.20)	0.197
Senior grade doctor[e]	87.9	92.0		425 (87.3)	1.28 (0.95–1.72)	0.107	469 (96.1)	0.40 (0.22–0.76)	0.005
Junior nurse (band 4–6)	78.8	82.8		777 (78.3)	0.67 (0.55–0.82)	<0.001	886 (88.4)	0.12 (0.08–0.19)	<0.001
Senior nurse (band 7–9)	81.4	86.6		346 (87.8)	1.34 (0.97–1.87)	0.080	378 (95.5)	0.31 (0.17–0.57)	<0.001
Other	82.6	86.6		163 (74.1)	0.53 (0.38–0.74)	<0.001	202 (90.2)	0.14 (0.08–0.26)	<0.001
Previous life support course experience									
Previous ALS experience	85.5	89.7	<0.001[a]	3204 (89.3)	1.97 (1.73–2.24)	<0.001	3515 (98.0)	2.27 (1.73–2.98)	<0.001
No previous ALS experience	82.3	86.1		3727 (81.0)			4411 (95.6)		
Previous ILS experience	83.2	87.4	<0.001[a]	4666 (85.6)	1.24 (1.09–1.40)	0.001	5302 (97.2)	1.64 (1.29–2.09)	<0.001
No previous ILS experience	84.5	88.3		2265 (82.7)			2624 (95.5)		
Core member of resuscitation team	84.4	88.8	<0.001[a]	3305 (88.0)	1.67 (1.48–1.90)	<0.001	3668 (97.7)	1.91 (1.48–2.47)	<0.001
Not a core member of resuscitation team	83.0	86.6		3540 (81.4)			4173 (95.7)		
Age (years)			−0.33 ([−0.52] to [−0.11])[c] 0.003		0.98 (0.97–0.98)	<0.001		0.93 (0.93–0.94)	<0.001
Time spent on e-learning (h)			−0.24 ([−0.30] to [−0.19])[c] < 0.001		0.93 (0.91–0.94)	<0.001		0.90 (0.87–0.93)	<0.001

[a] Independent samples *t*-test.
[b] One way ANOVA.
[c] Linear regression to predict post course MCQ score (B value with 95% confidence intervals).
[d] ST3+, registrar equivalent.
[e] Consultant or associate specialist.

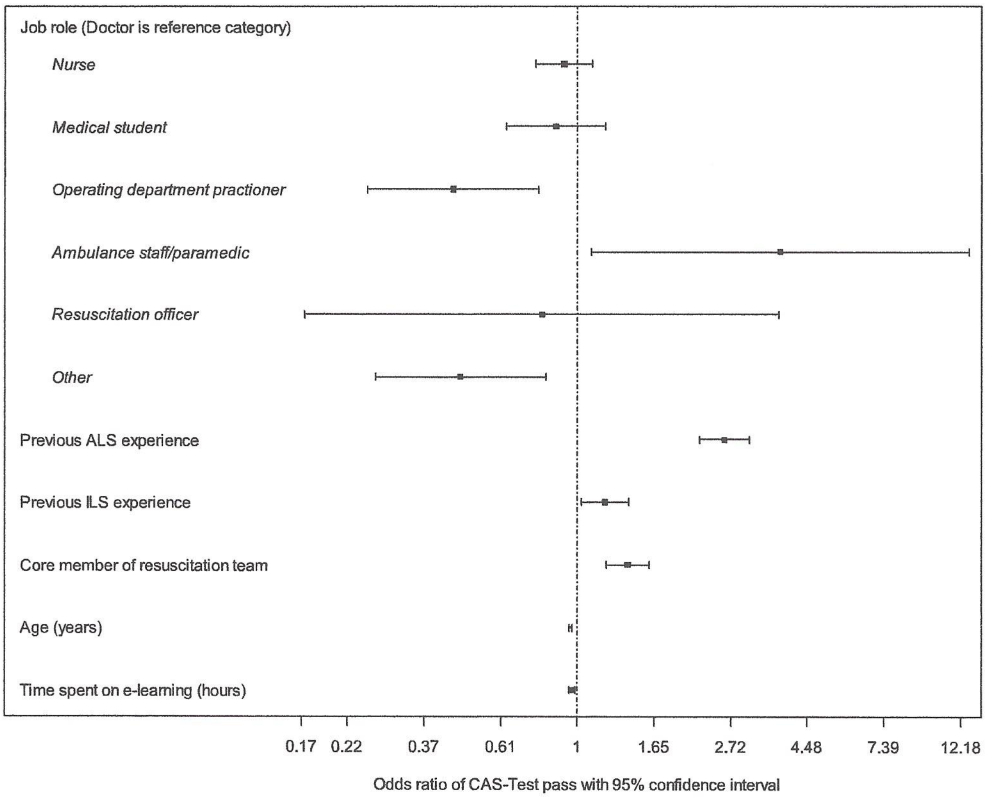

Fig. 1. Multivariate analysis demonstrating factors that influence CAS-Test outcome.

Table 3
Duration spent on individual ALS modules stratified by grade, profession and speciality background (min).

	ALS in perspective	ALS algorithm	Causes and prevention of cardiac arrest	Acute coronary syndromes	Post resuscitation care	Monitoring, rhythm recognition and 12-lead ECG	Tachycardia, cardioversion and drugs	Bradycardia, pacing and drugs	Special circumstances	Decisions relating to resuscitation	Arterial blood gas analysis
Grade/healthcare profession											
Foundation Year doctor	9.2	44.0	17.0	27.1	22.5	34.3	32.3	15.7	25.1	8.0	14.5
Junior grade doctor (ST1/ST2)	9.8	45.3	17.7	26.6	22.7	32.5	30.4	14.6	24.6	8.9	15.3
Middle grade doctor	9.5	43.8	17.0	26.4	21.8	30.7	27.8	13.6	22.8	8.0	12.4
Senior grade doctor	10.1	48.0	17.8	25.8	21.4	33.5	31.6	14.2	26.1	9.0	15.4
Junior nurse	11.0	51.0	21.4	31.1	24.9	53.5	39.6	19.9	32.7	10.3	25.1
Senior nurse	10.6	50.1	19.7	29.9	24.8	46.9	38.2	17.6	31.0	9.7	22.4
Paramedic	10.5	42.9	19.4	29.7	25.2	42.4	36.4	17.6	28.9	10.2	19.8
Operating department practitioner	10.6	49.5	22.6	29.5	24.8	57.8	43.8	20.3	33.0	12.1	28.6
Resuscitation officer	13.3	41.7	20.0	40.0	25.9	83.8	42.2	25.6	41.4	11.4	29.9
Medical student	9.3	45.0	17.8	28.1	24.1	38.5	35.8	16.5	28.7	9.3	15.6
Speciality background											
Anaesthetics	9.7	45.5	17.9	27.5	23.0	36.2	32.9	16.0	26.1	8.6	16.0
Cardiology	10.0	44.6	17.9	25.7	21.7	33.1	33.9	15.4	31.8	9.0	19.1
Surgery	9.3	45.0	17.9	28.0	23.0	35.9	33.7	15.5	25.5	8.1	15.5
Medicine	9.3	44.2	17.2	26.5	22.4	33.0	30.9	14.8	25.3	8.1	14.3
Emergency	10.0	45.2	18.2	27.6	23.4	38.3	32.6	16.4	25.6	9.1	18.3
Critical Care	11.1	52.1	20.8	30.7	23.8	46.1	38.2	18.9	32.0	9.8	18.5

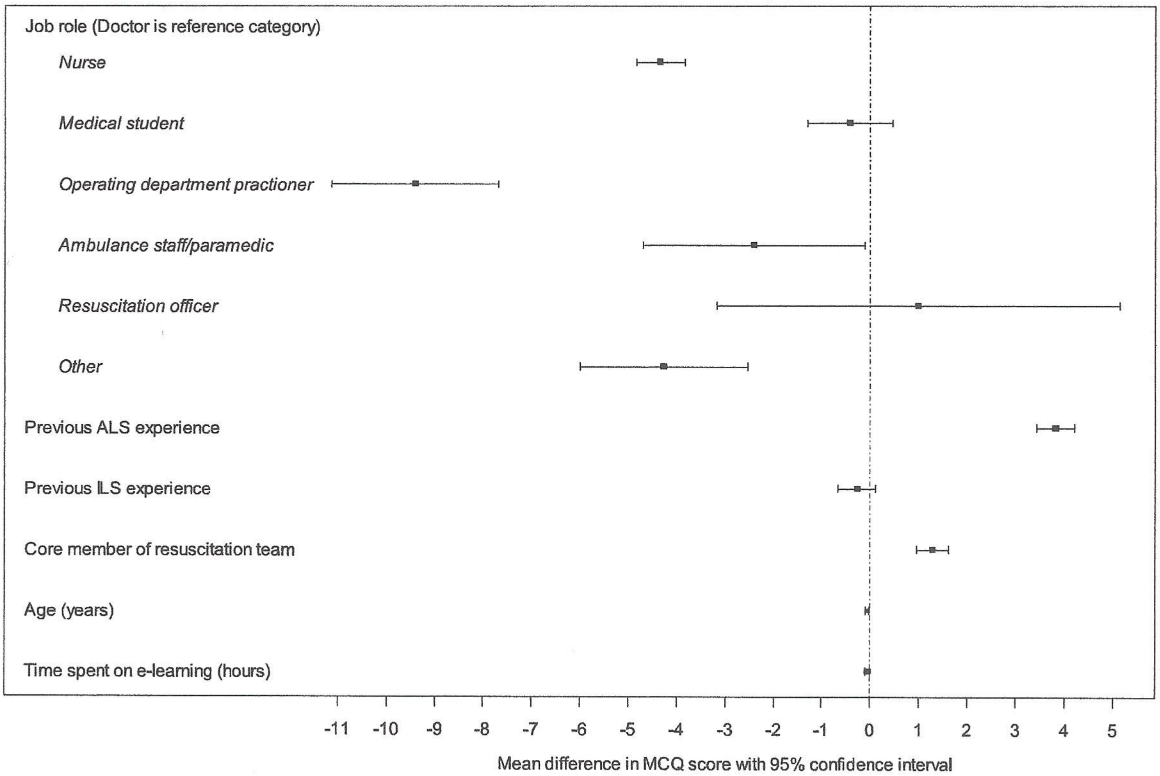

Fig. 2. Multivariate analysis demonstrating factors that influence post-course MCQ score.

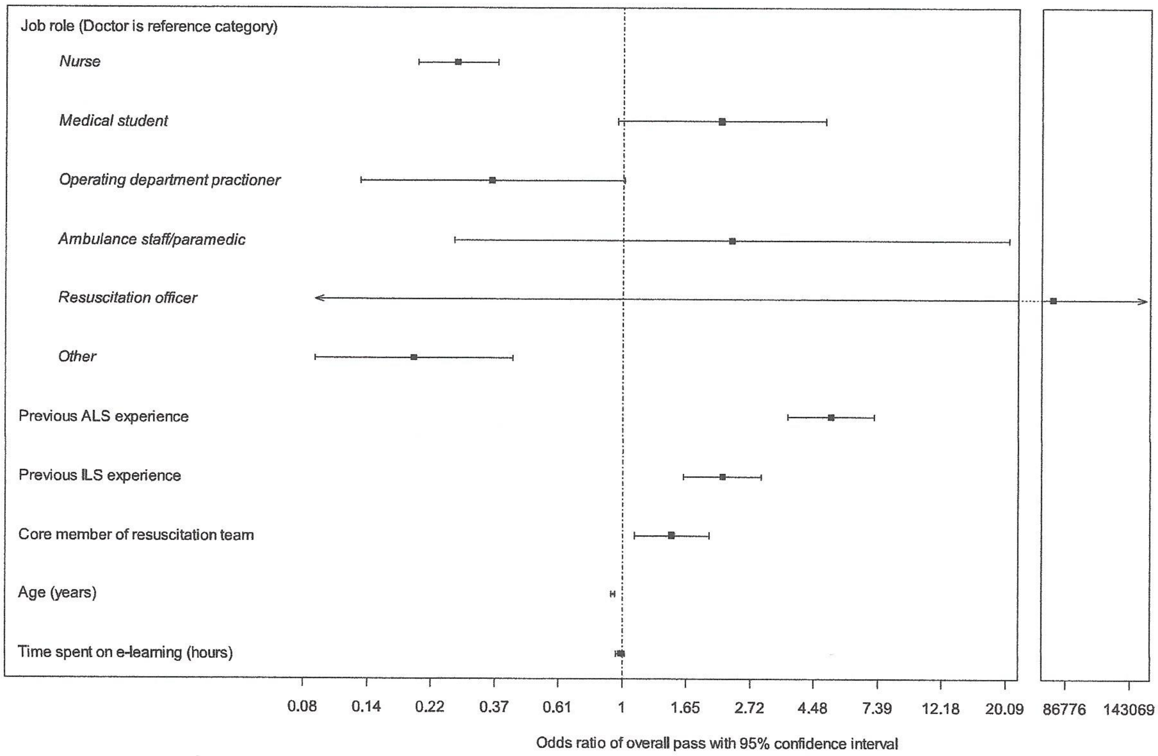

Fig. 3. Multivariate analysis demonstrating factors that influence overall course outcome.

demonstrated in Table 3 where middle grade doctors spend the least time on every module. In the univariate analysis, increased hours spent accessing e-learning was a statistically significant predictor of failing the post-course MCQ (B = −0.24, 95% CI [−0.30] to [−0.19], P < 0.001), the CAS-Test assessment (OR 0.93, 95% CI 0.91–0.94, P < 0.001) and the overall course (OR 0.90, 95% CI 0.87–0.93, P < 0.001). When all other co-variates were controlled for in the multivariate regression, time spent accessing e-learning remained a significant predictor of CAS-Test failure (OR 0.96, 95% CI 0.95–0.98, P < 0.001) but was not a significant predictor of overall course failure (OR 0.98, 95% CI 0.95–1.02, P = 0.367).

Table 3 demonstrates the homogeneity between time spent on individual e-learning modules when stratified by speciality. Those from a critical care background spent slightly more time on modules compared to others, but this is likely due to the high proportion of nurses participating in the e-ALS course from this speciality (357/487, 73.3%).

Discussion

This study has shown that previous experience in life support courses and being a core member of the resuscitation team predicts a favourable outcome on an e-ALS course. It also identifies the extent to which different candidate groups access the e-learning material and highlights particular modules that may be more challenging. Time spent accessing e-learning material was not related to course outcome; this was thought to be because participants who utilise these skills on a daily basis are already familiar with the material and thus require less time to re-familiarise themselves.

There are increasing pressures to minimise time spent on courses for both participants and faculty and to improve outcomes. It has been postulated that pre-course preparation could lead to either better outcomes or a reduced amount of face-to-face time needed on the course. This could in theory lead to equivalent or better participant outcomes with less resources (time off work for faculty/participants, venue hire etc.). There is very little evidence relating specifically to pre-learning for ALS courses, so this study goes some way towards filling that void.

Perkins et al.[11] looked at one example of pre-course preparation. This open label, multicentre RCT was a study of 572 participants on Resuscitation Council (UK) ALS courses. The control group received the course manual four weeks before the course. The intervention group received the course manual and also a CD with an interactive e-learning simulation programme. Although there were no significant differences in the primary outcome (performance during a standard cardiac arrest simulation), user evaluations were favourable. The results however cannot necessarily be generalised to all other types of pre-course learning or pre-course learning for other populations/course groups.

A multi-centre RCT demonstrated equivalence in outcome when comparing e-ALS and c-ALS learning methods and was significantly less costly to deliver.[8] The findings of this were corroborated by a large observational study of 27,170 participants which demonstrated almost identical assessment outcomes for participants enrolled on either a c-ALS or e-ALS course.[9] These studies were a comparison of a standard life support course against specific pre-course e-learning associated with a shorter duration hybrid life support course.

The topic of pre-course learning was addressed during the 2015 ILCOR international consensus on science process. It was felt that a specific recommendation for or against pre-course preparation in ALS courses was too speculative due to the lack of evidence in the literature.[15] These findings were balanced with a statement highlighting the considerable ambiguity in the definition of "pre-course learning" and the difficulty in comparing single interventions like a pre-course CD[11] with an intervention followed by a hybrid version of the face-to-face element.[8,9]

With regard to the findings from this study, we found some unexpected and interesting results. The most surprising result was that time spent accessing prerequisite e-learning material was actually associated with worse assessment and overall course outcome in the univariate regression. On further analysis however, this is explained by the fact that those with greater clinical experience spent less time accessing the e-learning but paradoxically performed better in the course assessments. This demonstrates the educational notion that when learning can be based on previous experience; it will normally lead to improved outcomes. This is demonstrated in the multivariate regression where time spent on e-learning was no longer a significant predictor of overall course outcome. Increased age was associated with significantly poorer assessment outcomes. Whilst there is a paucity of evidence for the literature regarding the effect of age on ALS outcomes, this pattern has been found in BLS studies and has been attributed to skill decline over time[16,17] and psychological factors where younger participants are more motivated to learn.[18] It has been found that those working in a high risk area for area for cardiac arrest were more motivated to learn life support skills.[19]

Participants with greater experience in managing critically unwell patients (paramedics, middle grade doctors, previous ALS/ILS experience, core member of the resuscitation team) performed substantially better in the CAS-Test and overall result. This should not come as a surprise, but is a useful insight for course organisers when identifying participants at the start of a course who do not fall into these groups and may benefit from additional support.

The e-learning package allows participants to dictate their own level of access dependent upon their prior knowledge, experience and speciality background. They can access material at an appropriate time for them and dedicate a greater amount of time to their weaker knowledge areas. The need for this degree of flexibility is demonstrated by the vastly different durations spent accessing the online content. This is exemplified in Table 3 which highlights that certain candidate groups (junior nurses and operating department practitioners) spent twice as long on the 'Monitoring, rhythm recognition and 12-lead ECG' module compared to middle grade doctors, perhaps because they do not routinely utilise such skills on a daily basis. The flexibility that the e-ALS course creates is just one reason amongst many why participant satisfaction is greater on e-learning courses than compared to traditional didactic courses.[20,21]

Limitations and further research

The main limitation of this exploratory study is its observational nature. This means that the authors are only able to suggest causality when determining whether independent variables influence assessment outcome. A specifically designed RCT would be needed to establish a cause–effect relationship on assessment outcome.

Time is not necessarily an accurate marker of whether participants have truly engaged with the material and as this study has shown, it is significantly confounded by clinical experience (i.e. if participants are already well versed in ECG interpretation they will spend less time on this module). Furthermore, different individuals possess a spectrum of learning abilities with some participants learning faster than others. A proportion of participants may have chosen to preferentially utilise the course manual as opposed to the e-learning package and others may leave the e-learning running whilst not at the computer, providing a falsely elevated time spent accessing the material. There remains a need for more specific markers for determining whether participants have truly engaged with the e-learning material.

A final limitation is that it does not determine whether accessing e-learning actually affects patient outcome from cardiac arrest. Whilst this should be the overriding aim behind all resuscitation-related research, such studies are very difficult to achieve. The authors believe however, that by critically appraising course outcome data and continuously improving the delivery methods of resuscitation courses this will ultimately improve the care of the critically unwell patient.

Conclusion

Clinical experience through core membership of cardiac arrest teams and previous ILS or ALS training were independent predictors of performance on the e-ALS course whilst time spent accessing e-learning materials did not affect course outcomes. The large variation in time spent accessing e-learning reflects the diverse nature of participants on our e-ALS courses and the spectra of learning needs that they possess. This supports the blended approach to e-ALS which allows participants to tailor their e-learning experience to their specific needs.

Conflict of interest statement

CJT is a Trainee Representative for the ALS Subcommittee for the Resuscitation Council (UK). ASL is Honorary Secretary of the Resuscitation Council (UK) and a member of the European Resuscitation Council ALS Course Committee. IB is an Educator for the Resuscitation Council (UK). SH is Director of Course Development and Training for the Resuscitation Council (UK). SB-A is Project and Development Manager for the Resuscitation Council (UK). GDP is Chair of the ALS Subcommittee for the Resuscitation Council (UK) and member of the European Resuscitation Council ALS Course Committee.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2017.02.014.

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Paper 5 is a descriptive analysis of the demographics and assessment outcomes for 8,218 participants attending an RC(UK) e-ALS course between January 2013 and June 2014 (Thorne et al., 2017, p. 83). My contribution to this paper included conception and design, drafting of the article, critical revision of the draft, and final approval of the article.

In parallel with the descriptive analysis of overall outcomes for participants on both c-ALS and the definitive e-ALS course (Paper 4), this study aimed to identify if there are any specific variables that are associated with better educational outcomes for participants on the e-ALS course. On the assumption that candidates do not always access prior learning opportunities, an objective of this study was to identify if the amount of time accessing e-learning correlated with better or worse outcome scores. One advantage of the investment in an LMS was that the RC(UK) now had the ability to collate data on time spent per module per participant. As the face-to-face element of the course was now reduced to one day and participants could choose whether or not to access e-learning (which was not mandatory), there were concerns that this may result in adverse educational outcomes.

The aim of this paper was to describe the variables which are associated with better outcomes for candidates on an e-ALS course. The methodology used was descriptive in nature, which could be viewed as a limitation although this was mitigated by the large numbers studied and the very small drop-out rate. The population analysed included every participant of an e-ALS course between 1 January 2013 and 30 June 2014. There was no randomisation, and each participant had the option to attend the course of their choice. The variables analysed were participant demographics (healthcare background, stage of training, previous ILS or ALS experience, core membership of resuscitation team), time spent on individual e-learning modules, and educational outcomes (mean post e-learning and post course MCQ, CasTest pass rates, and overall course pass rates).

Out of 8,218 participants, only 15 started then failed to complete the course. In addition, there was a very small amount (1.8%) of missing data due to incomplete data entry by participants or local facilitators on the LMS.

With regard to the domain of knowledge, resuscitation officers scored highest (90.5%, SD 5.5) and operating department practitioners scored the lowest (79.2%, SD 17.0) in the post-course MCQ. Resuscitation officers are NHS employees who are responsible for co-ordinating the teaching and training of staff in resuscitation. Their role also involves attending medical emergencies and cardiac arrests, audit, and organisation of emergency equipment provision. Operating department practitioners are regulated healthcare providers who provide care for patients in the overall planning and delivery of perioperative care. Those with prior ALS experience and/or core members of resuscitation team performed significantly better in the post course MCQ ($p<0.001$). Senior doctors and nurses performed significantly better in the post course MCQ ($p<0.001$), whilst those with prior ILS experience performed significantly worse in the post course MCQ ($p<0.001$).

The e-ALS course also assesses the domain of clinical skills. With regard to the first attempt at CasTest, those with previous ALS experience were more likely to pass (OR 1.97; 95% CI 1.73 to 2.24; $p<0.001$). Participants with core resuscitation team experience were also more likely to pass (OR 1.67; 95% CI 1.48 to 1.90; $p<0.001$) with middle grade doctors outperforming junior doctors (OR 1.75; 95% CI 1.40 to 2.17; $p<0.001$).

Overall, resuscitation officers had the highest overall course pass rate (100%) and junior nurses had the lowest (88.4%). Participants were more likely to pass if they had previous ALS experience (OR 2.27; 95% CI 1.73 to 2.98; $p<0.001$) or previous ILS experience (OR 1.64; 95% CI 1.29 to 2.09; $p<0.001$). They were also more likely to pass if they were core members of a resuscitation team (OR 1.91; 95% CI 1.48 to 2.47; $p<0.001$). When compared with doctors, other healthcare professional groups had significantly lower pass rates.

The median time spent accessing e-learning was 5.2 hours (IQR 3.7 to 7.1). Resuscitation officers spent the longest time accessing the e-learning (median 7.5 hours, IQR 5.7 to 9.2), and doctors spent the least amount of time (median 4.9 hours, IQR 3.4 to 6.7). Those with more experience spent less time accessing the e-learning. It was calculated that an increased amount of time spent accessing e-learning was a statistically significant predictor of failing the post course MCQ (B= -24, 95% CI -0.30 to -0.19; $p<0.001$), failing the first CasTest assessment (OR 0.93, 95% CI 0.91 to 0.94; $p<0.001$), and failing the course overall (OR 0.90, 95% CI 0.87 to 0.93; p<0.001). When all other co-variates were controlled for in multivariate regression, time spent accessing the e-learning remained a significant predictor of CasTest failure (OR 0.96; 95% CI 0.95 to 0.98; p<0.01), but not of overall course failure (OR 0.98; 95% CI 0.95 to 1.02; p=0.367). This paper concluded that prior participation on an ILS or ALS course and existing membership of a cardiac arrest team were independent predictors for success on the e-ALS course. Increasing age was associated with poorer educational outcomes including first CasTest pass (OR 0.98, 95% CI 0.97 to 0.98; p<0.001) and overall course success (OR 0.93, 95% CI 0.93 to 0.94, p<0.001). The time spent accessing e-learning modules did not affect their course outcome.

A strength of this paper is its ability to describe the outcomes for a large number of participants. As with Paper 4, it is an observational study and not randomised, but the large and detailed sample size assists in mitigating this limitation. Another strength is the ability, through the LMS, to accurately capture and quantify the time spent on each module for each candidate. A potential limitation of this study however is that less experienced participants may have left e-learning modules open whilst doing other activities, thus giving an artificially long access time. In addition, experienced participants may have relied more heavily on the course manual rather than the e-learning package, thus giving them an artificially short access time.

In summary, the findings from Paper 5 give a valuable insight into the participant variables that are more likely to be associated with better educational outcomes on the e-ALS course. Paper 4 had concluded that the definitive e-ALS course delivered equivalent educational outcomes for participants who chose to attend it over the c-ALS course. The outcomes from Paper 5 would now enable the RC(UK) to provide guidance to prospective candidates as to which course may be more appropriate for them to attend.

Chapter 5: Discussion

In this chapter, I will discuss the relevance of each publication with regard to the overall aims and objectives of this programme of research. I will summarise the existing body of knowledge at the time of each publication and discuss the novel contribution that each study made to that field of research. I will also describe any studies that have been subsequently published that add any further evidence to the body of knowledge. In addition, I will discuss the findings from each paper in context with the evidence for a blended learning approach as detailed in Chapter 3. Each publication resulted in the identification of future areas of research, and these will be discussed. As the portfolio represents a programme of research spanning several years, the conclusions from the earlier studies prompted the later research that is also presented in this chapter. Finally, I will outline any ongoing research gaps and will describe how this research has informed changes in recommendations for practice at an international and national level.

5.1 Paper 1

In order to articulate the novel contribution to knowledge of Paper 1, I will discuss the importance of the problem that it addresses, the certainty of evidence, desirable and undesirable effects, balance of effects, resources required including cost effectiveness, equity, acceptability, and feasibility. One of the objectives of this research was to assess the impact of advanced life support training on the outcomes of patients who suffer, or who are at high risk of suffering a cardiorespiratory arrest. This is important as in-hospital cardiac arrest has already been described in Chapter 1 as a significant global issue. I will describe how the evidence described in Paper 1 shows that the advanced life support courses that are delivered internationally have a positive effect on patient outcomes, thus establishing their importance as an educational intervention.

This systematic review addressed a problem that is of great importance to global healthcare delivery. The scale of the issue in terms of numbers of patients having an in-hospital cardiac arrest has already been described in Chapter 1. Despite improvements over the years, one person in every 1,000 hospital admissions in the UK (*Key Statistics from the National Cardiac Arrest Audit 2018/19*, 2019, p. 1) and as many as 10 patients per 1,000 hospital admissions in the USA (Andersen, Holmberg, Berg, Donnino, & Granfeldt, 2019, p. 1200) have a cardiac arrest. It is reasonable to expect that healthcare professionals will be trained to identify and treat medical emergencies, yet knowledge of advanced life support amongst healthcare professionals has been shown to be poor in several different countries (Einav, Wacht, Kaufman, & Alkalay, 2017, p. 22; Martínez, Delgado, Fernández, & González, 2018, p. 508; Pantazopoulos et al., 2011, p. 278). Advanced cardiac life support training is delivered globally with an estimated 1.3 million candidates per annum undertaking either the AHA ACLS course or the RC(UK)/ERC/ARC ALS course (Lockey, Lin, & Cheng, 2018). In the UK, ALS training is a core component of the foundation curriculum that is undertaken by all newly qualified doctors and it is also a mandatory requirement for specialty medical training in clinical areas where cardiac arrest management is expected (e.g. emergency medicine). Attendance of candidates on an ALS course comes at a cost however in terms of time and financial expense to both candidates and institutions. It is therefore important to demonstrate whether this participation has any meaningful impact upon patient outcomes.

The certainty of evidence for this review was very low as the studies were predominantly old and of very poor quality. They were mostly retrospective single-centre studies, using historical controls, with poor reporting on patient characteristics. Only one study adjusted outcomes for possible confounding (Dane, Russell-Lindgren, Parish, Durham, & Brown Jr, 2000, p. 83) and some studies were conducted with small sample sizes and are likely to be underpowered. The most recent study, which was the only one reporting data post-2000 (Sodhi, Singla, & Shrivastava, 2011, p. 209), showed a significant benefit to the addition of advanced cardiac life support training to staff already trained in basic life support. This study was also subject to significant confounding, as the authors only reported unadjusted outcomes and provided very limited data on patient and arrest characteristics between the two periods. It is, however, the study that analyses the impact of the most recent and therefore contemporary version of the course.

When considering how substantial the desired effects are, there are several factors that should be taken into consideration. Patients value survival with good neurological outcome (Haywood et al., 2018, p.

e783). The studies in this review only looked at the impact of advanced cardiac life support on patient survival and no data was available to assess the quality of life in the survivors. It should be noted that all of the studies were conducted prior to contemporary evidence-based interventions such as targeted temperature management, which have been proven to strengthen the post resuscitation phase of care (Lascarrou et al., 2019, p. 2327). There is a possibility therefore that candidates on current iterations of the course are being trained to consider interventions that have a better chance of delivering higher quality of survival in comparison with the time period of the papers reviewed in Paper 1. The most recent study in this systematic review included participants attending courses between January 2009 and June 2010 (Sodhi et al., 2011, p. 209). Since then, the clinical resuscitation guidelines have been updated in 2015 and another update is pending in Spring 2021. There is also an increased emphasis in the contemporary course on the strengths of the team approach, and also on the importance of non-technical skills (Yeung et al., 2014, p. S71). In addition, conversations about end of life care, patient choice, and ‘do not attempt CPR’ (DNACPR) decision making are more common now. The importance of this was highlighted in the UK in a report by the National Confidential Enquiry into Patient Outcome and Death report (Findlay, Shotton, Kelly, & Mason, 2012, p. 1) which showed that patients were undergoing inappropriate resuscitation attempts because DNACPR forms were not completed in a timely manner. The course itself has changed over the years since its inception, as described in Chapter 3. It has become more aligned with contemporary learning theory resulting in the introduction of a blended learning e-ALS course in the UK. All of these factors have the potential to provide an even greater positive impact not only on patient survival rates but also on neurological outcome. A research challenge for the future will be to devise a study that is powered to analyse in particular that latter outcome. If a robust randomised controlled trial or cohort study were feasible then it is essential that some measure of neurological function be collated as well as survival data. ALS and ALCS courses are now fully established in many countries throughout the world, which makes it more difficult to perform higher levels of research as it is more likely that practitioners have already had some kind of exposure to such training. This would make a true randomised controlled trial, or even a historical control trial, difficult to perform. The only opportunity for such a research project would be if there were plans to introduce advanced life support training into a new healthcare setting with no previous exposure to similar training.

A particularly important desired effect identified in the review was that the provision of training can actually lead to the delivery of different care to patients. Whilst this produces a confounding element to historical cohort studies, it represents a welcome evolution in quality of care. Training can prompt individuals and institutions to reflect on which patients should actually be receiving resuscitation to optimise survival rates. In two of the historical cohort studies identified in the review (Camp, Parish, & Andrews, 1997, p. 529; Lowenstein, Sabyan, Lassen, & Kern, 1986, p. 512), the authors noticed an increase in the number of resuscitation attempts after the introduction of ACLS courses. Whilst it is not clear if this represented an increase in appropriate resuscitation attempts or not, the overall increase in survival rates are encouraging. However, this once again highlights the importance of including neurological outcome in reported data to confirm whether this is a desirable or undesirable effect of training.

Most treatment effects in this review favoured the intervention of accredited advanced cardiac life support training. It was unclear whether this was achieved due to improved knowledge, skills, user satisfaction or a combination of these factors. The systematic reviews for the impact of blended learning that addressed knowledge, skills, and user satisfaction detailed in Chapter 3 therefore describe, in effect, surrogate outcomes. The findings of this review, however, is that these courses are likely to improve the overall care provided during cardiac arrest, and thus improve survival for patients which is a much more important outcome. Whilst the positive effects are presented with very low evidence, they likely offset the potential negative effect of untrained healthcare professionals and inappropriate resuscitations attempts.

It is also important to take into consideration the resource implications of providing this training. The financial implications of running advanced life support courses include costs to the overseeing resuscitation council (e.g. manual production and development of e-learning platforms), course centre (e.g. faculty costs, facility costs, equipment purchase, and maintenance), employers (e.g. course fees, covering study and professional leave time for candidates and faculty), and employees (e.g. course fees in some cases). These costs will vary between different healthcare settings. When looking at advanced life support training from an international perspective, there may be a further impact on health equity as the resources and costs needed may prohibit advanced cardiac life support training in some low resource healthcare settings. In fact, provision of training in these settings may actually come at a cost to other healthcare interventions if prioritised. There is evidence for the benefits of providing resuscitation training for newborn and trauma situations in low resource settings (Berkelhamer, Kamath-Rayne, & Niermeyer, 2016, p. 573; Meaney et al., 2010, p. 1462). Educational programmes that advocate simple and cheap interventions (e.g. basic airway management and first aid for haemorrhage control) can have profound positive effects on morbidity and mortality in both of these situations. There is very little evidence however for the benefits of advanced cardiac life support training in those settings. It is important to evaluate through research the epidemiology of cardiac arrest and tailor training to match each local situation. The reason for this is that priorities of management may differ, particularly in areas of the world with no pre-hospital emergency medical service (Aufderheide et al., 2013, p. 1289). Some barriers, including the resource and cost implications of providing training, can be surmountable. A potential solution to make delivery of training more affordable could be the development of alternative methods of course delivery. This could include blended learning approaches to training consisting of e-learning modules and reduced face-to-face time. The benefits of such an approach, including the cost of delivery, have been described in Chapter 3 and this concept will be further explored in the subsequent discussion of the papers in this programme of research.

Ultimately, the potential for lives saved by healthcare professionals participating in an advanced life support course would seem to outweigh the costs of candidates attending these courses. Paper 1 provides evidence to stakeholders that attendance of members of the cardiac arrest resuscitation team on these courses leads to improved patient outcomes. The findings also provide evidence to patient groups that the healthcare professionals who will manage them in the most critical of times are well equipped to save their life. As such, this paper provides a novel and welcome contribution to the body of research knowledge.

Prior to conducting the systematic review for Paper 1, there had only been one other published review of the evidence for this specific topic (Williams, 2011, p. 240) and a broader review encompassing all variants of life support courses (Mosley, Dewhurst, Molloy, & Shaw, 2012, p. e349). The review by Williams et al was limited to studies published between 2005 and 2010 to coincide with the 2005-2010 international guideline cycle. It included studies analysing the educational outcomes from simulation assessments as well as actual patient outcomes. As such, only one of the papers from Paper 1 was included in their review (Moretti et al., 2007, p. 458). The authors concluded that "some evidence is available that advanced life support interventions can improve outcome for patients suffering in-hospital cardiac arrest". In contrast, Paper 1 included all studies published about the adult advanced life support course with no date restrictions and specifically looked at studies relating to patient outcomes only (i.e. no simulation studies). Whilst the courses before 2005 represent a different era of course content and resuscitation guidelines, the fundamental principles of how the course was delivered remain similar. The advanced life support course has always been delivered to multi-professional healthcare candidates and has consistently combined didactic delivery with simulation and workshop training. The assessment strategies have also remained similar with a summative knowledge and skills assessment strategy remaining relatively unchanged over the years. Another advantage for including the courses from before 2005 in Paper 1 is that this was an era where the control group was more likely to have had no exposure to the intervention thereby representing a purer and more valid comparative group. Finally, Paper 1 included the only paper that has been published since 2010 (Sodhi et al., 2011, p. 209), which bears a much closer resemblance to contemporary advanced life support courses. The review by Mosley et al covered studies including neonatal, paediatric, adult and trauma life support courses. It also included studies describing non-accredited training curricula delivered to a pre-defined group of participants over a finite period of time in a predefined structured manner. Their analysis of impact on patient outcomes included four studies relating to the ACLS course (Camp et al., 1997, p. 529; Dane et al., 2000, p. 83; Makker, Gray-Siracusa, & Evers, 1995, p. 116; Moretti et al., 2007, p. 458), which were all included in the systematic review for Paper 1. The remaining nine papers that they included related to other life support courses (ILS, ATLS, Prehospital Trauma Life Support, and Paramedic ACLS training). They elected not to perform a meta-analysis due to the heterogeneity of the research designs, educational interventions, and outcome measures. This is not surprising given the broader scope of their review that involved different course styles and the addition of simulation studies. Instead they performed a qualitative data synthesis of the research methods and outcomes before agreeing on key themes. The authors concluded that the introduction of structured resuscitation training leads to a reduction in mortality. This is in concordance with the conclusions of Paper 1. A recently published review by the Cochrane group (Merriel et al., 2019, p. 1) addressed the wider picture of the effects of interactive training of healthcare providers on the management of life-threatening emergencies in hospital on patient outcomes, clinical care practices, or organisational practices. The review included randomised or cluster randomised studies only and included any situation where immediate lifesaving interventions may be needed. They identified eleven studies and the only study that directly related to adult cardiac resuscitation (Weidman, Bell, Walsh, Small, & Edelson, 2010, p. 1556) described 4-hour immersive simulation sessions rather than formal accredited advanced life support training. It therefore falls out of the scope of the inclusion criteria for Paper 1. The review concluded that the benefits of interactive training were uncertain due to the very low certainty of evidence.

In contrast to these reviews, the systematic review for Paper 1 was broader in its time frame and focused purely on patient outcomes. The literature review was initially conducted on 6 March 2018 and identified eight observational studies. It was repeated on 31 October 2019 and no additional studies were identified.

The evidence from similar life support courses is also important as, whilst not directly comparable, a treatment effect in the same direction as that for adult advanced life support courses would support the benefits of life support training as a concept. A systematic review and meta-analysis of the impact of neonatal resuscitation training (NRT) on neonatal and perinatal mortality identified twenty trials with 1,653,805 births (Patel, Khatib, Kurhe, Bhargava, & Bang, 2017, p. e000183). The authors concluded that NRT compared with no NRT (control) decreased the risk of stillbirths by 21% (RR 0.79, 95% CI 0.44 to 1.41), 7-day neonatal mortality by 47% (RR 0.53, 95% CI 0.38 to 0.73), 28-day neonatal mortality by 50% (RR 0.50, 95% CI 0.37 to 0.68), and perinatal mortality by 37% (RR 0.63, 95% CI 0.42 to 0.94). In addition, the authors analysed eighteen pre and post intervention studies and concluded that after NRT training there was a decrease in the risk of all stillbirths by 12% (RR 0.88, 95% CI 0.83 to 0.94), fresh stillbirths by 26% (RR 0.74, 95% CI 0.61 to 0.90), 1-day neonatal mortality by 42% (RR 0.58, 95% CI 0.42 to 0.82), 7-day neonatal mortality by 18% (RR 0.82, 95% CI 0.73 to 0.93), 28-day neonatal mortality by 14% (RR 0.86, 95% CI 0.65 to 1.13), and perinatal mortality by 18% (RR 0.82, 95% CI 0.74 to 0.91). The level of heterogeneity in the NRT versus control analysis was generally very low due to the small number of studies included, with a highest I^2 score of 68% for analysis of perinatal deaths. In contrast, the levels of heterogeneity in the pre and post NRT analyses were moderate to high with a range of I^2 scores of 47% to 95%. The quality of evidence was deemed to be high for 7-day and 28-day neonatal mortality in the NRT versus control analyses and moderate for perinatal mortality in the same analysis. All other analyses were stated to be based upon very low quality evidence. Whilst this review produced conclusions largely based upon pre and post intervention trials, it is unique in that two randomised controlled trials between NRT and control were identified (Bang, Bang, Baitule, Reddy, & Deshmukh, 1999, p. 1955; Gill et al., 2011, p. d346). The implications for practice from this review are that NRT reduces the rate of stillbirths and improves the survival of newborn patients.

A systematic review of the impact of Advanced Trauma Life Support (ATLS) courses (Abu-Zidan, 2016, p. 12; Mohammad, Branicki, & Abu-Zidan, 2014, p. 322) was able to demonstrate positive educational value for the course but clear evidence that the training reduced trauma patient deaths was lacking. The review consisted of one prospective cohort study and six retrospective studies. Five studies showed no effect, one showed significant improvement, whilst one showed worse outcomes for trauma patients managed by ATLS certified doctors. The review concluded that it is important to perform large prospective cohort studies of high quality data and use advanced statistical modelling. The need for future research was also concluded by a Cochrane review on ATLS training, that was unable to identify any controlled trials for this topic (Jayaraman, Sethi, Chinnock, & Wong, 2014, p. 1). The evidence for ATLS is therefore less conclusive than the evidence for NRT.

The findings of Paper 1 hold particular international importance as they have recently been incorporated into the ILCOR 2020 process (Lockey, 2020, p. 1). Despite the fact that it was not primarily commissioned as an ILCOR worksheet (the formal summary of the evidence evaluation process for each topic), the quality of the review and the structure used for the review was felt to be sufficient to make it eligible for inclusion. The review was presented to the ILCOR EIT Taskforce on 3 November 2019 for further discussion. This Taskforce consists of 17 members, of which I am one, representing ten countries (Australia, Austria, Belgium, Canada, Denmark, Germany, Japan, Taiwan, UK, and USA). All worksheets are presented to the group by the Evidence Reviewer and then a group discussion leads to collective decision making about the outcomes and recommendations. Any conflicts of interest are disclosed prior to any discussion. Following the discussion on 3 November 2019, it was decided that the results for ‘survival to hospital discharge’ and ‘survival to thirty days’ should be pooled as they effectively describe a similar outcome. The taskforce also decided to subgroup studies into those that enrolled participants who had taken the course before and after 2001 to reflect the impact of the first set of international guidelines that were introduced in 2000. Only one study (Sodhi et al., 2011, p. 209) contained participants who had participated in a course post 2001.

The results for the outcomes of ROSC and survival to one year remained unchanged. The updated results for survival to hospital discharge or survival to thirty days are presented in Figure 3. For survival to hospital discharge or survival to thirty days, very low quality evidence was identified (downgraded for risk of bias, inconsistency, indirectness and imprecision) from seven observational studies enrolling 1,507 patients showing benefit for advanced cardiac life support training (OR 2.43, 95% CI 1.04 to 5.70). Analysis of the pre and post 2001 subgroups showed a trend towards better outcomes with the more contemporary course (Sodhi et al., 2011, p. 209), and this potentially reflects the advances in medical science.

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI	Year
2.1.1 Courses Pre 2001							
Lowenstein 1986	12	53	5	37	14.3%	1.87 [0.60, 5.86]	1986
Sanders 1994	2	35	1	29	7.4%	1.70 [0.15, 19.72]	1994
Camp 1997	52	179	15	42	17.0%	0.74 [0.36, 1.50]	1997
Dane 2000	33	88	3	29	13.5%	5.20 [1.46, 18.53]	2000
Pottle 2000	67	160	57	139	18.2%	1.04 [0.65, 1.64]	2000
Moretti 2007	22	102	2	54	12.1%	7.15 [1.61, 31.69]	2007
Subtotal (95% CI)		**617**		**330**	**82.6%**	**1.77 [0.89, 3.54]**	
Total events	188		83				
Heterogeneity: Tau² = 0.41; Chi² = 13.81, df = 5 (P = 0.02); I² = 64%							
Test for overall effect: Z = 1.62 (P = 0.11)							
2.1.2 Courses Post 2001							
Sodhi 2011	67	276	12	284	17.4%	7.27 [3.83, 13.78]	2011
Subtotal (95% CI)		**276**		**284**	**17.4%**	**7.27 [3.83, 13.78]**	
Total events	67		12				
Heterogeneity: Not applicable							
Test for overall effect: Z = 6.07 (P < 0.00001)							
Total (95% CI)		**893**		**614**	**100.0%**	**2.43 [1.04, 5.70]**	
Total events	255		95				
Heterogeneity: Tau² = 0.98; Chi² = 36.65, df = 6 (P < 0.00001); I² = 84%							
Test for overall effect: Z = 2.05 (P = 0.04)							
Test for subgroup differences: Chi² = 8.62, df = 1 (P = 0.003), I² = 88.4%							

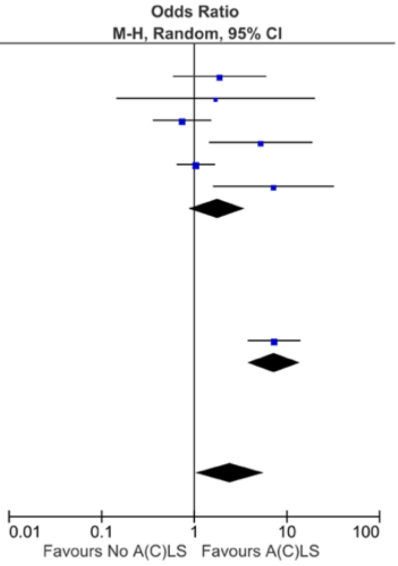

Figure 3 *– Updated meta-analysis for survival to hospital discharge or survival to thirty days*

Following a video conference of the taskforce on 18 November 2019, it was agreed that the following treatment recommendation would be proposed for public consultation: “We recommend the provision of accredited adult advanced cardiac life support training for health care professionals (weak recommendation, very low quality of evidence)". In making this recommendation it was recognised that the evidence in support of this recommendation came from observational studies of very low quality and only related to accredited adult advanced life support courses. It was also recognised that the provision of accredited adult advanced cardiac life support training may not be feasible in low resource settings. In the absence of any comments from the 14-day public consultation period between 31 December 2019 and 12 January 2020, the wording of the treatment recommendation was confirmed for inclusion in the ILCOR 2020 CoSTR (Lockey, 2020, p. 1).

In summary, Paper 1 provides evidence that the attendance of one, or more, members of an adult in-hospital cardiac team who have participated on an advanced life support course leads to improved patient survival. This evidence has been used by ILCOR to produce a treatment recommendation as part of the Guidelines 2020 process. Its impact is therefore significant as it will consolidate the position of this course in healthcare training and stimulate further research to further evaluate its impact, in particular on neurological outcomes. Paper 1 is presented as the first part of this programme of research as it identifies the importance of advanced life support training and provides a credible baseline to benchmark against when developing new variants of the course. It fulfils a key objective of this programme of research in that it is an educational approach that has a positive effect on the outcomes of patients who suffer, or who are at high risk of suffering a cardiorespiratory arrest.

5.2. Paper 2

In the early part of the 21st century, concerns were being raised in the UK by healthcare institutions about the time spent teaching on life support courses by their employees. The introduction of Foundation Training for doctors in 2005 had seen the welcomed statement that all Foundation Year 2 doctors should have training to "advanced life support level", and this is still an important component of the 2016 curriculum (Committee, 2016, p. 1). Despite this, healthcare institutions were also starting to look critically at the time and resources available for study leave for candidates.

In 2008, in my capacity as Chairman of the ALS Sub-Committee of the RC(UK), I commissioned the development, piloting, and evaluation of the e-ALS course. The proposed course structure would mean that only one day of face-to-face attendance would be required. I was aware that no large-scale studies had been performed looking specifically at a blended learning alternative to the ALS course and it was therefore important that a robust evaluation should be undertaken and published to inform future practice.

Paper 2 set out to determine whether a blended learning approach to ALS training provides outcomes equivalent to those of the conventional ALS course. As such, it addressed another of the objectives of this programme of research. It was clearly stated in the paper that the pressure on budgets across the UK healthcare system had driven the need to explore more cost-effective solutions for training. The intervention was aimed at candidates on RC(UK) ALS courses across the UK and Australia. The ARC deliver an identical course and it was felt that the inclusion of international data would strengthen the study. The aim of the intervention was to deliver the didactic content of the traditional ALS course via e-learning, with a reduction in the face-to-face content of the course to one day. The objective was to ensure that this did not have a negative impact on the learning of key ALS principles by the participants.

The primary outcome studied was performance at the first CasTest (the summative assessment of the ability of a candidate to manage a patient in cardiac arrest using a simulated scenario). This was important as studies analysing blended learning in healthcare tended to focus predominantly on the impact on the knowledge domain. As has been described in Chapter 3, there was very little convincing evidence in the literature regarding the impact on clinical skills, and it was proposed that the performance at the first CasTest provided a better indicator of the global learning in all domains of the participants. The standardised structured CasTest format used for the ALS course had previously been analysed and validated (Perkins et al., 2007, p. 484) and it was felt that this, along with the fact that two instructors conducted every assessment, mitigated the open-label nature of the study. Secondary outcomes included knowledge (pre- and post-course MCQ results), technical skills assessments, CasTest domain scores, overall course pass rate, proportion of participants judged to have exceptional performance, and the costs of training. Data was collected between December 2008 and October 2010 and 3,732 healthcare professionals were recruited across 31 course centres in the UK and Australia.

One of the possible reasons for the relatively poor performance of the e-ALS participants in the first CasTest in this study was the reduced amount of time spent learning as a group. The evidence that supports the concept of blended learning, as well as the theory of social learning, highlight the importance of allowing candidates the opportunity to learn alongside their peers. The reduced face-to-face time may therefore have impacted on the amount of time that they were able to receive feedback and benefit from shared learning with fellow participants. It is important to note, however, that the cumulative amount of face-to-face practical skill station and simulation-based education was the same for both courses.

For this initial study, the existing PowerPoint presentations from the c-ALS course had been processed using Articulate software (www.articulate.com). This enabled the inclusion of a voiceover to the presentation, although it was still quite basic in terms of interactivity. As stated in Chapter 3, simply adding an e-learning module or replacing didactic content on a new platform is likely to add very little to the learning experience and may not improve student engagement. In retrospect, this is a prime example of such a situation, although the justification for such an approach at the time was to limit expense for an approach that may or may not be beneficial. It was proposed that the e-learning component should be further improved and developed to increase engagement and participant satisfaction prior to any further research. It was on the basis of this that the definitive iteration of the e-ALS was developed and the evaluation of this is detailed in the critique of Paper 4.

It was also noted that participants consented to be randomised to either limb of the study and therefore were unable to choose their preferred style of course. It is stated in the paper that "introducing free choice or removing choice (if conventional programmes were withdrawn in favour of the blended approach) would require close monitoring". Plans were made therefore to analyse outcomes when participants had the ability to choose a course that suited their perceived learning style and the results of this are presented in Paper 4. A parallel study was also conducted at the same time as Paper 2 looking at participant self-perceptions with regard to their learning styles as well as their opinions of the two course formats, and the results of this are presented in Paper 3.

The results from Paper 2 demonstrated that non-inferiority was inconclusive for the primary outcome, but that it was proven for the secondary outcomes. Although not stated explicitly in the paper (to avoid allegations of spin, as described on page 78), we felt that the differences in the primary outcome were not *educationally* significant, as the overall pass rates were only 2.5% inferior and the confidence intervals for that outcome were within the NI margin. This conclusion also took into account the fact that clinical performance is not necessarily negatively impacted by a failure to pass the ALS course. In other words, it is entirely feasible that a candidate who fails the course can build upon their course result and, through experiential learning, deliver better care than before for patients in cardiac arrest. With regard to resource use, the e-ALS was estimated to be 50% cheaper than the c-ALS course. This was of particular importance as cost-saving was one of the factors relevant to a health service undergoing considerable austerity measures at that time.

Before the introduction of the internet, the forerunner for e-learning was multimedia learning (Nicholson, 2007, p. 1). Audio, video, or CD-ROM based teaching materials were used to augment learning from manuals and face-to-face courses. There are relatively few studies that relate specifically to the delivery of a multimedia blended approach to the adult advanced life support course which indicates the importance of the research in contributing to current understanding. I will now discuss these studies, which looked at replacing all or part of the traditional face-to-face course with a multimedia format.

A small non-randomised cohort study conducted in 1998 compared a multimedia version of an AHA ACLS course with a standard version of the course and found evidence that the multimedia approach can produce equivalent cognitive and psychomotor outcomes (Christenson et al., 1998, p. 702). The multimedia course consisted of seven individual modules, comprised of software, a laser videodisc, and a CD-ROM. The outcomes measured were MCQ and mock arrest scores. An educationally important difference was stated as being 10%, although there are no power calculations to support this. Another limitation is that convenience samples were used with no evidence of any randomisation. In addition, some of the participants were analysed in groups that they were not originally assigned to, meaning that the study demonstrated significant levels of bias. All assessments were videotaped and assessed by blinded instructors as well as on-site unblinded instructors. The two groups were all final year medical students and were treated equally. The results presented were that there was no difference between the two groups for MCQ results (89.3% ± 4.9% for multimedia vs 89.3% ± 4.8% for standard; p = not significant). There was no difference for on-site psychomotor assessment (14.1 ± 2.5 for multimedia vs 14.1 ± 2.0 for standard; p = not significant). There was a difference between the two groups for blinded psychomotor assessment from videotaped recordings (13.1 ± 2.9 for multimedia vs 14.4 ± 2.9 for standard; p=0.024) although this was noted to be less than the required 10% to be educationally important. Therefore, the authors concluded that the multimedia course provided immediate educational outcomes similar to the standard course. Of note was the fact that a significantly larger proportion of participants in the multimedia group needed to repeat their summative practical assessment (47% vs 24%), and it was postulated that this was because those on the standard course had been familiarised with this approach throughout the course. This prompted the authors to conclude that there may need to be some face-to-face element to the course after all under instructor supervision. They described, in effect, a model resembling the e-ALS approach ten years earlier than the RC(UK) project. This study also presented evidence that students in the multimedia group were less satisfied with their experience due to lack of instructor interaction and a feeling of less preparatory experience for the summative test, irrespective of whether they passed or not. This reflects the broader evidence for blended learning in healthcare presented in Chapter 3, in that such an approach was not always popular amongst participants due to the lack of instructor interaction. It also foreshadowed our experiences with e-ALS, as will be detailed in the discussion of Paper 3.

At a similar time, another interactive multimedia training system was described (Xie, Chen, Scamell, & Gonzalez, 1999, p. 117). This was a multimedia training module that could be run on the Windows 95 platform and was particularly advocated for training crew medical officers on space flights in the eventuality that a cardiac arrhythmia may occur on a manned mission into space. Whilst there is no evaluation of the product, it serves as a detailed description of an approach that was cutting edge for its time at the end of the 20th century.

A descriptive case study in 2000 studied an alternative to the AHA ACLS course format. This study described multiple preparatory options including attending optional lectures, viewing lectures on video recordings, using an interactive computer-assisted instruction programme, watching a series of ACLS core case videos, and participating in teaching sessions (Darr, 2000, p. 116). This study was small with only 17 participants and it did not evaluate learning outcomes. The primary intent of the study was to evaluate learner attitudes, and most of the respondents favoured this format. It was also noted that face-to-face time was decreased, and the costs associated with this approach were 42% lower than the traditional course format. Another limitation of this study was that an unvalidated survey was used. The study did not look at a direct replacement of the didactic components of the ACLS course with a multimedia approach, as there were still options for students to attend lectures. It is clear that the primary motivation of the authors was that they were exploring a more cost effective and practical alternative to the ACLS course, and they concluded that this could be a viable approach. It should be noted however that an unspecified number of participants needed frequent reminders and, indeed, warning letters before they completed the course at the last minute. This represents a risk of non-compliance with some participants in an approach where training is taken out of a structured and regulated format.

Although relating to a different life support course, it is worthwhile to look at evidence from the approach to paediatric resuscitation training as well. A comparison was performed between the cognitive and psychomotor performances of participants attending a traditional AHA Paediatric Advanced Life Support (PALS) course with those attending an e-learning (Web-PALS) equivalent followed by a 1-day skills and testing course (Gerard et al., 2006, p. 649). This model is very similar to the e-ALS approach. There was no randomisation and convenience samples were used. All participants were accounted for in the analysis and there was no crossover between groups. The study was powered for a 2.5% difference in marks with 40 participants of similar demographics in each arm (80% power with a significance level of $p=0.05$). Whilst instructors and participants were not blinded, the psychomotor tests (identical for both groups) were all videotaped and independently assessed by instructors blinded to the arm of the study that they were from. All participants passed the MCQ on their first attempt with a 1.7% difference between the groups favouring the traditional course format. There was a 2% difference between the groups for psychomotor skills assessment favouring the Web-PALS format. The authors concluded that the Web-PALS was an acceptable format for administering the PALS course. The findings from this smaller study are similar to the findings from Paper 4, and whilst this reflects the experience from a different life support course, the inference is that a blended learning approach to such learning is beneficial.

I co-authored a worksheet that included the aforementioned studies for the 2010 ILCOR process. This worksheet looked at the impact of multimedia pre-course learning with a specific focus on reduced face-to-face time for advanced cardiac life support courses as an outcome.

The findings were incorporated into the 2010 ERC Guidelines, which stated that:

> There are numerous studies of alternative teaching methods that claim equivalence or benefit for computer or video- based training and decrease the time instructors spend with learners. Any method of pre-course preparation that is aimed at improving knowledge and skills or reducing instructor to learner face-to-face time should be formally assessed to ensure equivalent or improved learning outcomes compared with standard instructor-led courses (Soar et al., 2010, p. 1434).

I revisited this worksheet for the 2015 ILCOR process, this time using GRADE methodology for the data analysis (Schünemann, 2013, p. 1). The review was expanded to include the remit of e-learning as well as multimedia. Due to the specific wording of the PICO generated by the EIT Taskforce, only one paper was identified for inclusion (Perkins et al., 2010, p. 877). This open label, multi-centre, randomised controlled study looked at the educational impact of a pre-course CD-ROM based learning module called MicroSim (Lærdal, 2008). 572 participants were randomised and the control group (n=285) underwent the traditional ALS course as normal with the course manual sent to them four weeks in advance. The intervention group (n=287) were also sent a CD-ROM containing MicroSim. This programme presented them with a simulated patient on their computer desktop and enabled them to interact in real-time with the scenario to deliver key interventions. At the end of the scenario, detailed feedback on their performance was presented to them. The primary outcome was performance in the first CasTest on the ALS course. There was no significant difference between the two groups. Similarly, there was no significant difference for the secondary outcomes (MCQ score and individual skill station assessment results). The product was popular however with 79% stating that they would recommend it to colleagues and over 70% feeling that it improved their understanding of the concepts of ALS. The study was supported by an unrestricted research grant from Laerdal (UK), who also donated the CD-ROMs at no cost. Whilst this may have raised the question of a conflict of interest, the conclusions were not supportive of the product. The 2015 CoSTR concluded that the confidence in effect estimates was so low that the Taskforce decided a specific recommendation for or against pre-course preparation in ALS courses was too speculative (Bhanji et al., 2015b, p. S242). The lack of published evidence in the area of specific blended learning training for life support education was highlighted as a research gap. The evidence for the use of a multimedia approach to life support education differs slightly from the contemporary evidence from the wider healthcare literature with regard to the impact of a blended learning approach to education, as presented in Chapter 3. The findings from the multimedia studies are mixed for the acquisition of knowledge and user satisfaction. In contrast to the general findings about blended learning for healthcare education, there is some historic evidence from these multimedia studies to support its use for clinical skills training. This is important as cardiac arrest management is predominantly a clinical skill, and this may indicate that the blended approach may be beneficial for this particular topic.

In summary, Paper 2 was the first large scale randomised controlled trial looking at educational outcomes following attendance at a blended learning approach to ALS training as opposed to a traditional version of the course and therefore its conclusions were a significant and novel contribution to knowledge. Unfortunately, the findings from Paper 2 failed to clearly achieve the objective that the e-ALS course is equivalent in terms of educational outcomes for candidates on the course when compared with the conventional approach to training. It was clear that further work was needed to develop and improve the pilot version of the course. A crucial element to this review would be an analysis of the participant satisfaction outcomes as presented in Paper 3.

5.3 Paper 3

The aim of this study was to determine the acceptability to participants of a blended learning approach to ALS education. Paper 2 had concluded that non-inferiority was inconclusive for the primary outcome (first CasTest), but that it was proven for the secondary outcomes (knowledge, technical skills assessments, CasTest domain scores, overall course pass rate, proportion of participants judged to have exceptional performance, and the costs of training). The Trustees of the RC(UK) concluded that there was no educationally significant difference between the two courses, but that it was important that the participant views and preferences were taken into account prior to proceeding with a definitive version of the course. This would help to shape the product to further match the needs of the course participants, and therefore helped to fulfil one of the objectives for this programme of research which was to evaluate the acceptability of this approach to healthcare professionals undertaking the pilot e-ALS course.

The study was mixed methodology in its design. A quantitative approach was used to analyse the responses to a series of questions rating individual elements of the type of course attended. The course components and the impact upon personal development were assessed using a six-point Likert response structure, and a binary scale was used for the learning style questions. In addition, a qualitative appraisal was used for the free text response to three questions relating to learning styles. Data was collected anonymously from participants attending both courses in the UK and Australia and the groups were evenly matched in terms of their profiles, as documented in Paper 2.

The paper concluded that the inclusion of face-to-face training is invaluable. This was consistent with the evidence presented in Chapter 3 supporting a blended learning approach to learning as opposed to a pure e-learning approach. Quantitative feedback showed a clear preference for c-ALS, whereas the qualitative data was more measured with most respondents finding the e-learning aspects of e-ALS beneficial. It was felt that the mixed response to e-ALS probably related to participants' own personal learning styles. An important aspect of the feedback was that the participants found the mode of delivery of the e-learning components to be dull and lacking interactivity. This indicated that more work was needed on the e-learning product and platform to improve its effectiveness and popularity.

It is clear from this paper that a blended learning approach does not suit all learning styles. Despite this, some participants enjoyed the course. It was concluded in Paper 3 that participants attending ALS courses have different ways of learning, and that the identification of these learning styles may enable the e-learning components to be redesigned to benefit a broader range of learners. The concept of learning based upon reflection, developing new ideas, and then putting those new ideas into practice is critical for ALS training. This approach is consistent with the constructivist and social theories of education, as each ALS candidate gets to reflect on their own performance as well as the performance of others during the face-to-face elements of the courses. There are many different theoretical definitions of learning styles, with some authors declaring over twenty frameworks, models and dimensions (Vasquez, 2009, p. 53). The framework that primarily resonates with advanced life support education is the Kolb Experiential Learning Cycle (Kolb, 1975, p. 33). This concept is cited in the manual used for life support course instructor training as a key underpinning educational principle for learning in this environment (Bullock, Davis, Lockey, & Mackway-Jones, 2016). Kolb stated that learning is enhanced when students are actively involved and immersed in a concrete experience. He described four specific learning styles based upon his Learning Cycle, with learners preferring either concrete experience, reflective observation, abstract conceptualisation, or active experimentation. Learners who prefer to learn by concrete experience tend to prefer an environment where they can directly interact with peers and teachers in a collaborative and competitive approach (Diaz & Cartnal, 1999, p. 130). Those who favour such face-to-face learning recognise its strength for dealing with communication issues and situations where shared learning needs to be achieved to develop knowledge (Paechter & Maier, 2010, p. 292). In contrast, those who favour the abstract approach to learning are more likely to be intrinsically motivated, prefer self-directed learning, and have a preference for the e-learning approach (Chapman & Calhoun, 2006, p. 576; Dille & Mezack, 1991, p. 24; Gee, 1990, p. 1; Paechter & Maier, 2010, p. 292). This gives some insight into the different learning styles that may lead a participant to favour one course approach over the other. It is important to remember however that Paper 3 analyses a situation where the learners did not have any choice about the modality of course they were assigned to. The results therefore reflect the opinions of learners who may not have been exposed to a course that ideally matched their learning style. This may not be significant however as the e-learning platform can still be seen to be a supportive learning environment irrespective of learning style (Ross & Lukow, 2004, p. 41). The reality is that learners may possess a spectrum of learning styles and that no one fixed approach is correct (Brown et al., 2009, p. 1). Indeed, exposing learners to environments that do not suit their preferred learning style may lead them to develop otherwise undeveloped styles of learning (Grasha & Yangarber-Hicks, 2000, p. 2).

There is evidence in the literature of mixed opinions from healthcare students with regard to the different elements of a blended learning approach, and this has been discussed in Chapter 3 (Dunleavy et al., 2019, p. e12937; George et al., 2019, p. e13269; McCutcheon, Lohan, Traynor, & Martin, 2015, p. 255;

Milanese, Grimmer-Somers, Souvlis, Innes-Walker, & Chipchase, 2014, p. 86; Nagendrababu et al., 2019, p. 181; River, Currie, Crawford, Betihavas, & Randall, 2016, p. 185). The conclusions of Paper 3 are consistent with these findings as it was stated that the pilot version of the e-ALS course was well received by most, but not all participants.

A significant proportion of the participants attending the RC(UK) ALS and e-ALS courses are newly qualified doctors, and this was reflected by the demographics presented in Paper 2. The proportion of participants who were Foundation Year doctors (first two years post qualification) were 40.6% in the e-ALS group and 38.9% in the c-ALS group. This is important as this is the demographic of candidate that would be expected to be more accepting of an e-learning approach, and the opinions of this group of candidates to blended learning is therefore important. A questionnaire survey of 69 Foundation Year 1 doctors attending a weekly blended learning programme covering the Foundation curriculum concluded that they valued e-learning as an adjunct to experiential and lecture-based tuition (Goh & Clapham, 2014, p. 20). Course modules that relied on a higher level of theoretical content, such as the safe prescribing e-programme, were felt to be more useful when delivered using e-learning. Some students value the ability to continue their learning outside the classroom and an e-learning component of a blended learning approach can give them that opportunity to further their learning at a time that is more personally convenient (Carroll, Booth, Papaioannou, Sutton, & Wong, 2009, p. 235). Students who value self-directed online learning can also value face-to-face interaction with an instructor where more complex learning is needed. Conversely, there are also situations where the lack of human interaction is not a disadvantage, particularly if the tuition is focussed and didactic. This was demonstrated in an American study that identified that medical students exhibited a preference for passive online lectures as opposed to online modules that required constructivist activity (Prunuske, Henn, Brearley, & Prunuske, 2016, p. 135). Course presentation and design is vital, as online communities do not always deliver the extent of interaction needed to optimise social learning (Bradley et al., 2007, p. 164; Carroll et al., 2009, p. 235), however this may change in the future with further technological developments including greater use of personal learning environments (Raspopovic & Jankulovic, 2017, p. 869).

Paper 3 presents a comprehensive descriptive analysis of the opinions of 95.3% of the candidates who participated in the pilot e-ALS study, and therefore addresses an objective of this programme of research. The results also provided a sense check on the validity of the pilot e-ALS approach and caused the RC(UK) trustees to pause and reconsider how they could improve the product to suit the needs of the participants. In addition, the findings of this paper, along with the findings from Paper 2, consolidated the viewpoint that e-ALS was an educational product that could not simply replace c-ALS. The two courses would need to be delivered in parallel for the foreseeable future. Further work was needed to improve the e-learning content for e-ALS to improve its interactivity and popularity. The results for Paper 2 and Paper 3 were presented at the RC(UK) Symposium in Birmingham in November 2010. The Trustees of the RC(UK) realised that the course needed development before it could be disseminated further and decided to invest in a formal procurement for an e-learning package along with the development of an LMS. A project team was convened, and a budgetary allocation was committed to develop a definitive version of the e-ALS course. A condition of this commitment was that any further iterations of the e-ALS course would be subject to formal analysis to ensure that it was fit for purpose, and the results of this are presented as Paper 4.

5.3 Paper 4

Paper 4 presents a descriptive analysis of the educational outcomes from the updated version of the e-ALS course, that was introduced in January 2012, in comparison with the outcomes from participants of the c-ALS course. The e-ALS course had been piloted and evaluated, and the conclusion from Paper 2 and Paper 3 indicated that further work was needed to improve the e-learning product. The randomised non-inferiority trial approach that had been used for the pilot course study was limited in that it did not allow candidates to choose the course that ideally suited their learning preferences. A decision was made therefore to allow candidates the freedom to choose which course they wanted to attend and to descriptively analyse data from all e-ALS and c-ALS courses run over an 18-month period. The limitations for such an approach have already been discussed in Chapter 4, but the large sample size and homogeneity between the groups was felt to mitigate this limitation. One of the advantages of investing in a new LMS to host this new course was that it allowed the RC(UK) to analyse a significant amount of anonymised data about candidates, their demographics, their use of the e-learning modules, their assessment outcomes, and also their feedback about the course they attended. The aim of this study was to address one of the objectives of this of this programme of research; namely to demonstrate that the definitive version of the e-ALS course produced educational outcomes equivalent to the c-ALS course. Whilst the data analysed was only from UK courses, the intention was that the results would be shared internationally.

In the intervening time between the publication dates of Paper 2 and Paper 4, there were no publications in the literature relating to a comparison between blended learning and traditional advanced life support courses. Other studies analysed the use of e-learning for refresher training for advanced life support training with mixed results (Delasobera et al., 2010, p. 217; Jensen, Mondrup, Lippert, & Ringsted, 2009, p. 903), but no study other that Paper 2 had analysed the impact of a blended learning approach to the course itself. More recently, a systematic review was performed of twenty randomised controlled trials covering a range of digital interventions only for resuscitation training including multimedia, graphics, animations, games, video, online and offline software (Lau et al., 2018, p. 14). The overall quality of evidence was very low and there was a high level of heterogeneity between the studies. There were numerous limitations with the review, including small sample sizes from single institutions and the inclusion of studies in the English language only. Nevertheless, the review concluded that digital interventions alone may result in better knowledge and equivalent skills when compared with standardised training although it was also stated that the evidence suggesting its use is "inadequate".

Evidence has subsequently been published in the literature of other healthcare systems using our work as an exemplar to develop similar projects. A teaching hospital in Malaysia conducted a prospective interventional study from January 2016 to May 2017 comparing a traditional ACLS course (presumably the AHA course, although not explicitly stated) with a bespoke e-ACLS course (Arithra Abdullah et al., 2019, p. 1). The reasons stated for developing a blended learning approach were the lengthy duration and cost of the conventional course as well as a lack of availability of qualified instructors. In other words, the motivations for developing such an approach were similar to those encountered in the UK. The online modules consisted of six hours of recorded lectures and scenarios. A total of 96 participants were included in the study, with 48 participants in each arm. This study was not randomised, and participants were able to choose which course they attended, although the authors have presented demographic data which is comparable between the two groups. Participants in the e-ACLS group scored higher mean scores for pre-course MCQ (69.1, SD 19.1 vs 58.6, SD 16.6; $p<0.001$) and post-course MCQ (78.9, SD 12.0 vs 70.6, SD 13.9; $p<0.001$). Participants in the e-ACLS group also scored higher for CasTest (95.8% vs 87.5%; $p=0.134$) and overall course pass (93.8% vs 83.3%; $p=0.099$), although neither difference reached statistical significance. An eight-question attitudinal survey of the e-ACLS course participants concluded that most participants favoured e-learning. The number of participants studied was small and represented less than 1% of the number of participants analysed for Paper 4. It is reassuring to note that the results from this study mirror the findings reported in Paper 4, namely that a blended learning course leads to improved scores for knowledge and skills acquisition. It is also gratifying to see that our work has prompted similar developments internationally. In line with the evidence for blended learning for healthcare in general, this blended learning approach has therefore been shown by both Paper 4 and the international evidence above to be beneficial for knowledge acquisition. In this particular focussed topic area, however, blended learning appears to be beneficial for skills acquisition as well. Finally, when candidates are able to choose the course that they attend, the user satisfaction is also better.

The evolution of the AHA ACLS course has followed a similar trajectory over the years. In 2015, the AHA introduced an updated set of guidelines for ACLS. This included a recommendation that It may be reasonable to use alternative instructional modalities for BLS and/or ACLS teaching in resource-limited environments (Bhanji et al., 2015a, p. S561). In response to this, a group of researchers from the University of California Irvine School of Medicine developed a ‘flipped classroom’ version of the ACLS course. In this model, instructional content is delivered outside the classroom (usually online) and elements that would previously have been considered as pre-course learning are moved into the classroom (McDonald & Smith, 2013, p. 437). This approach has been successfully used in healthcare education for teaching various skills in emergency medicine (Lew, 2016, p. 25; Rose et al., 2016, p. 284; Tan, Brainard, & Larkin, 2015, p. 453). The California group replaced 12 hours of classroom lectures with 9 hours of pre-recorded podcasts and 10.5 hours of team-based learning. They performed a cohort analysis of 4th year medical students, with the intervention group of 95 students undertaking the flipped classroom approach compared with a historical cohort of 259 students who had undergone the traditional ACLS course (Boysen-Osborn et al., 2016, p. 1). A second publication by the same group compared the same historic control group with an expanded intervention group that had the data from a subsequent year of students included in the analysis (Langdorf et al., 2018, p. 1). In both studies, the outcome measured was the knowledge test score. In the latter study which had the larger intervention sample size of 209 participants, the median knowledge scores improved from 93.5% (IQR 90.6 to 95.4) to 95.1% (IQR 92.5 to 96.8), which they stated was significant (p=0.0001). Neither of the studies looked at student competencies, but they concluded that this approach can improve written scores in comparison with the conventional approach.

The flipped classroom approach to ACLS education has also been analysed in a randomised single-blinded study of 108 fourth year medical students in Seoul (Beom et al., 2018, p. e0203114). This study did not actually use an accredited ACLS course as the control group but compared a traditional classroom-based approach to teaching ACLS skills (1-hour lecture followed by question and answer session) with a flipped classroom approach. The intervention group received the PowerPoint lecture by email along with a recorded explanation three days before a scheduled classroom session. At this session, they watched a video of a poor example of ACLS followed by a group discussion. Both groups then underwent the same assessment sessions. For the primary outcome of simulation rating score, the intervention group scored higher (70.9 ± 10.9 vs 67.1 ± 11.3, p=0.339). There was no significant difference in participant satisfaction scores (p=0.655). The study had limitations due to a potential for cross-contamination between groups and the possibility that students may not have been compliant with their preparation for the educational sessions. Whilst this study did not use an accredited ACLS course as the control, it is still interesting to note the improved performance in the intervention group.

Our findings with regard to cost savings for a blended learning approach to ALS education have also been replicated elsewhere. A study analysing the costs of a blended learning version of the ACLS course in Singapore concluded that it delivered significant cost savings and, therefore a positive return on investment (George et al., 2018, p. 234). The blended learning approach (11 hours online and 5 hours face-to-face) had an annual cost of S$43,467 as opposed to S$72,793 for the traditional 1.5-day course. This supports our conclusions that a blended approach to training can be a more cost-effective solution.

The results from Paper 4 provided assurance that there was no significant difference in terms of educational outcomes for participants who attended the definitive e-ALS course as opposed to the c-ALS course. The outcomes from Paper 2 had failed to clearly satisfy the objective of this programme of research that a blended learning approach to ALS training produced equivalent educational outcomes to a conventional approach. The results from Paper 4 achieved this objective and provided welcome assurance to the RC(UK) Trustees that the investment in the development of the e-ALS course had been justified. In addition, the rich data set data available from the LMS introduced the opportunity to analyse in more detail the profiles of participants who were more successful on the e-ALS course. This analysis is presented as Paper 5.

5.5 Paper 5

The findings from Paper 5 give a valuable insight into the variables that are more likely to be associated with better educational outcomes on the e-ALS course. This is an important aspect of the evaluation of the course and therefore addresses one of the objectives of this programme of research. Knowledge scores (MCQ results) were better in participants with longer and more relevant background clinical experience, in comparison with more junior and inexperienced colleagues. Knowledge scores were worse, however, for participants with previous ILS experience. The ILS course is designed for healthcare professionals who may have to act as first responders and treat patients in cardiac arrest until the arrival of a cardiac arrest team. These participants are therefore more likely to be inexperienced or come from a non-acute healthcare background. The fact that those with prior ILS experience performed worse for the knowledge assessment is not surprising, although it is interesting to note that prior ILS experience was still a predictive factor for overall course success. The teaching methodology used on the ILS course is similar in nature to that used on the ALS course. A familiarity with the style of teaching may be the reason why those who had previously attended an ILS course fare better. In addition, those participants with more relevant background experience performed better in the first CasTest. This reflects the positive benefit of participating in a course where the assessment scenario resembles a clinical situation that candidates are already familiar with from their day-to-day working practice. It is also clear that those who had undertaken a CasTest as part of a previous ALS course were more likely to understand what was required of them when faced with this assessment modality again. Overall, increasing participant age was associated with poorer educational outcomes. Finally, the conclusion that there was no direct correlation between increased time spent accessing modules and course success is of interest. This could be explained by the fact that participants with more experience may simply have chosen to advance through or ignore e-learning modules that contained content that they were already familiar with. This reflects the evidence behind a blended learning approach, described in Chapter 3, that learners perform best when they can choose what they want to learn and that mandating the e-learning modules is not necessary.

The findings from Paper 5 are an important addition to the literature as there are no other studies that have analysed the factors associated with success with a blended learning approach to advanced life support education. There is however published evidence from Italy of factors associated with success on the conventional ALS course. An analysis was conducted of 283 medical doctors with no previous ALS training participating in ERC ALS courses at one Italian course centre between November 2006 and June 2009 (Sandroni et al., 2010, p. 1521). Those who passed the course had a younger median age (31 vs 37.5 years, p=0.006) and they also had higher median scores in the pre-course MCQ (84% vs 72.4%, p<0.001). Following a multivariate analysis, the authors concluded that prior BLS certification (OR 5.00, 95% CI 1.12 to 22.42) and a higher pre-course MCQ score (OR 1.18, 95% CI 1.09 to 1.28) were predictors of success. When analysing the impact of age, they concluded that increasing age was associated with a higher rate of failure (OR 0.90, 95% CI 0.83 to 0.97). They did not find any association with participant specialty background, although it should be noted that they only analysed medical participants which is a limitation of the study. An additional limitation is that the analysis was performed in one course centre only. This prompted the development of a larger Italian multi-centre descriptive study, covering a five-year period between 2008 and 2012. This study analysed all participants irrespective of profession attending an ERC ALS course for the first time (Semeraro et al., 2015, p. 246). The analysis contained data from 13,264 participants with a mean age of 37 years. Just over half of the participants were doctors (7,352), with the remainder being nurses. Once again, those who passed were younger (37 vs 43 years, p<0.0001) and successful participants had a higher median pre-course MCQ score (88%, 95% CI 83 to 93 vs 80%, 95% CI 73 to 87; p<0.0001). In the multivariate analysis, higher MCQ scores predicted success (OR 1.033, 95% CI 1.026 to 1.040; p<0.0001), doctors were more likely to pass (OR 3.021, 95% CI 2.212 to 4.132; p<0.0001) and a higher age was associated with failure (OR 0.926, 95% CI 0.915 to 0.937; p<0.0001). In addition, candidates from emergency disciplines were more likely to pass the course. The large sample size in this study, along with a description of the outcomes for both doctors and nurses, makes this a valid analysis of outcomes from the ERC ALS course. Although the ERC ALS course is virtually identical to the conventional RC(UK) ALS course (on which it is based), the Italian healthcare system is different to the UK system limiting the applicability of the results. The main difference between the Italian and RC(UK) studies is that the Italian studies were limited to analysing the outcomes for participants attending the ERC ALS course for the first time. Nevertheless, the overarching conclusion that course success is associated with working in an emergency care discipline, younger age of participants, and a medical professional background is synonymous with the findings of Paper 5. This is of interest as there is an implication that the factors for success are very similar between the two types of ALS course, suggesting that the courses are more closely aligned than previously imagined. This would add further evidence that the two courses are equivalent in nature, but it also highlights an opportunity for future research to compare the weighting of the various factors for success for both courses.

In addition, similar evidence has been published from another type of advanced life support course. A review of 744 participants on an ATLS course at two course centres between 2007 and 2011 concluded that age greater than 55 (OR 4.6, 95% CI 1.9 to 11.1; p<0.001), lower pre-course MCQ scores (OR 2.3, 95% CI 1.2 to 4.1; p=0.010), and participants from non-trauma or emergency backgrounds (OR 2.1, 95% CI 1.2 to 3.6; p=0.005) were more likely to fail the course (Mobily et al., 2015, p. 942). The same findings with regard to age and background specialty amongst ATLS participants had also been described in Israel between 1990 and 1996 (Ben-Abraham et al., 1999, p. 169). It would appear therefore that younger age and relevant clinical background (including prior knowledge) are all key factors of success for participants of at least two types of life support course.

There are several potential reasons why advancing age may be associated with poorer outcomes, particularly for participants on the e-ALS course. It has been postulated that there is a decline of 1% per year for learning ability in adults between 22 and 50 years of age (Knowles, 1990, p. 1). Knowles also states that adults progress with age from learning things they “ought to” for biological and academic development to things they “need to” to address evolving social and professional roles. This is often seen on ALS courses, where the motivation for younger candidates is usually extrinsic as the course is required for their curriculum requirements, whereas older candidates have a more intrinsic motivation due to the need to be competent at managing cardiac arrest situations in their place of work. With advancing age there is a physiological decay in learning capabilities such as the ‘working memory’, which is the ability to temporarily hold information available for processing (Grady & Craik, 2000, p. 224). Courses that feel more rushed may therefore not suit older learners, and they may benefit from the longer duration of the c-ALS course to enable more time for memory processing. Another reason why candidate age is an important factor is that the evolution of technological sources of learning, as espoused by the Theory of Connectivity (Downes, 2010, p. 27; Siemens, 2004, p. 1), confers an advantage for learners who have grown up in the internet era. These learners are more used to seeking, sieving and synthesising as opposed to relying on single sources of information such as a book or lecture, and this may give them an advantage when exposed to a blended learning approach to education (Dede, 2005, p. 7).

There are also clear reasons why candidates from a relevant clinical background are more likely to be successful. It has previously been shown that doctors and nurses working in high risk areas for cardiac arrest have better knowledge of resuscitation guidelines than those who are from low risk areas (Fischer et al., 2012, p. 227; Passali et al., 2011, p. 365). Candidates who are more likely to use CPR at work are also more likely to have better training outcomes (Kämäräinen, 2005, p. 1). A key reason for this is that participants attending ALS courses from high risk clinical areas for cardiac arrest appear to be more highly motivated (Hopstock, 2008, p. 425) as they ascribe higher importance to the relevance of knowing about and using CPR skills in their workplace. This would also explain why those who actively work in high risk areas are more likely to attend ALS courses with a higher level of pre-course knowledge about the topic, thus explaining the correlation between higher MCQ scores and success.

In summary, Paper 5 is an essential aspect of the evaluation of the definitive e-ALS course and also fulfils an objective of this programme of research. The conclusions from Paper 5 present a profile of those candidates more likely to be successful when attending an e-ALS course and this has the potential to inform potential participants of which course to choose. The fact that younger candidates are more likely to be successful indicates that it is a feasible course for Foundation Year doctors, with the added benefit that it is preferable to release these doctors for only one day from a busy clinical job for a face-to-face component. The blended learning approach appears to be more valuable for candidates who have previously attended a c-ALS course, thus making it an ideal option for recertification. Current data suggests that only a third of candidates on all forms of the RC(UK) ALS course have undertaken an ALS course previously, therefore indicating that there is a low rate of recertification (personal communication, Helen Keen – Resuscitation Council (UK) ALS Courses Manager). Access to the e-ALS course may result in more candidates re-certifying their ALS status, as opposed to letting it lapse as they do not wish to attend a two-day face-to-face course again. Finally, the knowledge that candidates from critical care backgrounds perform better on the e-ALS may enable more prescriptive advice to be delivered about which course these candidates should attend. The results from the Italian studies suggest that this may be a more global factor for success on life support courses as a whole. Therefore, a more detailed comparative analysis is needed of factors for a successful outcome between both variants of the RC(UK) ALS course to identify which factors are generic and which are more specific to e-ALS or c-ALS course participants.

Chapter 6: Conclusions

The aim of this programme of research was to develop and evaluate a new blended learning approach to advanced life support education for healthcare professionals which would meet the needs of key stakeholders. The development process involved establishing the clinical importance of this educational intervention as well as piloting the RCUK e-ALS course. The evaluation process sought to determine if this new approach was equivalent to the conventional course in terms of educational outcomes and to identify which participant factors were associated with a successful course outcome.

The published papers and the accompanying narrative demonstrate how the research aim was achieved. Paper 1 concluded that there is a positive association between course participation and improved patient outcomes. The objective of Paper 2 was to prove educational equivalence between the two course variants, but the results of this study were inconclusive. Paper 3 evaluated the acceptability to participants of the pilot e-ALS course and the results were mixed. The findings from Paper 2 and Paper 3 therefore indicated that the pilot version of the e-ALS course needed improvement. This resulted in the development of the definitive e-ALS course, which was successfully evaluated in Paper 4 as being equivalent to the conventional course. Paper 5 identified that younger participant age, prior experience of a life support course, and a relevant clinical background are factors associated with a favourable e-ALS course outcome.

Educational theory provides the basis for the choice of teaching strategies that will improve instructional efficiency and therefore student learning. The principles espoused by constructivism and connectivism are particularly relevant to the context of advanced cardiac life support training.

This reflects the most important lesson that was learnt throughout my PhD candidature. By performing the overview of systematic reviews for blended learning in healthcare education and through my further reading around theoretical concepts, I have realised the importance of the application of learning theory in the instructional design process. The pilot e-ALS course was developed without full regard to underpinning educational theory. It was not evaluated well by participants and it failed to demonstrate non-inferiority. If these principles had been rigorously applied, there is a possibility that the pilot e-ALS course could have demonstrated non-inferiority without the need for further investment and development.

The research presented in this portfolio is novel because it adds valuable educational evidence to the body of international literature in the context of advanced cardiac life support training. This is important as the overview of systematic reviews identified that there is a paucity of high quality evidence for a blended learning approach to healthcare professional education.

The corresponding impact of this programme of research can be summarised by its effect on policy, practice, education, and research. From a policy perspective, the findings from Paper 1 were incorporated into the ILCOR 2020 international resuscitation guidelines process, resulting in a treatment recommendation in support of advanced life support training. This recommendation includes an important caveat that such training may not be feasible in some international locations due to low resource availability or inadequate healthcare infrastructure. With regard to practice, the requirements of the stakeholders have been met as the e-ALS course is more cost effective to run and requires half the face-to-face time. Educationally, the e-ALS course produces equivalent outcomes to the conventional course, Finally, the evidence from the published research, and the accompanying narrative, identifies opportunities for further research.

In conclusion, the research aim was achieved as the findings presented in this programme of research demonstrate the importance to patient outcomes of accredited advanced cardiac life support training, and they also prove that the definitive version of the RCUK e-ALS course delivers equivalent participant educational outcomes to the conventional ALS course. This is the first time that a blended learning approach to life support training has been positively evaluated on this scale. As a result, this programme of research provides an exemplar for resuscitation organisations around the world to develop, if appropriate, a similar blended learning approach to life support training in an era where reduction in cost and face-to-face training time is increasingly important for key stakeholders.

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Appendix 1: ALS Programme

Resuscitation Council (UK) ALS

GUIDELINES 2015

Advanced life support provider course programme

With suggested timings based on 24 candidates in 4 groups of 6

(To be adjusted according to candidate numbers)

Day 1

Timing to be decided locally		*Faculty meeting and registration*			
08:45	10 min	**Lecture:** Introduction to the ALS course			
08:55	25 min	**Lecture**: Recognition and prevention of deterioration using the ABCDE approach			
09:20	20 min	**Lecture:** Cardiac causes of cardiac arrest			
09:40	60 min	**Demonstration/lecture**			
		• CASDemo (including non-technical skills) • ALS Algorithm			
10:40	15 min	***Tea / coffee break***			
10:55		**Skill stations and workshops:** • Associated Resuscitation Skills including IO • The deteriorating patient (ABCDE approach) • Rhythm Recognition • High quality CPR and Defibrillation			
		Associated Resuscitation Skills Inc. IO			
10:55	70 min	Group 1	Group 2	Group 3	Group 4
		The deteriorating patient (ABCDE approach)			
12:05	30 min	Group 1	Group 2	Group 3	Group 4
12:35	45 min	***Lunch break***			
13:20		**Skill stations and workshops** *continued*			
		Rhythm recognition			
13:20	50 min	Group 1	Group 2	Group 3	Group 4
		High quality CPR and Defibrillation			
14:10	50 min	Group 1	Group 2	Group 3	Group 4
15:00	25 min	**Lecture:** Post-resuscitation care			
15:25	15 min	***Tea / coffee break***			
15:40		**Cardiac Arrest Simulations Teaching Sessions (CASTeach) 1-3**			
		CASTeach 1			
15:40	30 min	Group 1	Group 2	Group 3	Group 4
		CASTeach 2			
16:10	30 min	Group 1	Group 2	Group 3	Group 4
		CASTeach 3			
16:40	30 min	Group 1	Group 2	Group 3	Group 4
17:10	30 min	**Mentor feedback**			
17:40		**Faculty meeting** ***Course closure***			

Resuscitation Council (UK)
Tel: (020) 7388 4678 | Fax: (020) 7383 0773
ALS@resus.org.uk | www.resus.org.uk

Day 2

09:00	15 min	***Tea / coffee and mentor groups***			
09:15		**Peri-arrest workshops** *(continued after tea/coffee break)*			
		Assessing and treating tachycardia		**Assessing and treating bradycardia**	**Arterial blood gas analysis**
09:15	45 min	Group 1	Group 2	Group 3	Group 4
10:00	45 min	Group 3	Group 4	Group 1	Group 2
10:45	15 min	***Tea / coffee break***			
		Assessing and treating bradycardia		**Arterial blood gas analysis**	
11:00	45 min	Group 2	Group 4	Group 3	Group 1
		Resuscitation in Special Circumstances workshops *(continued after lunch)*			
		Special Circs 1		**Special Circs 2**	
11:45	30 min	Group 1	Group 2	Group 3	Group 4
12:15	30 min	Group 4	Group 3	Group 2	Group 1
12:45	45 min	***Lunch break***			
		Special Circs 3			
13:30	30 min	Group 1	Group 2	Group 3	Group 4
14:00		**Cardiac Arrest Simulations Teaching Sessions (CASTeach) 4-5**			
		CASTeach 4			
14:00	45 min	Group 1	Group 2	Group 3	Group 4
		CASTeach 5			
14:45	45 min	Group 1	Group 2	Group 3	Group 4
15:30	15 min	***Tea / coffee break***			
15:45	120 min	**CASTest and MCQ**			
CASTest		**Group 1**	**Group 2**	**MCQ**	**Groups 3 & 4**
15:45	10 min	Candidate 1	Candidate 7	15:45 to 16:45	Candidates 13 - 24
15:55	10 min	Candidate 2	Candidate 8		
16:05	10 min	Candidate 3	Candidate 9		
16:15	10 min	Candidate 4	Candidate 10		
16:25	10 min	Candidate 5	Candidate 11		
16:35	10 min	Candidate 6	Candidate 12		
CASTest		**Group 3**	**Group 4**	**MCQ**	**Groups 1 & 2**
16:45	10 min	Candidate 13	Candidate 19	16:45 to 17:45	Candidates 1 - 12
16:55	10 min	Candidate 14	Candidate 20		
17:05	10 min	Candidate 15	Candidate 21		
17:15	10 min	Candidate 16	Candidate 22		
17:25	10 min	Candidate 17	Candidate 23		
17:35	10 min	Candidate 18	Candidate 24		
17:45	15 min	**Faculty meeting**			
18:00		**Candidate feedback in mentor groups**			
		End of course			

Appendix 2: e-ALS Programme

Resuscitation Council (UK) e-ALS

GUIDELINES 2015

Advanced life support provider course programme

With suggested timings (based on 24 candidates in 4 groups of 6)

Timing to be decided locally		*Faculty Meeting and registration*			
08:30	10 min	**Introduction**			
08:40	15 min	**CASDemo (including non-technical skills)**			
08:55		**Skill Stations and workshop:** • The deteriorating patient (ABCDE approach) • Associated Resuscitation Skills inc. IO • High Quality CPR and Defibrillation			
		Associated Resuscitation Skills Inc. IO			
08:55	70 min	Group 1	Group 2	Group 3	Group 4
		The deteriorating patient (ABCDE approach)			
10:05	30 min	Group 1	Group 2	Group 3	Group 4
10:35	15 min	*Tea / coffee break*			
		High quality CPR and defibrillation			
10:50	50 min	Group 1	Group 2	Group 3	Group 4
11:40		**Cardiac Arrest Simulations Teaching Sessions (CASTeach) 1-3**			
		CASTeach 1			
11:40	30 min	Group 1	Group 2	Group 3	Group 4
		CASTeach 2			
12:10	30 min	Group 1	Group 2	Group 3	Group 4
		CASTeach 3			
12:40	30 min	Group 1	Group 2	Group 3	Group 4
13:10	45 min	*Lunch*			
13:55		**Cardioversion and pacing workshop**			
13:55	30 min	Group 1	Group 2	Group 3	Group 4
14:25		**Cardiac Arrest Simulations Teaching Sessions (CASTeach) 4-5**			
		CASTeach 4			
14:25	45 min	Group 1	Group 2	Group 3	Group 4
		CASTeach 5			
15:10	45 min	Group 1	Group 2	Group 3	Group 4
15:55	15 min	*Tea / coffee break*			
16:10	120 min	**CASTest and MCQ**			
CASTest		**Group 1**	**Group 2**	**MCQ**	**Groups 3 & 4**
16:10	10 min	Candidate 1	Candidate 7	16:10 to 17:10	Candidates 13-24
16:20	10 min	Candidate 2	Candidate 8		
16:30	10 min	Candidate 3	Candidate 9		
16:40	10 min	Candidate 4	Candidate 10		
16:50	10 min	Candidate 5	Candidate 11		
17:00	10 min	Candidate 6	Candidate 12		
		Group 3	**Group 4**	**MCQ**	**Groups 1 & 2**
17:10	10 min	Candidate 13	Candidate 19	17:10 to 18:10	Candidates 1-12
17:20	10 min	Candidate 14	Candidate 20		
17:30	10 min	Candidate 15	Candidate 21		
17:40	10 min	Candidate 16	Candidate 22		
17:50	10 min	Candidate 17	Candidate 23		
18:00	10 min	Candidate 18	Candidate 24		
18:10		**Faculty meeting and candidate feedback** *Course closure*			

Appendix 3: Literature search strategy for review of systematic reviews

1	Medline	("systematic review" OR "systematic literature review" OR "systematic scoping review" OR "systematic narrative review" OR "systematic qualitative review" OR "systematic evidence review" OR "systematic quantitative review" OR "systematic meta-review" OR "systematic critical review" OR "systematic mixed studies review" OR "systematic mapping review" OR "systematic cochrane review" OR "systematic search and review" OR "systematic integrative review").ti,ab	150721
2	Medline	((blended OR multifaceted OR hybrid) ADJ2 learning).ti,ab	962
3	Medline	((blended OR multifaceted OR hybrid) ADJ2 teaching).ti,ab	101
4	Medline	((inverted OR flipped OR face-to-face) ADJ2 (teaching OR learning)).ti,ab	480
5	Medline	("technology enhanced learning").ti,ab	99
6	Medline	("technology enhanced teaching").ti,ab	6
7	Medline	((integrated OR computer-aided) ADJ2 (teaching OR learning)).ti,ab	1286
8	Medline	((computer-assisted OR distributed) ADJ2 (teaching OR learning)).ti,ab	801
9	Medline	(hybrid ADJ2 (teaching OR learning)).ti,ab	322
10	Medline	Hospital ADJ2 (staff OR personnel) OR “healthcare personnel”	11651
11	Medline	LEARNING/ OR TEACHING/	106078
12	Medline	exp "EDUCATION, CONTINUING"/ OR exp "EDUCATION, MEDICAL, CONTINUING"/ OR exp "EDUCATION, NURSING, CONTINUING"/	60543
14	Medline	*"COMPUTER-ASSISTED INSTRUCTION -- METHODS"/	3461
16	Medline	*"EDUCATION, GRADUATE -- METHODS"/	358
18	Medline	*"EDUCATION, PROFESSIONAL -- METHODS"/	590

19	Medline	(2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 14)	6766
20	Medline	(11 OR 12 OR 14 OR 16 OR 18)	165687
21	Medline	(19 AND 20)	4490
22	Medline	(10 AND 21)	2181
23	Medline	(1 AND 22)	30
24	CINAHL	("systematic review" OR "systematic literature review" OR "systematic scoping review" OR "systematic narrative review" OR "systematic qualitative review" OR "systematic evidence review" OR "systematic quantitative review" OR "systematic meta-review" OR "systematic critical review" OR "systematic mixed studies review" OR "systematic mapping review" OR "systematic cochrane review" OR "systematic search and review" OR "systematic integrative review").ti,ab	76687
25	CINAHL	((blended OR multifaceted OR hybrid) ADJ2 learning).ti,ab	590
26	CINAHL	((blended OR multifaceted OR hybrid) ADJ2 teaching).ti,ab	64
27	CINAHL	((inverted OR flipped OR face-to-face) ADJ2 (teaching OR learning)).ti,ab	336
28	CINAHL	("technology enhanced learning").ti,ab	84
29	CINAHL	("technology enhanced teaching").ti,ab	7
30	CINAHL	((integrated OR computer-aided) ADJ2 (teaching OR learning)).ti,ab	634
31	CINAHL	((computer-assisted OR distributed) ADJ2 (teaching OR learning)).ti,ab	312
32	CINAHL	(hybrid ADJ2 (teaching OR learning)).ti,ab	87
33	CINAHL	Hospital ADJ2 (staff OR personnel) OR “healthcare personnel”	1113156
34	CINAHL	LEARNING/ OR TEACHING/	28624
35	CINAHL	(25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31 OR 32)	1906
36	CINAHL	("systematic review" OR "systematic literature review" OR "systematic scoping review" OR "systematic	76687

		narrative review" OR "systematic qualitative review" OR "systematic evidence review" OR "systematic quantitative review" OR "systematic meta-review" OR "systematic critical review" OR "systematic mixed studies review" OR "systematic mapping review" OR "systematic cochrane review" OR "systematic search and review" OR "systematic integrative review").ti,ab	
37	CINAHL	(35 AND 36)	48
38	EMBASE	("blended learning" OR "blended teaching").ti,ab	902
39	EMBASE	("systematic review" OR "systematic literature review" OR "systematic scoping review" OR "systematic narrative review" OR "systematic qualitative review" OR "systematic evidence review" OR "systematic quantitative review" OR "systematic meta-review" OR "systematic critical review" OR "systematic mixed studies review" OR "systematic mapping review" OR "systematic cochrane review" OR "systematic search and review" OR "systematic integrative review").ti,ab	191046
41	EMBASE	((blended OR multifaceted OR hybrid) ADJ2 learning).ti,ab	1208
42	EMBASE	((blended OR multifaceted OR hybrid) ADJ2 teaching).ti,ab	84
43	EMBASE	((inverted OR flipped OR face-to-face) ADJ2 (teaching OR learning)).ti,ab	533
44	EMBASE	("technology enhanced learning").ti,ab	134
45	EMBASE	("technology enhanced teaching").ti,ab	9
46	EMBASE	((integrated OR computer-aided) ADJ2 (teaching OR learning)).ti,ab	1053
47	EMBASE	((computer-assisted OR distributed) ADJ2 (teaching OR learning)).ti,ab	799
48	EMBASE	(hybrid ADJ2 (teaching OR learning)).ti,ab	303
49	EMBASE	(41 OR 42 OR 43 OR 44 OR 45 OR 46 OR 47 OR 48)	3616
50	EMBASE	(39 AND 49)	64

Appendix 4: AMSTAR 2 Template

AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both

1. Did the research questions and inclusion criteria for the review include the components of PICO?

For Yes:	Optional (recommended)	
☐ Population ☐ Intervention ☐ Comparator group ☐ Outcome	☐ Timeframe for follow-up	☐ Yes ☐ No

2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?

For Partial Yes:	For Yes:	
The authors state that they had a written protocol or guide that included ALL the following: ☐ review question(s) ☐ a search strategy ☐ inclusion/exclusion criteria ☐ a risk of bias assessment	As for partial yes, plus the protocol should be registered and should also have specified: ☐ a meta-analysis/synthesis plan, if appropriate, *and* ☐ a plan for investigating causes of heterogeneity ☐ justification for any deviations from the protocol	☐ Yes ☐ Partial Yes ☐ No

3. Did the review authors explain their selection of the study designs for inclusion in the review?

For Yes, the review should satisfy ONE of the following:	
☐ *Explanation for* including only RCTs ☐ OR *Explanation for* including only NRSI ☐ OR *Explanation for* including both RCTs and NRSI	☐ Yes ☐ No

4. Did the review authors use a comprehensive literature search strategy?

For Partial Yes (all the following):	For Yes, should also have (all the following):	
☐ searched at least 2 databases (relevant to research question) ☐ provided key word and/or search strategy ☐ justified publication restrictions (e.g. language)	☐ searched the reference lists / bibliographies of included studies ☐ searched trial/study registries ☐ included/consulted content experts in the field ☐ where relevant, searched for grey literature ☐ conducted search within 24 months of completion of the review	☐ Yes ☐ Partial Yes ☐ No

5. Did the review authors perform study selection in duplicate?

For Yes, either ONE of the following:	
☐ at least two reviewers independently agreed on selection of eligible studies and achieved consensus on which studies to include ☐ OR two reviewers selected a sample of eligible studies and achieved good agreement (at least 80 percent), with the remainder selected by one reviewer.	☐ Yes ☐ No

AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both

6. Did the review authors perform data extraction in duplicate?

For Yes, either ONE of the following: ☐ at least two reviewers achieved consensus on which data to extract from included studies ☐ OR two reviewers extracted data from a sample of eligible studies <u>and</u> achieved good agreement (at least 80 percent), with the remainder extracted by one reviewer.	☐ Yes ☐ No

7. Did the review authors provide a list of excluded studies and justify the exclusions?

For Partial Yes: ☐ provided a list of all potentially relevant studies that were read in full-text form but excluded from the review	For Yes, must also have: ☐ Justified the exclusion from the review of each potentially relevant study	☐ Yes ☐ Partial Yes ☐ No

8. Did the review authors describe the included studies in adequate detail?

For Partial Yes (ALL the following): ☐ described populations ☐ described interventions ☐ described comparators ☐ described outcomes ☐ described research designs	For Yes, should also have ALL the following: ☐ described population in detail ☐ described intervention in detail (including doses where relevant) ☐ described comparator in detail (including doses where relevant) ☐ described study's setting ☐ timeframe for follow-up	☐ Yes ☐ Partial Yes ☐ No

9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?

RCTs For Partial Yes, must have assessed RoB from ☐ unconcealed allocation, *and* ☐ lack of blinding of patients and assessors when assessing outcomes (unnecessary for objective outcomes such as all-cause mortality)	For Yes, must also have assessed RoB from: ☐ allocation sequence that was not truly random, *and* ☐ selection of the reported result from among multiple measurements or analyses of a specified outcome	☐ Yes ☐ Partial Yes ☐ No ☐ Includes only NRSI
NRSI For Partial Yes, must have assessed RoB: ☐ from confounding, *and* ☐ from selection bias	For Yes, must also have assessed RoB: ☐ methods used to ascertain exposures and outcomes, *and* ☐ selection of the reported result from among multiple measurements or analyses of a specified outcome	☐ Yes ☐ Partial Yes ☐ No ☐ Includes only RCTs

10. Did the review authors report on the sources of funding for the studies included in the review?

For Yes ☐ Must have reported on the sources of funding for individual studies included in the review. Note: Reporting that the reviewers looked for this information but it was not reported by study authors also qualifies	☐ Yes ☐ No

AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both

11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?

RCTs

For Yes:

- ☐ The authors justified combining the data in a meta-analysis
  - ☐ AND they used an appropriate weighted technique to combine study results and adjusted for heterogeneity if present.
  - ☐ AND investigated the causes of any heterogeneity

☐ Yes
☐ No
☐ No meta-analysis conducted

For NRSI

For Yes:

- ☐ The authors justified combining the data in a meta-analysis
  - ☐ AND they used an appropriate weighted technique to combine study results, adjusting for heterogeneity if present
  - ☐ AND they statistically combined effect estimates from NRSI that were adjusted for confounding, rather than combining raw data, or justified combining raw data when adjusted effect estimates were not available
  - ☐ AND they reported separate summary estimates for RCTs and NRSI separately when both were included in the review

☐ Yes
☐ No
☐ No meta-analysis conducted

12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?

For Yes:

- ☐ included only low risk of bias RCTs
- ☐ OR, if the pooled estimate was based on RCTs and/or NRSI at variable RoB, the authors performed analyses to investigate possible impact of RoB on summary estimates of effect.

☐ Yes
☐ No
☐ No meta-analysis conducted

13. Did the review authors account for RoB in individual studies when interpreting/ discussing the results of the review?

For Yes:

- ☐ included only low risk of bias RCTs
- ☐ OR, if RCTs with moderate or high RoB, or NRSI were included the review provided a discussion of the likely impact of RoB on the results

☐ Yes
☐ No

14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?

For Yes:

- ☐ There was no significant heterogeneity in the results
- ☐ OR if heterogeneity was present the authors performed an investigation of sources of any heterogeneity in the results and discussed the impact of this on the results of the review

☐ Yes
☐ No

15. If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?

For Yes:

- ☐ performed graphical or statistical tests for publication bias and discussed the likelihood and magnitude of impact of publication bias

☐ Yes
☐ No
☐ No meta-analysis conducted

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16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?

For Yes: ☐ The authors reported no competing interests OR ☐ The authors described their funding sources and how they managed potential conflicts of interest	☐ Yes ☐ No

To cite this tool: Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, Moher D, Tugwell P, Welch V, Kristjansson E, Henry DA. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ. 2017 Sep 21;358:j4008.

Appendix 5a: Joint Authorship Declaration for Paper 1

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Title of Publication (including citation):	Lockey AS, Lin Y and Cheng A. Impact of adult advanced cardiac life support course participation on patient outcomes – a systematic review and meta-analysis. Resuscitation 2018;129:48-54

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Title of Publication (including citation):	Thorne CJ, Lockey AS, Bullock I, Hampshire S, Begum-Ali S and Perkins GD. E-learning in advanced life support – an evaluation by the Resuscitation Council (UK). Resuscitation 2015;90:79-84

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Title of Publication (including citation):	Thorne CJ, Lockey AS, Kimani PK, Bullock I, Hampshire S, Begum-Ali S and Perkins GD. E-learning in Advanced Life Support – what factors influence assessment outcome? Resuscitation 2017;114:83-91

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