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Abstract

Malodorous wounds can be distressing for patients and their families, negatively impacting on quality of life outcomes. For healthcare professionals malodorous wounds can also cause distress manifesting in feelings of disgust when being faced with a wound emitting an unpleasant or repulsive odour. There has been investigation into the management of controlling odour particularly in relation to fungating wounds, however there is limited research which explores techniques for early identification and recognition of wound odours that may be indicative of infection. Electronic nose technology has received some attention but to date, has not been integrated into either diagnostics of infection in wounds or education of healthcare professionals to prepare them for the realities of clinical practice.

Key Words: E nose, infection, malodour, odour, technology, wound

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Introduction

Much like our other senses, the sense of smell is a tool for survival in the most primitive meaning. Good odours may signal that food is nearby, or that a mating partner is close. Bad smells, in contrast, can signal danger, for example toxicity or that the food emitting them is rotten. Our response to smells, and the smell of wounds in particular, is essentially driven by these primitive instincts. This paper presents an overview of the literature concerning early detection of wound infection through odour. The following literature search methodology [1] was used to compile existing knowledge regarding wound odours and the potential of early identification of wound infection through malodours. The databases searched were PubMed, Cochrane, Google Scholar and Google Patents. The search was limited to published literature written in the English language. Search terms were identical for each of the databases, and included: "wound", "pressure ulcer", "pressure sore", "bedsore", AND "odour", "smell", "malodour", AND "infection", "bacteria", "fungi", "exudate", OR "electronic nose", "e-Nose". All relevant types of clinical articles (e.g. case series studies, case reports, review papers etc.) and all US/European patent/patent applications to-date were analyzed.

Wound Odour

The negative impact that wounds and their associated symptoms have on an individual's quality of life have been reported[2]. Authors report that odour is cited by patients and professionals as being distressing, leading to social isolation, depression, feelings of guilt and repulsion[2-6]. Living with chronic malodourous wounds has been sparsely investigated[7-11] highlighting the impact on health related quality of life outcomes, altered body image, withdrawal from social activities, together with a detrimental effect on sexual expression and depression. The potential negative effects on relatives who take part in treating the affected individual and even professional carers who may be repulsed by the odour of the wound is another factor to be considered. Management strategies focus around use of dressings that can control or disguise odours [2, 12,13] rather than early detection of odours to prevent or treat early signs of infection.

Wound odour (or malodour) is often the result of necrosis or extremely poor vascularisation of tissues, bacterial colonisation or fungal infection in the wound, or a combination of these, and is hence clinically used as an indication for bioburden or other barriers to wound healing[14,15]. Anaerobic bacteria (which typically colonise in non-healing wounds) release the foul-smelling compounds cadaverine and putrescine as part of the putrefaction of tissues in the wound bed [16]. Likewise, aerobic bacteria including *Proteus* and *Klebsiella* may also be responsible for offensive odours [17,18]. Importantly, different bacteria types produce distinguishable odours, for example, fruity odours often indicate the presence of Staphylococcus whereas foul odours are typically due to the presence of gram negative bacteria[19]. Accordingly, treating wounds with systemic or topical antibiotics to eliminate underlying bacterial infection or surgical debridement of the devitalised tissues that generate the odour would hence be useful in treating the odour problem secondary to promoting tissue regeneration. Activated charcoal is widely used in dressings as a deodorizing agent, in cases where directly treating the odour-causing factors is not feasible for some reason. Nevertheless, certain dressing types e.g. hydrocolloids tend to produce a characteristic odour of their own, particularly upon their removal, as a result of chemical reactions that takes place between the dressing and the wound exudate, which then adds to the biologically-produced odours. Another approach for alleviating the malodour are to use external deodorisers such as air fresheners, scented candles, essential oils, coffee grounds, etc. which may mask malodour arising from the wound.

Since malodorous wounds are often a sign of infection in the wound bed, diagnosis of these infections must be undertaken promptly and confirmed by laboratory tests including microbiological investigations. However, microbiology testing is time-consuming and requires colonisation of samples (swabs) from the wound bed in culture, during which infection may spread and the wound may deteriorate. Hence, ideally, the wound odour itself may be used as an early indicator for the presence and identification of pathogens in a wound but this concept is certainly not new. Around 400 BD, Hippocrates recognized the diagnostic usefulness of body odours and reported on several disease-specific odours emanating from urine or sputum[20]. Surgeons, specifically, have used their sense of smell to predict non-healing of surgical wounds for hundreds of years. In the mid-19th-century it was generally accepted that foul-smelling bloody and watery pus exuding from wounds indicated septicaemia, which was often followed by death of the patient[21]. Pathological processes such as infection and endogenous metabolic disorders in a wound can influence odour fingerprints by producing new volatile organic compounds (VOCs) or by changing the ratio of VOCs that have been produced prior to the aforementioned pathological processes[22]. As such, healthcare professionals use their olfactory senses to identify signs of wound and other infections, with the progress in sensor technologies, computing power and virtual reality systems there is a strong possibility that effective identification of odours will become fully automated.

The use of the senses during patient assessment is promoted in nurse education text books[23]. Dewing[24] suggests that using senses is associated with active learning; citing the need for seeing, noticing and observing as a central principle; however other senses may be just as important in terms of active learning. Whilst it is known that smell is often a clinical indicator; advice for nurse educators concerning how the recognition of smells should be taught remains elusive. Clinical simulation, particularly digital-technology-aided simulation, is becoming increasingly important in nurse education providing the potential for learners to take on both the role of the nurse or the patient[24] and may provide a useful mechanism to investigate how students learn to recognise odours associated with wound infection. Early tentative results suggest that simulation can be effective in promoting empathy[26]. It is anticipated that through preparation of students for the real world of malodorous wounds there will be an earlier identification of infection, patients quality of life will be enhanced, as students will be prepared to manage odours and the potential disgust associated with malodorous wound will be reduced.

Relying on patients and carers themselves to detect wound infection based on odour may be problematic. Olfactory function has been shown to diminish with increasing age[27]. The ability to detect and in particular distinguish between different odours decreases with age; especially over the age of 70[28]. Natural decrease in olfactory ability increases with age and is further accentuated by several medical conditions also prevalent in older people; such as Parkinson's disease, dementia, diabetes and others[28]. Chronic, malodourous wounds such as leg ulcers and diabetic foot ulcers are increasingly common amongst the older population[29]. So whilst it is important for patients and carers to be able to recognise early signs of wound infection; older adults may not be able to do so; therefore; it is even more important for nurses to use their sense of smell in early recognition of wound infection. If nurses could be exposed to a range of safe, replica odours within simulated training environments odour memory may be enhanced; enabling these cues to be brought to the fore when odours are encountered in the real world of clinical practice. Nurses could then employ technology such as the electronic nose directly in practice to confirm or refute their assertions based on odour memory.

Detection of wound smells by electronic nose technology

Humans can distinguish over 10,000 odours[30], however Pierron et al.,[31] have suggested that olfactory capability in humans may be decreasing with Stephy and Puranik[32] reporting that the olfactory memory in humans can reduce in individuals who are diagnosed with brain degenerative disorders including Alzheimer's disease[33]. The importance of recognising different types of odours in identifying wound infection is applicable to both chronic and acute wounds. With regard to acute wounds, Tanner et al.,[34] investigated patient's perceptions and experiences of surgical site infections (SSI) identifying that patients lacked overall awareness, concern and understanding of SSIs. From the sample interviewed (n = 17) seven patients were unaware that they had an SSI due to a lack of understanding; were poorly informed regarding SSIs; were unaware of SSIs; did not recognize SSIs, and did not know the causes of, or risk factors for, SSI. If an automated, digital system for robust, accurate identification of wound odours had been clinically available, to either just early-detect the presence of an SSI or even better, to identify the specific pathogens in the wound bed, infection damage could be limited and controlled, and antibiotic or antifungal treatment could be optimised. Yet, smell is difficult to research and quantify, and even more so, to analyse automatically by means of digital systems, as any given odour may be made up of hundreds of different chemicals.

Machine olfaction is the generic name for the field of automated (machine) smell[35.] It is an emerging application of the frontier of engineering research, particularly nano-engineering, and has numerous applications other than in healthcare. Examples for applications in this field are in the military[35], industry safety (leakage of hazardous chemicals), law enforcement (detection of illegal substances), food safety and quality evaluations (freshness and contamination of products, aroma of wines and luxurious products), cosmetics (quality control of aroma and fragrance profiles of perfumes[36]) – to name just a few. Such prototype apparatuses are often called an electronic nose or e-nose. The field of machine olfaction is in its infancy, and is complicated by the fact that e-nose devices to-date have had a limited number of sensory elements, whereas each odour is produced by a unique set of (potentially numerous) odorant compounds. In healthcare there have been attempts to develop e-noses in order to early detect respiratory diseases (e.g. chronic obstructive pulmonary diseases related to viral or bacterial infections)[37]as well as lung tumours[38]. The industry is translating academic research in machine olfaction to applications, and companies that develop e-nose devices for medical applications exist, for example the eNose company (enose.nl; product: Aeonose®), Odournet UK Ltd (odournet.com; product: AromaScan®).

Published research employing such e-nose devices is fairly new and very little is specific to wound assessment. In a small pilot study of 15 patients with venous leg ulceration, Greenwood et al.,[39], identified that a characteristic aroma from a chronic deep ulcer base, and specifically those diagnosed with streptococcal species, was emitted and could be measured through aroma patterns. The researchers used the AromaScan instrument to measure electrical resistance when exposed to a mixture of volatile chemical. Using Sammon mapping they graphically mapped responses of the sensors 3-dimensionally against a different mixture of chemicals. In 13 of the 15 patients, the aroma pattern correlated with ulcer progression and the progress reported clinically. Another pioneering work specific to detection of wound odours was the WOUNDMONITOR project in framework of the European Commission Consortium grant program (EU project # IST-027859) led by the University of Manchester in the United Kingdom. The project members of WOUNDMONITOR have developed a method and system that automatically analyses swab materials by first using a solid-phase micro extraction pre-concentration step, and then, employs a pattern recognition system for detecting the types of the bacteria that are present in the wound bed[19]. Early results from that project have shown good differentiation between P. aeruginosa and S. aureus cultures[19]. Using a principal component analysis that was added later in the project to analyse the resultant VOC spectrum, the instrument has also been shown capable of differentiating between infected and uninfected burns by pre-concentrating VOCs from swabs and wound dressing materials[40]. The WOUNDMONITOR has unfortunately not matured into commercial technologies, but have provided a scientific basis for the feasibility of applying e-nose technology in wound infection assessment.

More recently, Shirasu et al.,[41] used gas chromatography – mass spectrometry to evaluate wound odour identifying that dimethyl trisulfide from exudate produced the sulfury odour released from wounds. The importance of early detection of infection in diabetic foot ulceration has been discussed by Yusuf and colleagues[41], who argued that technologies such as e-nose could benefit patients in order to start antibiotic therapy specific to the causative bacteria. Romanelli et al.,[43] previously highlighted using the e-nose to quantify wound odour through exposing the e-nose to odours, and using ploymer sensors the electrical resistance could be measured[44]. Odour assessment is subjective with Holloway et al.,[17] stating that sensory cells become desensitized over a period of time to protect individuals from the awareness of the smell. Yet there is no specific validated classification tool available for characterizing odours produced by wounds or standardised technique, either automated or non-automated, for detecting wound odours[43].

Recently, Yan et al.,[46] reported the performance of E-nose technology in the detection of wound infection arguing that feature extraction and selection were essential to allow effective E-Nose signals processing. They concluded that E-nose technology obtains the highest classification accuracy when the maximum value and db 5 wavelet coefficients are extracted as the hybrid features. A wavelet analysis is a mathematical/engineering approach to the study of oscillations in signals. The parameters of a wavelet analysis are often reported in terms of decibels (db), which quantify the gain or attenuation of signals, or the signal-to-noise ratios. This new method of detection, they argue, is ideal for the identification of wound infection.

Summary

To-date research and evidence has focused around the management of wound odour rather than effective strategies that can assist health care professionals and patients in early recognition of odour that may be indicative of wound infection. The literature presents a growing interest in developing technologies, generically called electronic noses that may be useful in early identification of wound odour.

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