Negative pressure wound therapy (NPWT) for spinal wounds: a systematic review

Karen Ousey, PhD[1], Ross A. Atkinson, PhD[2,3], J Bradley Williamson, MB ChB, FRCS[2], Steve Lui, MSc[1]

From the:

[1]*School of Human and Health Sciences, University of Huddersfield, Queensgate, Huddersfield, Yorkshire HD1 3DH.

[2]Greater Manchester Neuroscience Centre, Salford Royal NHS Foundation Trust, Stott Lane, Salford M6 8HD.

[3]The University of Manchester, Manchester Academic Health Science Centre, Salford Royal NHS Foundation Trust.

Address correspondence and reprint requests to Karen Ousey, Reader in Advancing Clinical Practice, School of Human and Health Sciences, University of Huddersfield, Queensgate, Huddersfield, Yorkshire, HD1 3DH; Email: k.j.ousey@hud.ac.uk

Declaration of Interest

Funding to undertake the review was received from the University of Huddersfield Collaborative Venture Fund and KCI Medical. No other conflict of interest is decalred.

Key words

Infection; Spine; Systematic review; Negative pressure wound therapy; Wound

Acknowledgements

We would like to thank Anna Fletcher and Linda Upton (Spinal Unit, Salford Royal NHS Foundation Trust) for their support.

Background

Description of the condition

The management of post-operative spinal wound complication remains a significant challenge. Surgical site infection (SSI) [1] and pre-operative radiotherapy [2] are the overwhelming causes of morbidity in post-operative spinal wound complications. SSI rates range from 0.4% to 20% following spinal surgery[1, 3-5]. Post-operative incontinence, posterior surgical approach and surgery for tumour resection are additional risk factors for SSI in spinal surgery [6].

Prophylactic antibiotics [7] ,drain placement [8-10] ,copious irrigation [11] and careful attention to wound closure are standard clinical interventions to reduce the risk of wound complications. Early detection of spinal wound complication is the key to preventing superficial infection from becoming deep infection [1]. Negative pressure wound therapy (NPWT) has been reported as a successful measure to aid closure [4, 5, 12] in patients with a spinal wound and may advance wound healing and prevent infection.

Description of the intervention

NPWT is based on the work of Dersch [13] who showed that positive pressure leads to a decrease in skin perfusion and therefore hypoxia, while negative pressure increases skin perfusion[14]. Briefly, the procedure involves placing an open-cell foam dressing into the wound and applying a controlled subatmospheric pressure by means of a pump device [15].

The wound healing mechanism by NPWT still remains unclear [16]. However, several mechanisms have been suggested that indicate NPWT could be an effective way to manage post-operative wounds. Firstly, NPWT has been shown to remove the third-space fluid from the wound area as a result of a decrease in tissue turgidity and capillary after load, which promotes improved capillary circulation and local oxygenation [15, 17]. This may in turn promote wound healing [16]. Secondly, an experimental study has shown that NPWT reduces the bacterial load and the potential for bacterial colonisation [18]. Finally, NPWT wound healing occurs via a mechanical effect on the wound bed. NPWT causes the wound dressing to collapse transferring the force towards the wound edges, thus drawing them closer together enabling small pieces of tissue to be drawn into a foam contact dressing causing micro-deformations [17]. This induces mechanical stress, which is thought to stimulate angiogenesis and tissue growth [16].

Why it is important to do this review

Significant morbidity is associated with delayed spinal wound healing. The management of wound complications is often prolonged and difficult. While NPWT is used currently to treat patients with spinal wound complications, there is a paucity of high quality published evidence to support this practice. A systematic review is necessary to determine the benefit of NPWT as a method to promote wound healing and treat SSI in spinal surgery patients. In addition, it is possible that NPWT may be an effective adjunct treatment on surgically closed wounds as it may remove fluid, increase circulation and stimulate granulation tissue

formation [5, 19]. As well as the obvious benefits of improved clinical outcome, lower rates of SSI would lead to reductions in costs associated with length of hospital stay, diagnostic tests for microbiology and use of antibiotics; antimicrobial resistance would also be limited if SSI could be avoided [20] (for a review, see Nicolau, 2011). To our knowledge, there are no reviews to date addressing the use of NPWT specifically in spinal surgery.

Objectives

This review examines any randomized controlled trials (RCTs) assessing the effectiveness of NPWT in patients with a spinal wound when compared to pharmacological interventions (e.g. antibiotics) and physical interventions (e.g. irrigation, gauze/hydrocolloid regime).

This review also examines non-RCTs to evaluate the potential benefits of NPWT in patients with a spinal wound.

Methods

Criteria for considering studies for this review

Types of studies

We sought all relevant RCTs or quasi-methods of participant allocation. Studies which compared NPWT versus pharmacological interventions (e.g. antibiotics) and physical interventions (e.g. irrigation, gauze/hydrocolloid regimen) were eligible for this review.

We also sought all other NPWT studies (case studies, retrospective studies) to evaluate the potential benefits and risks of NPWT in patients with a spinal wound.

Type of participants

This review includes any types of patient in any health care setting with a spinal wound of any aetiology.

Types of interventions

Trials in which participants received any form of NPWT associated with spinal surgery and the comparison group received any alternative wound treatment. All types of NPWT application, delivery modes of negative pressure (continuous or intermittent) were considered eligible.

For the non-trial studies, once again, all types of NPWT, application and delivery mode were considered.

Types of outcome measures

Each study must report, at a minimum, one of the following outcome measures:

Primary outcomes

The primary outcome of interest was wound healing including:

- Time to complete healing.
- Rate of change in wound area.

- Proportion of wound completely healed within the study period.

Secondary outcomes

- Infection rate or bacterial load.
- Quality of life.
- Adverse events.
- Hospitalization.
- Cost.

Search methods for identification of studies

We adapted the current searches based on the search strategies recommended and updated by the Cochrane Back and Wounds Review Groups [21] .

Electronic searches

We searched the following databases:

- The Cochrane Library (issue 2, 2011 which includes the Cochrane Back and Wounds Review Groups).
- MEDLINE (1950 to June 2011).
- EMBASE (1974 to June 2011).
- CINAHL (1982 to June 2011).

Search Strategies are shown in Appendix 1.

Search of other resources

We searched:

- The reference lists of all relevant papers to identify further studies.
- Some of the main electronic sources of ongoing trials (National Research Register, meta-register of Controlled trials).
- Journals (see Appendix 1) conference proceedings likely to have trials relevant to this review. We contacted experts in the field seeking information about unpublished or incomplete trials.

Data Collection and analysis

Selection of studies

Reviewers read all titles and abstracts resulting from the search process and eliminated any studies that were not relevant for this review. Full copies of all potentially relevant studies were obtained. All reviewers acted independently to classify these as include or exclude studies. Any discrepancy about the relevance and design of the studies between the reviewers was resolved by discussion and the decision to include the studies was based upon the inclusion criteria. The reviewers sought consensus when differences in opinion occurred.

Data Synthesis

Included studies were tabulated and entered into the "Characteristics of included studies." Studies or reports which did not involve NPWT of spinal surgery patients, or that were literature reviews, were excluded. However literature reviews were examined to ensure all appropriate evidence had been included in the current review. Critical interpretative synthesis [22] of literature was used to construct the themes of the included papers.

Results

Searching the different databases for this review yielded 232 publications; from MEDLINE 89 publications; EMBASE 123 publications; CINAHL 17 publications; and 3 publications from hand searched journals. After removing the duplicates, of which 209 did not meet the inclusion criteria; 23 publications were retrieved in full, of which 9 were excluded because they were not individual studies focusing on NPWT and spinal wounds; five were literature review and four were not primarily based on NPWT. Fourteen studies were therefore included in this review (Table 1).

None of the studies were RCTs involving the use of NPWT to treat delayed wound healing or SSI, or as a prophylactic wound treatment to prevent wound breakdown and infection, though one report described one patient where NPWT was used prophylactically after wound dehiscence in the absence of infection [27].

Most of the studies (n=9) [3-5, 19, 23-27] were retrospective studies and five were case studies [12, 28-31]. Thirteen studies described less than 50 patients; only one study reported more than 50 patients [19]. The mean age of patients varied with the majority of the studies (n=8) reporting NPWT use in adults (age range 21- 59 years); four studies [12, 24, 26, 29] carried out in paediatric setting (age range 12.6-13.5 years); and one study [25] did not report the mean age of the patients.

Cost of the NPWT was not reported in any of the studies.

Management

Three studies [3, 26, 29] reported the NPWT applied pressure as -125 mmHg. Irrigation and debridement prior to placement of the NPWT device was reported in 10 studies [3-5, 12, 19, 23, 24, 26, 27, 30], and three reported the use of debridement alone [25, 29, 31]. Jones et al (2007) [3] reported the use of saline containing bacitracin to irrigate the wound. The length of time for NPWT in situ ranged from 3 to 186 days and was provided by 5 studies [4, 23, 24, 26, 30].

Evaluations

Three studies [5, 12, 28] did not report the frequency of dressing being changed. Ten studies evaluated healing with NPWT and the general consensus seemed to be that this evaluation of the wound took place every 2-3 days.

Healing

Time to complete healing was reported by 11 studies [3-5, 12, 19, 23, 27-31] and varied from 7 days to 16 months. Two studies [12, 31] reported wound length. Yuan-Innes et al [12] reported that the defect created following debridement for wound infection after Luque instrumentation and fusion in one patient reduced from 10 cm to 6 cm following NPWT. Another study used NPWT prior to and intermittently between maggot debridement therapy (MDT) of infected spinal wounds in scoliosis patients [31]. Wound length in that study decreased from a mean of 24.2cm prior to initiation of MDT to 10.4 cm as a healed scar.

Organism types

All but two studies [25, 28], reported the organism type found, with the main isolates being Staphylococcus, Escherichia coli, Pseudomonas, Streptococcus, Enterobacter, Clostridium and MRSA.

Medication

Apart from two [24, 28], all of the papers reported the use of antimicrobial or antifungal treatment, depending on the organism cultured. Van Rhee et al [29] gave Cefuroxim prophylaxis until 3 days post primary surgery. Yuan-Innes et al [12] gave high dose corticosteroid and antibiotic impregnated beads during irrigation and debridement procedures, whereas Ploumis et al [19] reported the use of Vancomycin immediately at presentation of the infection, followed by appropriate antibiotics to which the cultured microorganisms were sensitive.

Complications, contraindications and hospitalization

Several complications were reported in spinal surgery patients where NPWT had been used in four studies [3, 19, 27, 30]. However not all of these complications were related to the NPWT device or dressing itself. Jones et al.[3] reported five major complications in four patients, including haemorrhage during NPWT placement in two patients, one of whom went on to become haemodynamically unstable and died. In this case, the authors report that while the latter patient did lose blood through the NPWT dressing, the blood loss must be viewed within a setting of post-operative blood loss and chronic anaemia due to malignant disease. This case was further complicated by the patient's refusal of a blood transfusion on religious grounds, which may have contributed to the failure of resuscitation of the patient [3]. Whilst cerebrospinal fluid leak did not result from the use of NPWT, it was used in one patient where this had occurred following surgery [3]. NPWT was then only initiated once an absence of cerebrospinal fluid leak was confirmed during Valsalva maneuvers. Additionally, Jones [3] reported persistent infection requiring re-operation in two patients and non-healing granulation tissue requiring a skin graft in one. On re-exploration, a fragment of packing foam left during the wet-to-dry dressing changes was found to have been retained in one of these patients after discontinuation of NPWT. Zehnder & Place [27] also reported recurrence

of infection subsequent to closure which required a repeat irrigation and debridement with removal of instrumentation over healed fusion.

Two cases of uncontrolled sepsis were reported by Ploumis et al. [19] after initiation of NPWT. However no further details were given relating to this complication. The only secondary effect noted by both patients in the study by Vicario et al. was a tingling sensation around the wound during treatment.

In light of these complications, three papers [3, 12, 27] reported contraindications to NPWT. The technique should not be used in the presence of an active cerebrospinal fluid leak [3]. Jones et al [3] stated that NPWT should be used with caution in patients with spine injuries or a bleeding diathesis as there may be risk of increased bleeding or failure of primary closure. Furthermore Yuan-Innes et al. [12], while reporting no complications related to the NPWT device in their study, indicated that blood dyscrasias and anticoagulants are relative contraindications because removal of the sponge causes granulation tissue to bleed. Use of the technique should also be avoided with metastatic or neoplastic disease in the wound [12, 27], in the presence of fistulas [12], and in patients with an allergy to the NPWT dressing [27].

Mendonca et al. [14] cautioned that the precise mechanism by which NPWT brings about wound healing is not fully understood. The growth factors and cytokines responsible for initiating the process of cell migration and angiogenesis are yet to be elucidated, and further evidence is needed to show that negative pressure influences cell growth.

Three studies [3, 4, 19] reported the average length of stay in hospital (range 14 to 43 days). It is interesting to note that effective use of NPWT has been reported in patients with pyoderma gangrenosum even though there is a theoretical risk of an exaggerated inflammatory response [32] .

Discussion

The NPWT technique has been employed with the intention of improving wound healing in patients undergoing spinal surgery. However, this review reveals no RCTs that have been undertaken to assess the clinical effectiveness of NPWT after spinal surgery. Furthermore, the majority of published reports describe use of the technique to treat SSI, with none formally investigating its potential to stimulate wound healing and prevent infection.

Two recent prospective RCTs investigating immediate use of NPWT in orthopaedic [33, 34] and abdominal surgery [33] reported conflicting results with respect to the efficacy of NPWT in reducing SSI rate. Based on 93 patients, Masden reported that the rate of SSI was not significantly different in the standard dressing (7%) and NPWT groups (14%). In contrast, Stannard and colleagues randomised a larger number of patients (249 patients representing 263 fractures) and demonstrated a significant difference in SSI rate between the standard dressing (10%) and NPWT groups (19%).

Several other prospective RCTs of NPWT use are available in the orthopaedic literature. Recently Dorafshar and colleagues [35] reported noninferiority of a sealed gauze dressing with suction when compared with NPWT in reducing wound volume and surface area in acute wounds. That study also noted significantly greater levels of pain and increased cost associated with NPWT [35]. Post-operative blistering has been reported as a further complication in a study involving total knee arthroplasty [36]. A lack of difference between the

NPWT and standard dressing groups in the time taken to attain a dry wound was also observed [36]. Despite this, another recent study suggested that NPWT was associated with a reduction in the size of post-operative seromas after total hip arthroplasty [37]. Moreover, Stannard et al [38] undertook a RCT investigating NPWT versus pressure dressing or standard post operative dressing in high-risk lower extremity fractures and concluded that NPWT reduced the duration of drainage in patients with haematomas or high-risk lower limb fractures compared with controls (mean 1.6 days versus 3.1 days for haematomas, p=0.03; and 1.8 days versus 4.8 days for high-risk fractures, p=0.02) [38].

The 14 retrospective and case studies involving spinal patients identified in this review suggest that NPWT could be a potential tool to aid wound healing worthy of further investigation. At present, there are no randomized controlled studies of NPWT use in spinal surgery as either a dressing alternative or adjunct, a management tool for superficial persistent wound drainage, the management of superficial wound dehiscence or for the management of deep infections. Additionally, it does not appear that NPWT is ever used by itself for the management of wound complications. Therefore, RCTs of NPWT as a treatment for wound breakdown and SSI, as well as for prophylactic wound treatment, would be needed to provide more definitive evidence for the use of the technique in this patient group. The nature of such large wounds [31] adds to the importance of finding ways to promote wound healing. While minimally invasive techniques are now available to the surgeon for procedures such as microdiscectomy, corrective surgery for scoliosis and other procedures involving spinal fusion necessitate more complex open surgical approaches. Certainly within the European market, a number of NPWT devices are currently available for the management of closed surgical incisions at risk of post-operative complications. NPWT, in our view, does not replace standard medical care for spinal patients [39] and continuous surveillance of the wound should remain standard practice to ensure safe and effective outcomes.

The original NPWT recommendation is -125 mmHg for pressure ulcers (black foam) to -175 mmHg (white foam), as outlined by Morykwas et al.[18] 1997. The studies [3, 26, 29] reported in this review applied pressure of -125 mmHg to surgical spinal wounds. Morykwas et al [40] found -125 mmHg was associated with higher rate of granulation formation in an experimental pig model, but McCord et al [41] suggested wound healing could be achieved using lower negative pressure (-100 mmHg) in infants and children. The general consensus in the literature (mainly for non-spinal wounds) indicated a negative pressure of -50 to -75 mmHg to be used in children 2 years or younger; -75 to -125 mmHg for children above 2 and -100 to -125 mmHg is used in adult patients [42]. Furthermore, some manufacturers of NPWT [43] recommend reducing the pressure settings to between -40 and -80 mmHg for patients who have pain, until the pain is relieved. In older individuals, malnourished patients or those receiving anti-coagulation therapy, pressures should commence at -75 to -100 mmHg, and be increased to -125 mmHg as tolerated [39].

The number of days for NPWT in situ ranged from 4 to 186 and spinal wound healing time varied from 6 days to 112 days in those studies where this outcome was reported. Odour has been reported as a problem during NPWT of chronic wounds [14] suggesting that frequent evaluation of the wound is important. It was identified that conventional dressings required changing 2-3 times per day [41]. In contrast, the general consensus was that NPWT dressings, were changed between 2-3 days [24-26], even though manufacturer's instructions suggest that NPWT could be kept in place for up to 7 days. This suggests that there are economic

implications of this type of treatment that require investigation; not only in terms of the cost of the dressing itself but the amount of clinical time spent treating patients with NPWT and the potential savings in bed days this therapy may lead to. This is in addition to any potential effects on quality of life. Several authors have undertaken cost-effectiveness studies of using NPWT as opposed to traditional wound dressings for the treatment of acute and chronic wounds [45-48]. They all argue that NPWT can benefit the management of many types of wound and may be an efficacious and cost-effective means to promote wound healing. Searle and Milne (2010) concluded that the types and quality of studies are mixed, ranging from RCTs to retrospective clinical studies. While evidence suggests that although the unit cost of NPWT may be perceived to be high [35], there is a real possibility that materials and rental costs can be offset by, for example, reduction in length of stay, lower frequency of dressing change, and a reduction in complications and further surgical interventions. However, there is a need to further analyze the cost-effectiveness of the advanced wound management technologies including NPWT on a long-term basis.

Most studies reported that the NPWT dressing was placed in theater following debridement [25, 29, 31] or irrigation and debridement [3, 4, 5, 12, 19, 23, 24, 26, 27, 30] of the wound. Only one study reported the use of a non-mechanical debridement method [31]. Preparation of the wound bed by debriding devitalized tissue is an important step in the wound healing process. Therefore in the treatment of dehisced or infected surgical wounds, such preparation prior to application of the NPWT device would be recommended. Other studies indicated that dressings were changed by the bedside [17, 29, 45] or even on an out-patient basis [12, 17, 29]. One study reported that where patients were insensate due to the presence of myelomeningocele [17], dressings were changed in their hospital room without the need for antianxiety medication. Children who experienced pain upon dressing change were taken to the paediatric intensive care unit where dressings were changed during conscious sedation to reduce psychological trauma and pain. Those patients whose parents had been instructed how to change the dressing by the wound specialist nurse and instructional video were allowed to have their dressing changed at home, thereby promoting patient autonomy and reducing unnecessary visits to theater.

McCord et al [41] found a reduction in the frequency of wound dressing changes decreased anxiety and the amount of pain relief required by patients. In this review, none of the studies objectively reported pain or the amount of pain relief used by patients. Bookout et al [49] suggested that the use of 1% Lidocaine via NPWT tubing into the foam could mitigate pain during dressing change. We did not find any studies reporting NPWT monitoring and maintenance of the machine. However, as with any medical device, it is good practice that the equipment is fully functioning and safety checks are undertaken regularly [50].

NPWT is contraindicated for use in metastatic or neoplastic wounds [12, 27], or with skin malignancy and excised skin malignancy, with the exception of its use in palliative care [51]. One publication included in this review reported the use of NPWT in a patient who had undergone surgery for metastatic spinal cord compression [3]. NPWT in this case was implemented following incision and drainage to treat SSI which occurred several weeks after the surgical procedure. Blood loss was a problem in this patient, and his refusal for a blood transfusion unfortunately led to the patient becoming haemodynamically unstable, likely contributing towards death. Furthermore, another report in the spine literature details the use of NPWT in a patient with malignant desmoplastic melanoma and neurofibromatosis [28], apparently with success with regards to preparation of the wound for successful application

of a graft. While no adverse events were encountered in that report, the authors do suggest that long-term follow-up of the patient was required to determine the true efficacy of NPWT usage in a wound with possible malignancy. Interestingly, Ford-Dunn [52] also reported good symptom control in a patient with a malignant lower limb wound. NPWT in this case was initiated purely to manage copious exudate and to reduce pain upon dressing change in a patient in the end stages of life. Despite the apparent success with the use of the NPWT method, Ford-Dunn does not indicate that NPWT is contraindicated with malignancy. The current recommendations of most NPWT manufacturers still state that the technique should be avoided in malignant wounds. However, it is possible that use of NPWT on closed surgical incisions following palliative operations (where the negative impact of wound complication would be judged to severely compromise quality of life) could be viewed as an exception.

Despite cerebrospinal fluid leak being reported as a contraindication in spine patients, this was not reported to be a consequence of NPWT itself [3]. The rationale for this is presumably to avoid exacerbation of the leak (in a similar way to avoiding excessive blood loss in patients at risk of haemorrhage). While no clinical evidence exists to suggest that NPWT contributes towards progression of cerebrospinal fluid leak, as a precautionary measure, it is reasonable to recommend that NPWT usage is avoided in cases where this may be suspected.

Mooney et al. [50] noted that some paediatric patients experienced a higher rate of tissue granulation which may have caused in-growth into the polyurethane foam. The use of polyvinyl alcohol foam or a non-adhesive barrier to prevent such granulation is recommended by NPWT manufacturers. Rash development (without itching or pain) due to contact with the suction sponge has previously been reported in 2.2% of patients from one study [53]. However this generally resolved within 48 hours. Interestingly, it has been recommended that a setting of -50 mmHg can be used in wounds where there is an overlap of the skin, such as in surgical wounds, to minimise the risk of a rash developing [53].

Furthermore, has been recommended that NPWT should be used with caution in patients where there is active bleeding in the wound, when haemostasis is difficult following debridement, when there is inadequate debridement, necrotic tissue with eschar, in the presence of untreated osteomyelitis or sepsis in the wound area or when anticoagulant therapy is used [54, 55].

Authors' Conclusion

The literature indicates that NPWT may warrant further investigation as a method to aid wound closure and treat infection following spinal surgery. While the quality of evidence within the spinal field is limited to small retrospective and case studies, with no reports of NPWT used as a prophylactic treatment, it should be recognized that clinical experience is often useful in identifying emerging therapies. High quality studies in the orthopaedic literature currently report ambiguous results. Therefore there is a need for larger, prospective RCTs of NPWT specifically after spine surgery to assess its effectiveness both to promote wound healing and treat SSI, and as a prophylactic treatment to *prevent* SSI, before a definitive assessment on the benefits of the technique can be made. Future studies should

ensure they report data relating to health economics and treatment costs, as well as clinical effectiveness and safety.

Implication for research

RCTs involving larger sample sizes are warranted to investigate the use of NPWT in patients undergoing spinal surgery. It is anticipated that definitive conclusions may require multi-center studies to maximise recruitment since SSI rate is generally relatively low. Future studies should ensure they collect data relating to both NPWT wear time and healing rate/time. Data relating to quality of life, economic cost of the treatment and its associated potential savings should also be reported as this information is currently lacking in the published literature.

Appendix 1

MEDLINE Search strategy for the review:

1. SPINE/;
2. discitis.ti,ab;
3. SPINAL DISEASES/
4. ((disc ADJ degeneration)).ti,ab;
5. ((disc ADJ prolapse)).ti,ab;
6. (disc ADJ herniation).ti,ab;
7. SPINAL FUSION/;
8. SPINAL NEOPLASMS/;
9. (facet ADJ joints).ti,ab;
10. INTERVERTEBRAL DISK/;
11. postlaminectomy.ti,ab;
12. arachnoiditis.ti,ab;
13. (failed ADJ back).ti,ab;
14. 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13;
15. SUCTION/;
16. VACUUM/;
17. ("negative pressure" OR "negative-pressure" OR NPWT).ti,ab;
18. (sub-atmospheric OR subatmosphereic).ti,ab;.
19. (seal* AND next AND surface*).ti,ab;
20. (seal* AND next AND aspirat*).ti,ab;
21. (wound* AND near AND suction).ti,ab;
22. (wound* AND near AND drainage).ti,ab;
23. (foam AND next AND suction).ti,ab;
24. (suction AND next AND dressing*).ti,ab;
25. (vacuum AND next AND therapy).ti,ab;
26. (vacuum AND next AND dressing*).ti,ab
27. (vacuum AND next AND seal*).ti,ab;
28. (vacuum AND near AND closure).ti,ab; .
29. (vacuum AND next AND compression).ti,ab;
30. (vacuum AND next AND pack*).ti,ab;
31. (vacuum AND next AND drainage).ti,ab;
32. 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31;
33. 14 AND 32;

Hand searching

Each Review Group registers the journals for which they take prime responsibility for searching. Many journals are now available online, which makes the task a little easier. However, some journals are still difficult to find. The CBRG is currently registered to search:

- American Journal of Orthopedics
- European Spine Journal
- Journal of Back and Musculoskeletal Rehabilitation
- Journal of Spinal Disorders
- Seminars in Spinal Surgery
- Spine
- Journal of the American Osteopathic Association
- The Spine Journal

References

1. Mithani SK, Tufaro AP. Management of wound complications in spinal surgery. *Contemporary Spine Surgery* 2008; **9**(8)**:** 1-6.

2. Ghogawala Z, Mansfield FL, Borges LF. Spinal radiation before surgical decompression adversely affects outcomes of surgery for symptomatic metastatic spinal cord compression. *Spine (Phila Pa 1976)* 2001; **26**(7)**:** 818-24.

3. Jones GA, Butler J, Lieberman I, Schlenk R. Negative-pressure wound therapy in the treatment of complex postoperative spinal wound infections: complications and lessons learned using vacuum-assisted closure. *J Neurosurg Spine* 2007; **6**(5)**:** 407-11.

4. Labler L, Keel M, Trentz O, Heinzelmann M. Wound conditioning by vacuum assisted closure (V.A.C.) in postoperative infections after dorsal spine surgery. *Eur Spine J* 2006; **15**(9)**:** 1388-96.

5. Mehbod AA, Ogilvie JW, Pinto MR, Schwender JD, Transfeldt EE, Wood KB *et al.* Postoperative deep wound infections in adults after spinal fusion: management with vacuum-assisted wound closure. *J Spinal Disord Tech* 2005; **18**(1)**:** 14-7.

6. Olsen MA, Mayfield J, Lauryssen C, Polish LB, Jones M, Vest J *et al.* Risk factors for surgical site infection in spinal surgery. *J Neurosurg* 2003; **98**(2 Suppl)**:** 149-55.

7. Barker FG. Efficacy of prophylactic antibiotic therapy in spinal injury: met-analysis. *Neurosugery* 2002; **51:** 391-400.

8. Payne DH, Fischgrund JS, Herkowitz HN, Barry RL, Kurz LT, Montgomery DM. Efficacy of closed wound suction drainage after single-level lumbar laminectomy. *J Spinal Disord* 1996; **9**(5)**:** 401-3.

9. Scuderi GJ, Brusovanik GV, Fitzhenry LN, Vaccaro AR. Is wound drainage necessary after lumbar spinal fusion surgery? *Med Sci Monit* 2005; **11**(2)**:** CR64-6.

10. Brown MD, Brookfield KF. A randomized study of closed wound suction drainage for extensive lumbar spine surgery. *Spine (Phila Pa 1976)* 2004; **29**(10)**:** 1066-8.

11. Cheng MT, Chang MC, Wang ST, Yu WK, Liu CL, Chen TH. Efficacy of dilute betadine solution irrigation in the prevention of postoperative infection of spinal surgery. *Spine (Phila Pa 1976)* 2005; **30**(15)**:** 1689-93.

12. Yuan-Innes MJ, Temple CL, Lacey MS. Vacuum-assisted wound closure: a new approach to spinal wounds with exposed hardware. *Spine (Phila Pa 1976)* 2001; **26**(3)**:** E30-3.

13. Dersch T, Morykwas M, Clark M, Argenta L. Effects of negative and positive pressure on skin oxygen tension and perfusion. In: *4th Annual Meeting of Wound healing Society*. San Francisco, 1994. p 64.

14. Mendonca DA, Papini R, Price PE. Negative-pressure wound therapy: a snapshot of the evidence. *Int Wound J* 2006; **3**(4)**:** 261-71.

15. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. *Ann Plast Surg* 1997; **38**(6)**:** 563-76; discussion 577.

16. Ubbink DT, Westerbos SJ, Evans D, Land L, Vermeulen H. Topical negative pressure for treating chronic wounds. *Cochrane Database Syst Rev* 2008; (3)**:** CD001898.

17. Plikaitis CM, Molnar JA. Subatmospheric pressure wound therapy and the vacuum-assisted closure device: basic science and current clinical successes. *Expert Rev Med Devices* 2006; **3**(2)**:** 175-84.

18. Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. *Ann Plast Surg* 1997; **38**(6)**:** 553-62.

19. Ploumis A, Mehbod AA, Dressel TD, Dykes DC, Transfeldt EE, Lonstein JE. Therapy of spinal wound infections using vacuum-assisted wound closure: risk factors leading to resistance to treatment. *J Spinal Disord Tech* 2008; **21**(5)**:** 320-3.

20. Nicolau DP. Current challenges in the management of the infected patient. *Curr Opin Infect Dis* 2011; **24 Suppl 1:** S1-10.

21. Furlan AD, Pennick V, Bombardier C, van Tulder M. 2009 updated method guidelines for systematic reviews in the Cochrane Back Review Group. *Spine (Phila Pa 1976)* 2009; **34**(18)**:** 1929-41.

22. Dixon-Woods M, Cavers D, Agarwal S, Annandale E, Arthur A, Harvey J *et al.* Conducting a critical interpretive synthesis of the literature on access to healthcare by vulnerable groups. *BMC Med Res Methodol* 2006; **6:** 35.

23. Antony S, Terrazas S. A retrospective study: clinical experience using vacuum-assisted closure in the treatment of wounds. *J Natl Med Assoc* 2004; **96**(8)**:** 1073-7.

24. Canavese F, Gupta S, Krajbich JI, Emara KM. Vacuum-assisted closure for deep infection after spinal instrumentation for scoliosis. *J Bone Joint Surg Br* 2008; **90**(3)**:** 377-81.

25. Canavese F, Gupta S, Emara KM, Krajbich JI. Use of the vacuum assisted closure in instrumented spinal deformities for children with neuromuscular scoliosis who developed post-operative deep spinal infection. *Developmental Medicine and Child Neurology* 2009; **51**(5)**:** 50.

26. Horn PL, Ruth B, Kean JR. Use of wound V.A.C. therapy in pediatric patients with infected spinal wounds: a retrospective review. *Orthop Nurs* 2007; **26**(5)**:** 317-22; quiz 323-4.

27. Zehnder SW, Place HM. Vacuum-assisted wound closure in postoperative spinal wound infection. *Orthopedics* 2007; **30**(4)**:** 267-72.

28. Adams J, Hakim EM. A critical analysis of existing evidence on the management of a wound with Malignant Desmoplastic Melanoma and Neurofibromatosis: a caser report. *Rehabilitation Oncology* 2009; **27**(1)**:** 26-27.

29. van Rhee MA, de Klerk LW, Verhaar JA. Vacuum-assisted wound closure of deep infections after instrumented spinal fusion in six children with neuromuscular scoliosis. *Spine J* 2007; **7**(5)**:** 596-600.

30. Vicario C, de Juan J, Esclarin A, Alcobendas M. Treatment of deep wound infections after spinal fusion with a vacuum-assisted device in patients with spinal cord injury. *Acta Orthop Belg* 2007; **73**(1)**:** 102-6.

31. Hwang JH, Modi HN, Suh SW, Hong JY, Yang JH, Park JH. Maggot debridement therapy for postsurgical wound infection in scoliosis: a case series in five patients. *Spine (Phila Pa 1976)* 2011; **36**(4)**:** 313-9.

32. Mandal A, Addison P, Steward K, Neligan P. Vacuum-assisted closure therapy in pyoderma gangrenosum *European Journal of Plastic Surgery* 2006; **28**(8)**:** 529-31.

33. Masden D, Goldstein J, Endara M, Xu K, Steinberg J, Attinger C. Negative pressure wound therpy for at-risk surgical closures in patients with multiple comorbidities. *Ann Surg* 2012; **255**(6):1043-7.

34. Stannard JP, Volgas DA, McGwin G, Stewart RL, Obremskey W, Moore T, Anglen JO. Incisional negative pressure wound therapy after high-risk lower extremity fractures. *J Orthop Trauma* 2012; **26**(1):37-42.

35. Dorafshar AH, Franczyk M, Gottlieb LJ, Wroblewski KE, Lohman RF. A propsective randomized trial comparing subatmospheric wound therapy with a sealed gauze dressing and the standard vacuum-assisted closure device. *Ann Plast Surg* 2012; **69**(1):79-84.

36. Howell RD, Hadley S, Strauss E, Pelham FR. Blister formation with negative pressure dressings after total knee arthroplasty. *Curr Orthop Pract* 2011; **22**(2):176-9.

37. Pachowsky M, Gusinde J, Klein A, Lehrl S, Schulz-Drost S, Schlechtweg P, Pauser J, Gelse K, Brem MH. Negative pressure wound therapy to prevent seromas and treat surgical site incisions after total hip arthroplasty. *Int Orthop* 2012; **36**(4):719-22.

38. Stannard JP, Robinson JT, Anderson ER, McGwin G, Jr., Volgas DA, Alonso JE. Negative pressure wound therapy to treat hematomas and surgical incisions following high-energy trauma. *J Trauma* 2006; **60**(6)**:** 1301-6.

39. Baharestani M, Amjad I, Bookout K, Fleck T, Gabriel A, Kaufman D *et al.* V.A.C. Therapy in the management of paediatric wounds: clinical review and experience. *Int Wound J* 2009; **6 Suppl 1:** 1-26.

40. Morykwas MJ, Faler BJ, Pearce DJ, Argenta LC. Effects of varying levels of subatmospheric pressure on the rate of granulation tissue formation in experimental wounds in swine. *Ann Plast Surg* 2001; **47**(5)**:** 547-51.

41. McCord SS, Naik-Mathuria BJ, Murphy KM, McLane KM, Gay AN, Bob Basu C *et al.* Negative pressure therapy is effective to manage a variety of wounds in infants and children. *Wound Repair Regen* 2007; **15**(3)**:** 296-301.

42. Contractor D, Amling J, Brandoli C, Tosi LL. Negative pressure wound therapy with reticulated open cell foam in children: an overview. *J Orthop Trauma* 2008; **22**(10 Suppl)**:** S167-76.

43. Smith and Nephew. Pressure Wound Therapy Clinical Guidelines, 2008.

44. KCI. V.A.C. Therapy Clinical Guidelines, 2004.

45. Mouës CM, van den Bemd GJ, Meerding WJ, SE. H. An economic evaluation of the use of NPWT on full-thickness wounds. *J Wound Care.* 2005; **14**(5)**:** 224-7.

46. Flack S, Apelqvist J, Keith M, Trueman P, D. W. An economic evaluation of VAC therapy compared with wound dressings in the treatment of diabetic foot ulcers. *J Wound Care.* 2008; **17** (2)**:** 71-8.

47. Bollero D DV, Glat P, Gupta S, Lázaro-Martínez J L, Lyder C, Ottonello M, Pelham F, Vig S, Woo The role of negative pressure wound therapy in the spectrum of wound healing In, 2010.

48. Searle R, Milne J. Tools to compare the cost of NPWT with advanced wound care: an aid to clinical decision-making. *Wounds UK* 2010; **6**(1)**:** 106-9.

49. Bookout K, McCord S, McLane K. Case studies of an infant, a toddler, and an adolescent treated with a negative pressure wound treatment system. *J Wound Ostomy Continence Nurs* 2004; **31**(4)**:** 184-92.

50. Mooney JF, 3rd, Argenta LC, Marks MW, Morykwas MJ, DeFranzo AJ. Treatment of soft tissue defects in pediatric patients using the V.A.C. system. *Clin Orthop Relat Res* 2000; **376:** 26-31.

51. Guy H, Grothier L. Using negative pressure theraoy in wound healing. *Nursing Times* 2012; **108**(36): 16-20.

52. Ford-Dunn S. Use of vacuum assisted closure therapy in the palliation of a malignant wound. *Palliat Med* 2006; **20**(4)**:** 477-8.

53. Webb L. New techniques in wound management: vacuum-assisted wound closure. *J Am Acad Orthop Surg.* 2002; **10**(5)**:** 303-11.

54. Kloth L. *Adjunctive interventions for wound healing*, 3rd edn FA Davis: Philadelphia, PA, 2001.

55. Agency for Healthcare Research and Quality. Negative pressure wound therapy devices: Technology Assessment Report, 2009.

1

2 Table 1. Characteristics of included studies:

Author	Study Design	Type of surgery	No of cases	Characteristics	Main Outcomes
Adams and Hakim, 2009 [28]	Case study	Post-lumbar spine surgery for malignant desmoplastic melanoma	1	**Mean age**: 58 **Gender**: 1 female **Management**: Not reported **Time to complete healing**: 16 weeks **Medication**: Not reported **Contraindications:** Not reported **Evaluation**: Not reported **Main bacteria types**: Not reported **Hospitalisation**: Not reported	NPWT[i] proved effective in preparing the wound for successful graft application and also in ensuring post graft stabilisation.
Antony et al, 2004 [23]	Retrospective study	Spinal wound (no further details given)	16	**Mean age**: 59 **Gender**: 11 females, 5 males **Management**: NPWT 27.6 days; operative and no-operative debridement until healthy bleeding and/or bone revealed; pulse lavage irrigation in	NPWT in combination with antimicrobial therapy and surgical debridement should be standard management in the treatment of difficult to heal

				some patients. **Time to complete healing**: 8 weeks **Medication**: All had anti-microbial treatment, no details given. **Contraindications**: Not reported **Evaluation**: Every 2 to 3 days **Main bacteria types**: Staphylococcus, Enterococcus, Candida, Pseudomonas **Hospitalisation**: Not reported	wounds.
Canavese et al., 2009 [25]	Retrospective study	Spinal instrumentation and fusion (with subsequent deep infection).	16	**Mean age**: Not reported **Gender**: Not reported **Management**: NPWT applied average of 25.4 days (range 5-42 days); surgical debridement. **Time to complete healing**: Not reported **Medication**: All started with broad spectrum antibiotics until sensitivities were available; no further details given.	NPWT is a reliable and easy tool to use when dealing with patients with susceptible spinal wound infections.

				Contraindications: Not reported **Evaluation**: NPWT changed twice weekly. **Main bacteria types**: Not reported **Hospitalisation**: Not reported	
Canavese et al., 2008 [24]	Retrospective study	Instrumentation and fusion for spinal deformity (with subsequent deep infection)	14	**Mean age**: 13.4 (range 3-19 years) **Gender**: 10 females and 4 males **Management**: NPWT (21 (range 5-42) days); intra-operative debridement; thorough lavage and removal of macroscopic contamination, devitalized tissue and loose bone graft. **Time to complete healing**: All wounds healed but 2 required plastic surgery to increase healing time. **Medication**: All started with broad spectrum antibiotics until sensitivities were available, when treatment was changed to a more specific antibiotic; patients received IV[ii] and/or oral antibiotics for at least 6 weeks based on wound	NPWT is a reliable and easy to use tool when dealing with patients with susceptible spinal wound infections.

				culture results, and maintained on antibiotics for the length of time the wound was open. Mean time for IV antibiotics was 6 weeks (range 1-12); followed by oral antibiotics for mean of 6 months (4 weeks-12 months). **Contraindications**: Not reported. **Evaluation**: Regular review, mean NPWT change 3.4 (range 1-10). **Main bacteria types**: Staphylococcus, Escherichia coli, Pseudomonas, Streptococcus, Enterobacter **Hospitalisation**: Not reported	
Horn et al., 2007 [26]	Retrospective study	Posterior spinal fusion (paediatric spinal surgery).	11	**Mean age**: 13.3 (range 7-19) years **Gender**: 5 females, 6 males **Management**: NPWT (125 mm Hg) (4-186 days); multiple incision and debridements, followed by NPWT.	Wound closure in all cases that used NPWT.

				Time to complete healing: Not reported. **Medication**: Antibiotics and antifungal were used depending on the organism. **Contraindications:** Not reported. **Evaluation**: Dressing changed 2-3 times per week. **Main bacteria types**: Staphylococcus and MRSA[iii]. **Hospitalisation**: Not reported	
Hwang et al. 2011 [31]	Case study	Posterior-only pedicle screw fixation and posterior fusion for correction of scoliosis	5	**Mean age**: range 17-32 years **Gender**: 2 females, 3 males **Management**: NPWT 4.8 ± 2.3 weeks (14-56 days); repeat debridement with NPWT as adjunct therapy. **Time to complete healing**: Scar healing (range 6-16 months). Average reduction in scar size 13.8 cm but note that this is probably not due to	NPWT with maggot debridement therapy for treatment of wound after scoliosis surgery as an alternative to conventional treatment.

				NPWT alone. **Medication**: Range of antibiotics and antifungal were used. **Contraindications:** Not reported. **Evaluation**: Not reported directly, but maggot debridement therapy was used for two 48-72 hour cycles per week, with NPWT in between. **Main bacteria types**: Pseudomonas, Acinetobacter, and MRSA. **Hospitalisation**: Not reported; but total duration of therapy reported as being 10 ± 4.3 months.	
Jones et al., 2007 [3]	Retrospective study	Variety of spinal surgical procedures (with subsequent deep infection)	14	**Mean age**: 50 (range 14-76) years. **Gender**: 7 females, 7 males **Management**: NPWT (125 mmHg); multiple operative debridements and irrigated with 2 L of bacitracin-containing saline; one patient also treated with polymethylmethacrylate beads.	Serious complications are associated with NPWT to patient with spinal injuries. Risk should be addressed in the pre-operation discussions with patients.

				Time to complete healing: 90 days post removal of NPWT. **Medication**: All received antibiotics in line with microbiological results. **Contraindications**: NPWT should not be used in presence of active cerebrospinal fluid leak. NPWT should be used with caution in patient with bleeding diathesis and allergy. **Evaluation**: NPWT changed every 48 to 72 hours. **Main bacteria types**: Staphylococcus, Candida, Pseudomonas **Hospitalisation**: Average 22 days.	
Labler et al., 2006 [4]	Retrospective study	Dorsal spinal surgery for stabilization of traumatic and	15	**Mean age**: 48 (range 18-75) years **Gender**: 11 females, 4 males. **Management**: NPWT in situ 3-64 days; meticulous operative debridement and copious	NPWT as a valuable alternative for spinal wound management.

		pathological fractures; decompression of spinal stenosis or stabilization for spondylolisthesis in degenerative disease.		irrigation. **Time to complete healing**: 6-64 days. 1 case – 169 days. **Medication**: Antibiotics for all patients. **Contraindications**: Not reported **Evaluation**: NPWT changed after 3 (range 1-7) days. **Main bacteria types**: Staphylococcus, Clostridium, Enterococcus, Escherichia coli, Enterobacter, Pseudomonas **Hospitalisation**: (16-118) 43 days	
Mehbod et al., 2005 [5]	Retrospective study	Combined anterior-posterior fusion; posterior fusion; transforaminal lumbar interbody	20	**Mean age**: 55 (31-81) years **Gender**: 8 females, 12 male. **Management**: Irrigation and debridement and NPWT. Mean 1.8 irrigation and debridement prior NPWT placement. **Time to complete healing**: Average 7 days	NPWT devices can be an effective adjunct in closing complex deep spinal wounds. NPWT may decrease the number of repeat debridement.

		fusion (with subsequent deep infection).		(range 5-14). All wounds healed at the end of 6 months. **Medication**: 6 weeks course of IV antibiotics. **Contraindications:** Not reported. **Evaluation**: Not reported. **Main bacteria types**: MRSA, Escherichia coli, Pseudomonas, Eenterococci, Staphylococcus, Streptococcus **Hospitalisation**: Not reported.	
Ploumis et al., 2008 [19]	Retrospective study	Surgery for degenerative disease and spinal tumors.	73	**Mean age**: 58.4 (range 21-82). **Gender**: 39 females, 34 males **Management**: Operative debridement and irrigation prior to NPWT. **Time to complete healing**: Wound close 7 days (range 3-14) days. All but 2 healed and closed by 12 months follow up. **Medication**: Vancomycin commenced	NPWT may be effective adjunct therapy in closing spinal wound even after repeat procedures.

				immediately followed up by antibiotics to which microbes were sensitive to for 6 weeks. **Contraindications:** Not reported. **Evaluation**: Return 3-5 days for **evaluation**. **Main bacteria types**: MRSA, Enterococci, Streptococci, Staphylococcus, Pseudomonas, Escherichia coli. **Hospitalisation**: Up to 14 days.	
Van Rhee et al., 2007 [29]	Prospective case series	Posterior fusion for scoliosis.	6	**Mean age**: 12.6 (6-16) years **Gender**: 3 females, 3 males, **Management**: NPWT 125 mm Hg. Surgical debridement performed once deep wound cultures had been taken. **Time to complete healing**: Wound closure average 3 (range 2-4) months. **Medication**: All received prophylaxis 1500 mg Cefuroxim parenteral 3 time per day from start of	NPWT with antibiotic therapy seemed to be is a good solution for treatment of deep wound infections after spinal fusion.

				the operation until the third postoperative day. Parenteral antibiotic treatment for 6 weeks continues with oral antibiotics. For at least 2 months. **Contraindications:** Not reported. **Evaluation**: NPWT changed 3 times per week. **Main bacteria types**: Staphylococcus, MRSA, Enterobacter **Hospitalisation**: Not reported.	
Vicario et al., 2007 [30]	Case study	Posterior fusion for spinal cord injury.	2	**Mean age**: 21 (18 and 24) years **Gender**: 2 males **Management**: Irrigation and debridement, NPWT in situ average 7 (range 5-14) days. **Time to complete healing**: Wound healed and sutures removed 12 and 14 days post-operation. **Medication**: IV antibiotics **Contraindications:** Not reported	NPWT excellent option in the treatment of deep wound infections after spinal surgery.

				Evaluation: NPWT sponge changed 3 times per week. **Main bacteria types**: Staphylococcus, Escherichia coli **Hospitalisation**: Not reported.	
Yuan-Innes et al., 2000 [12]	Case study	Instrumentation and fusion.	2	**Mean age**: 13.5 (10 and 17) years. **Gender**: 2 females. **Management**: Case 1: irrigation and debridement with IV antibiotics. NPWT. Case 2: Outpatient NPWT. **Time to complete healing**: Case 1+2: healed wound after 6 weeks. Wound stable at 6 and 10 months. **Medication**: Case 1: high dose corticosteroid, antibiotic impregnated bead at irrigation and debridement. Further IV antibiotics. Case 2- not reported.	The usefulness of NPWT as adjunct in closing complex spinal wounds with exposed spinal hardware.

				Contraindications: Tissue biopsy to rule out Marjolin ulcer prior to NPWT. NPWT not applied to Metastatic disease and osteo myelitis. **Evaluation**: Not reported. **Main bacteria types**: Staphylococcus, Pseudomonas **Hospitalisation**: Not reported.	
Zehnder & Place, 2007 [27]	Retrospective study	Instrumented posterior spinal surgery (with post-operative wound complication).	11	**Mean age**: 58.7 (range 40-75) **Gender**: 6 females,5 males **Management**: NPWT commenced between 1st and 3rd irrigation of wound and antibiotics. Mean date of NPWT and debridement = 3.8 days **Time to complete healing**: 31.5 (range 9-57) days. **Medication**: Antibiotic treatment depending on microbes. Remain on antibiotic until wound healed.	NPWT may be adjunct to help reduce spinal wound complications. NPWT reduces the frequency for surgical debridements and improves overall patient care.

				Contraindications: Allergy to dressing. NPWT not applied to active neoplasia in the wound bed. **Evaluation**: NPWT change every 2-3 days. **Main bacteria types**: Staphyloccus, MRSA, Escherichia coli, Pseudomanses **Hospitalisation**: Not reported.	

1

2

3

4

[i] Negative pressure wound therapy

[ii] IV - Intravenous

[iii] MRSA – Methicillin-resistant Staphylococcus aureus