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Risk factors, prevention and management of wound blistering: A scoping review

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ABSTRACT:*Background:*

Blistering to the skin causes pain and increased risk of infection, and impacts an individual's physical and psychological health, while increasing the burden on clinicians and healthcare systems. Blistering is recognised as a significant problem associated with surgical wounds, particularly following orthopaedic surgery, and specifically following hip and knee surgery. Healthcare professionals must adopt approaches to prevent and effectively treat blistering to optimise care and promote recovery.

Objectives:

- To identify risk factors for causation of wound blisters
- To identify the ideal dressing to prevent wound blisters
- To explore how to prevent wound blisters.

Design:

Scoping review.

Methods:

Searches were conducted in Medline, British Nursing Index (BNI), CINAHL (Cumulative Index to Nursing and Allied Health Literature) Embase and Google Scholar, without date limits.

Results:

Of the 177 papers located, 29 met the inclusion criteria and were included in the review.

Conclusions:

There is a significant lack of research exploring risk factors that can lead to skin blistering. The research available is outdated and unclear, with a lack of consistency. Large-scale empirical international studies are needed to enable standardised guidance across all healthcare settings. Additionally, there is a need for healthcare professionals to work collaboratively to prevent skin blistering and manage wounds effectively.

What is already known

- Skin blistering occurs when the epidermis of the skin is separated from the dermis
- A range of causes of wound blisters exist, including diseases, infections, burns, ischaemia, dermatitis, fluid accumulation and trauma (e.g. surgical procedures).
- Skin blistering is a significant problem in orthopaedic surgery, specifically post-operative hip and knee joint procedures
- The rise in the ageing population is likely to result in an increase in the number of patients requiring orthopaedic surgery.

What this paper adds:

- The type of dressing applied following a surgical procedure can reduce or increase the risk of skin blistering
- The clinical skill of the healthcare professional during dressing application plays a critical role in mitigating the risk of blister formation

- This review identified the need for international large-scale randomised controlled trials (RCTs) on skin blistering, specifically comparing types of dressings, cost, frequency of dressing changes, skills of the healthcare professional and length of hospital stay/recovery
- Other factors also need to be considered in terms of the patient's health status and other risk factors such as comorbidities, age, frailty, body mass index (BMI) and mobility, and surgical variables such as operation time and technique
- Healthcare professionals require education and clear guidance on wound management, specifically in post-operative patients
- Clear guidelines are required to reduce risks of blistering and optimise patient care in the most efficient, cost-effective way to ensure consistency of care and standardisation of treatment.

Background

In a seminal publication on blistering, Bork (1978) outlined three phases of blister formation on the skin, which can occur consecutively or simultaneously:

1. *The phase of a loosening of the structure, i.e. a diminished cohesion of epidermal cells or a decreased adhesion of epidermis to the corneum*
2. *The phase of discontinuity, of cleft formation between the kerinocytes or in the different levels of the junction zone*
3. *The phase of fluid accumulation.”*

In a more recent publication, the National Library of Medicine (NLM) defined blisters as ‘visible accumulations of fluid within or beneath the epidermis’ (NLM, 2024). There are numerous causes of blistering of the skin, including: a broad spectrum of diseases; the result of a bacterial or viral infection, such as herpes or impetigo; local injury to the skin, such as burns, ischaemia and dermatitis (Diaz and Giudice, 2000). Diaz and Giudice (2000) describe how, in some diseases, blistering can occur as a primary event, with tissue injury and fluid accumulation within a layer of the skin (intraepidermal, derma-epidermal junction, or subepidermal) and can be due to a genetic mutation or an autoimmune response.

Skin blistering occurs when the epidermis is separated from the dermis, due to friction on the skin. The development of blisters resulting from soft tissue injury following trauma is recognised as a significant aspect of surgical care and can often occur in areas of the body with limited tissue coverage, such as the ankle and knee (Hoover and Siefert, 2000). Tosoundis et al (2020) describe how significant tissue trauma results in fracture blisters, which present between 6 and 72 hours post-injury, typically overlying the fracture site, causing delays to fracture treatment and an increased risk of post-operative wound complications.

Considering the global ageing population, it is anticipated that surgical procedures including joint replacements and spinal surgery will continue to rise. The post-operative risk of wound blistering can lead to delayed healing, increased pain levels and risk of infection to wound sites due to compromised skin integrity (Bredow et al, 2015). Skin blistering is a common problem within orthopaedics, where dressings are applied for prolonged periods of time over a joint, with friction between the skin and dressing causing a shear force (Ravenscroft et al, 2006). Other factors can also contribute to blistering, such as skin changes in older patients, tissue oedema following surgery, the type of dressing used and how it is applied. The formation of a blister removes the barrier or protection of the skin against infection; consequently, a wound blister can result in a superficial infection, which can lead to an infected prosthetic joint (Jester et al, 2000; Gupta et al, 2002).

Fast Track Protocols (Rapid Recovery protocols) have been widely implemented in total hip (THR) and total knee replacement (TKR) surgery. Early mobilisation of the patient is one of the major goals of these protocols; however, the combination of the use of a standard dressing with early mobilisation may increase the risk of skin complications such as irritation and blisters (Eastburn et al. 2016).

Methods

This scoping review was undertaken in accordance with the Manual for Evidence Synthesis (Peters et al, 2020) by the Joanna Briggs Institute (JBI, 2025). The PCC strategy (population, concept, context) was used to refine the research question:

P=adults

C=cause/prevention of skin blisters

C=use of dressings.

The research question was ‘What evidence is available on the factors causing/preventing skin blisters and the use of dressings for effective wound management?’.

A three-step search strategy was employed:

1. The searches were performed in February 2025 using the databases BNI, CINAHL, Embase and Google Scholar. All study types and methods, including grey (i.e. unpublished) literature, published in all languages without time restrictions, were included.
2. All titles, abstracts and index terms were then analysed for key words to ensure the relevance of each publication.
3. The reference list of each publication was assessed to identify further relevant articles/publications (JBI, 2025).

Key words and data extraction

The key words used for the search were: ‘wound blistering’; ‘blister formation’; ‘blister pathophysiology’; ‘friction blisters’; ‘post-surgical wound blisters’; ‘wound blister complications’; ‘negative pressure wound therapy (NPWT), Closed Incision negative pressure wound therapy (ciNPWT) and wound dressings’; ‘acrylic versus silicone dressings’.

Data extraction was achieved in line with the Joanna Briggs Institute template, composed of the following details: authorship; year of publication; country of publication; objectives; population and sample; method; results and findings related to blisters and the use of dressings for effective skin management.

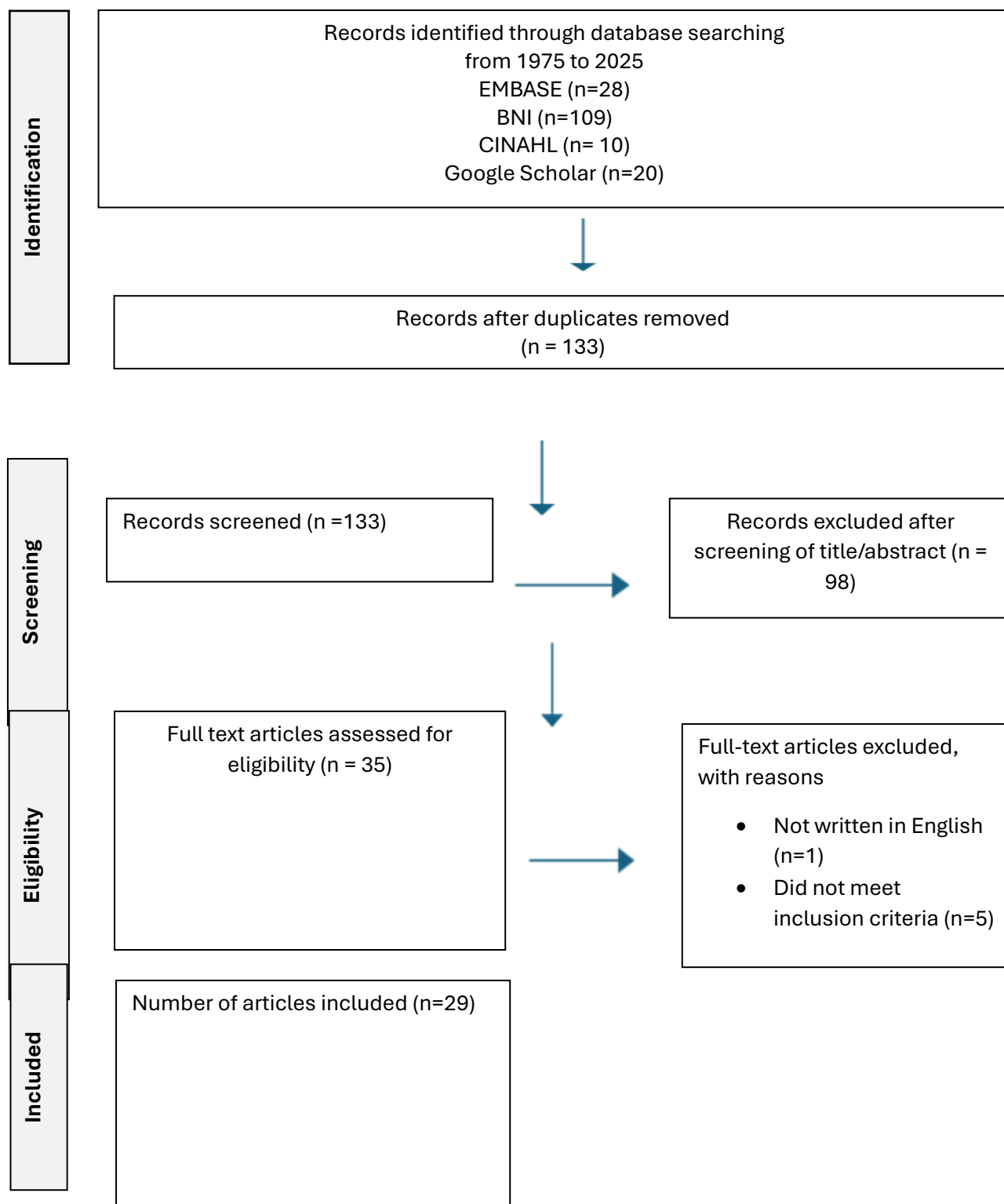


Figure 1: PRISMA flow diagram illustrating the literature review, which resulted in 29 relevant papers.

Results

Of the 167 results identified in the initial searches, a final sample of 29 met the inclusion criteria (**Figure 1**). A summary of each publication included in the review is provided (**Table 1**). The number of publications pertaining to skin blistering is scarce and what is

available is outdated. The three main themes emerging from the available evidence were:

1. Use of negative pressure wound therapy (NPWT) and closed-incision negative pressure wound therapy (ciNPWT)
2. Types of dressings
3. Responsibilities of healthcare professionals.

The majority of studies identified were based on hip and knee post-surgical patients; several reported on obstetric patients, one was trauma and one general surgical patients.

Table 1: The factors causing/preventing skin blisters and the use of dressings for effective wound management			
Study	Country	Methods	Results
Hahn et al. (1999)	USA	Comparative study to determine wound complications following hip surgery in patients treated with compressive spica wrap versus those with traditional taping methods.	Significantly lower incidence of blisters and drainage was found in the group using a compressive wrap, with no higher incidence of DVT or infection with the wrap. The authors recommend using a compressive wrap to reduce wound complications.
Jester et al. (2000)	UK	Quasi-experimental design to investigate prevalence of wound blistering in 169 patients following primary total hip and knee replacement.	13% developed blisters. Only 8 out of 88 patients with Opsite Post-Op developed blisters compared with 4 out of 28 patients with Mepore. This supports previous findings that lack of elasticity of dressings coupled with wound oedema contributes to blistering.
Lawrentschuk et al. (2002)	Australia	RCT to compare the rate of wound blisters with two commonly used dressings: non-adherent absorbable (NAA) and paraffin tulle gras (PGT) in 50 patients following hip surgery.	A significant difference was observed in the NAA group, with 64% developing blisters compared to only 8% in the PGT group. This suggests that PGT produces fewer wound blisters following hip surgery than NAA dressings.
Gupta S et al. (2002)	UK	Practitioners on an orthopaedic ward used three different types of dressing on two groups of 100 patients who had undergone hip or knee operations, and compared the number of blisters that resulted.	In the first group of 100 patients, the incidence of blistering was 39% (Microdon), 21.7% (Mepore) and 0% (spirit-soaked gauze held with Mefix). In the second group, the incidence was 17.2%, 18.1% and 0% respectively.
Cosker et al. (2005)	UK	RCT to compare three dressings (Primapore; Tegaderm with pad; OpSite Post-Op) across a sample of 300 post-surgical	Dressings employing a clear film and with a high vapour transmission rate reduced the rate of blistering and wound discharge. These dressings may be cost-effective due to reduced dressing changes and earlier

		patients. Total knee replacements; total hip replacements; hip hemi-arthroplasty; dynamic hip screw; tibial nailing; femoral nailing.	discharges. Most blistering occurred between 5 and 6 days post-operatively; there was a significantly lower incidence in blistering with the application of OpSite, despite the patients being older with friable skin. This could be due to the elasticity of OpSite. Lack of elasticity in dressings has been found to increase the risk of blistering (Blaylock et al, 1995).
Abuzakuk et al. (2006)	UK	Randomised controlled trial (RCT) comparing a hydrofibre (Aquacel) and central pad (Mepore) dressing in the management of wounds following total hip or knee arthroplasty.	Out of 61 patients, there was a significant reduction in the requirement for dressing changes before 5 days in the hydrofibre group (43% compared to 77%) and fewer blisters in the hydrofibre group (13% compared to 26%). The authors concluded there is a potential role for hydrofibre dressings in the management of arthroplasty wounds.
Ravenscroft et al. (2006)	UK	Prospective RCT comparing Aquacel and Tegaderm dressings with Cutiplast on a sample of 183 patients following hip and knee surgery.	The Aquacel and Tegaderm dressings were 5.8 times more likely to result in a wound without complications compared with Cutiplast. 22.5% of patients with Cutiplast developed blisters, compared with only 2.4% of patients with Aquacel and Tegaderm, making Aquacel and Tegaderm the preferred dressings following hip and knee surgery.
Leal and Kirby (2008)	UK	RCT to compare traditional dressings (Mepore) with OpSite Post-Op dressings. The sample consisted of 67 women post-hysterectomy.	No blisters formed in the sample treated with Opsite dressings, compared to 8 in the group treated with Mepore dressings, who developed blistering to the skin.
Tustanowski (2009)	UK	Literature review on dressing choice and outcomes after hip and knee arthroplasty.	This paper calls for a collaborative approach and more large-scale RCTs on the effectiveness of dressings, highlighting that wound management commences in theatre.
Collins (2010)	UK	Literature review to determine how post-operative dressings	No single treatment was preferred; a range of dressings were recommended to reduce the risk of blistering post-operatively.

		affect wound healing after hip/knee arthroplasty.	
Howell et al. (2011)	USA	RCT to compare the number of days to a dry wound after TKA with application of a negative pressure dressing compared with sterile gauze dressing in 51 patients undergoing 60 TKA surgeries (9 bilateral).	There were two post-operative infections, one in each arm of the study. The study was stopped prematurely when 15 of 24 knees (63%) treated with the negative pressure wound dressing developed skin blisters.
Ousey et al. (2011)	UK	Discussion paper on skin blistering and how to prevent it.	The authors recommend that wound dressings should provide a warm, moist healing environment that does not damage the peri-wound area, which can lead to blistering. Protection of the peri-wound area is essential and can be achieved through choosing a dressing that does not adhere to the surrounding skin, and is flexible, easy to apply and remove.
Sanusi (2011)	UK	Report on the first case of laparoscopic cholecystectomy wound traction blistering and ways to avoid it.	The method of application of the wound dressing caused traction blistering, which was an avoidable complication. This emphasises the importance of the skills of the practitioner applying the dressing, to avoid stretching the dressing, which can result in disruption to the skin structure.
Siddique et al (2011)	UK	Literature review and cross-sectional study to evaluate the effectiveness of hydrocolloid dressings for post-operative hip and knee wounds and to determine the prevalence of SSI and blister formation.	Hydrocolloid dressings (Duoderm) were found to help to prevent SSIs and blister formation in patients undergoing lower limb orthopaedic surgery.
Ousey et al. (2012)	UK	Two-stage delphi study to establish the most effective	13 international panel members suggested that the wound dressing should conform easily to the wound and be easy to apply and remove, while allowing for

		wound management to prevent skin blistering.	swelling and minimising pain. The primary dressing should remain in place for as long as possible, providing there was no leakage or signs of infection.
Ousey et al. (2013)	UK	Systematic review exploring physical and psychological morbidity and patient/family resilience following acute wound development and blistering post-orthopaedic surgery.	No papers focused on resilience in post-surgical orthopaedic wounds. Four papers discussed quality of life outcomes and how they could be improved; the majority of papers focused on the management of chronic wounds.
Bredow et al. (2015)	Germany	RCT in one hospital to compare the risks of post-operative blistering and wound infections within the first 6 days post-surgery associated with three types of dressings.	Three types of dressings were compared across a sample of 150 patients following hip surgery (Mepore Pro; Mepilex Border and Hypafix Transparent) for the occurrence of tape blisters. Blister prevalence was significantly lower for the Mepilex Border group (3%) than for the Mepore Pro group (59%) and Hypafix group (61%). The time between surgery, blister re-occurrence and the number of dressings used was also significantly lower for the Mepilex Border group. Therefore, the dressing with a silicone adhesive (Mepilex Border) significantly reduced the prevalence of blistering following hip surgery.
Heller et al. (2015)	USA	Prospective study on 135 patients undergoing primary total knee arthroplasty, with the tourniquet released immediately after wound closure in theatre. This sample was compared with 200 patients where the tourniquet was released after application of the dressing.	There was a significant difference in the incidence of blisters between the two groups: 7.5% vs early release 2.2%. Releasing the tourniquet prior to dressing application reduced the incidence of blistering following TKA.

Willey et al. (2016)	Germany	Literature review (2000-2016) to identify risk factors for SSIs	The most common risk factors include obesity, diabetes mellitus, tobacco use and prolonged surgical time. This paper recommends surgeons assess the risks of SSI alongside risk of morbidity, and to consider the use of ciNPWT for patients with one or more comorbidity.
Eastburn et al. (2016)	UK	Literature review of blistering due to wound dressings and the impact on post-operative rehabilitation and discharge.	Blisters were found to be common in patients post-operatively, due to the patient's pathology and types of dressings used. Blisters caused pain, risk of infection, risk of deep vein thrombosis (DVT) and delayed discharge. Physiotherapists must work with other clinicians to promote rehabilitation and prevent blistering.
Manoharan et al. (2016)	Australia	Prospective analysis of 33 patients undergoing knee arthroplasty. 12 patients had conventional dry dressings (CDD) applied, 21 patients had either CDD or NPWT.	There was no benefit in wound healing or cost associated with NPWT post-arthroplasty. There was some benefit to quality-of-life factors with NPWT, such as reduced leakage and better protection.
Ruhstaller K et al. (2017)		RCT to evaluate the prophylactic use of NPWT to prevent wound complications in obese women following caesarean section	Although there was no statistically significant difference, four times as many women who received the NPWT system had a skin blister after removal of the device compared with standard wound care (13.1 % NPWT vs 3.6% standard wound care, p=0.10).
Gianni et al. (2018)	Italy	RCT to compare the effectiveness of NPWT with a standard dressing in patients following hip or knee revision surgery (110 patients in one hospital).	The results do not support the use of NPWT after hip and knee revision, although it would be beneficial for selected patients with specific risk factors.
Lumbers et al. (2018)		Discussion paper on the selection of appropriate post-	Appropriate dressings were found to promote wound healing by providing a moist environment and reducing the

		operative dressings to promote healing and reduce SSIs.	risk of infection and blistering. The authors recommended that practitioners need to manage wounds effectively by considering the wound location, method of closure, exudate levels and dressing wear time when selecting a product.
Cole et al. (2020)		RCT to compare incidence of blistering between post-operative dressings (92 patients) against those with a barrier film underneath the dressing (93 patients).	15% of spine surgery patients developed erythema, soreness or blistering post-operatively on the skin underneath the border of the adhesive dressing. Further research is needed to determine the potential causes of dressing-related skin blisters post-operatively. There was no difference between either group.
Ailaney et al. (2021)	USA	Meta-analysis of level I studies to determine the effect of closed incision negative pressure wound therapy (ciNPWT) on the risk of surgical site infections (SSIs) and wound complications following a total joint arthroplasty (TJA).	ciNPWT decreased SSI risk and hospital stay compared to standard dressings but increased non-infectious wound complications (blisters, seroma, haematoma, persistent drainage and wound edge necrosis). ciNPWT was associated with a greater than 12-fold increased risk of wound blistering after primary total knee arthroscopy. Further RCTs are needed to draw conclusions regarding ciNPWT after primary total joint arthroscopy.
Doman et al. (2021)	USA	RCT to compare wound complications in 130 patients post-knee arthroscopy to compare the use of ciNPWT with an occlusive silver-impregnated dressing.	The ciNPWT group had fewer incisional wound complications (6.9% vs 16.2%) but significantly more non-incisional wound complications (16.9% vs 1.5%). Among high-risk patients undergoing TKA, ciNPWT decreased incisional wound complications; although an increase in dressing reactions was evident were noted the clinical impact was minimal.
Feng-Chih et al. (2021)	Taiwan	Meta-analysis to compare wound dressings after hip/knee joint arthroplasty	An antimicrobial dressing is optimal to prevent joint infection. If NPWT therapy is used, surgeons must be aware of the increased incidence of blister formation. Further studies are needed to focus on alginate versus

			hydrofibre and hydrocolloid dressings to determine optimal dressing to reduce blisters.
Zhang et al. (2021)	China	RCT to compare the occurrence of blisters in 53 patients using a traditional method of NPWT application with a modified NPWT dressing technique. In the modified group, the dressing was trimmed before application.	There were 9 linear blister formations in the conventional group and 1 linear blister formation in the novel group. The modified technique decreased the incidence of linear blister formation from 27.3% to 3.7%. The infection rate was higher in the conventional group at 30.3% compared with the novel group 18.5%. The average hospital stay was shorter in the novel group (6-19 days) compared with the conventional group (5-23 days).

Discussion

NPWT and ciNPWT

NPWT was first described by Fleischmann et al (1995), as a controllable negative pressure and constant drainage system resulting in successful surgical wound outcomes. Since then, it has been used to improve the healing of complex wounds, reducing both healing time and hospital stay (Liu et al, 2016). NPWT is used to accelerate the healing of both superficial and deep wounds through increasing blood flow and stimulating granulation, while reducing the level of bacteria and the factors preventing cell repair (Lambert et al, 2005). NPWT has also been found to reduce wound complications such as dehiscence, infection, haematoma and seroma (Huang et al, 2014). Liu et al (2018) reported that, upon treatment with NPWT, patients with an open fracture had a much lower infection rate, reduced wound recovery and healing time, reduced hospital stay and reduced amputation rate when compared with those treated without NPWT.

ciNPWT is a type of NPWT developed specifically for covering and promoting the healing of closed incisions and has been shown to reduce oedema and improve blood flow, resulting in reduced surgical site infections (SSIs) and improved overall outcomes when employed for appropriate patients (Ozkan et al, 2020). Both traditional and single-use NPWT systems can be employed for ciNPWT (Banasiewicz et al, 2019).

Despite the significant benefits of NPWT, Howell et al (2011) described how NPWT resulted in the formation of linear blisters (LBs) along the sides of dressings, reporting an LB formation rate of 63% in an NPWT test group, with patients following TKA compared with wounds treated with a sterile gauze dressing. The size of the LBs was substantial, ranging from 1cm to 10cm in length. It was reported that blisters in the experimental group occurred on intact skin between the tape and polyurethane foam.

A further study to evaluate the outcome of NPWT following open fracture surgery (Suzuki et al. 2014) identified from a sample of 14 patients, four developed maceration of the skin under the foam and two developed skin blisters under the drape. There was no evidence of skin necrosis or infection. The authors concluded that NPWT had no negative effects on the wound or fracture healing. However, this finding supported previous evidence that one of the side effects of NPWT is skin blistering, which must be considered when managing wounds (Howell et al, 2011). Howell et al (2011) suggested that the LBs could be a result of friction on intact skin at the junction of the foam and the adhesive tape, but were unable to suggest a method to prevent blistering.

More recently, Zhang et al (2021) proposed a mechanism for LB formation (**Figure 2**), suggesting that mechanical and osmotic factors, such as injury or post-traumatic oedema, may compromise the dermal-epidermal junction at the injury site. This disruption creates a region of elevated permeability, facilitating fluid migration. The resulting pressure imbalance across the dermis contributes to further separation of the epidermis from the dermis, culminating in fluid accumulation and blister formation.

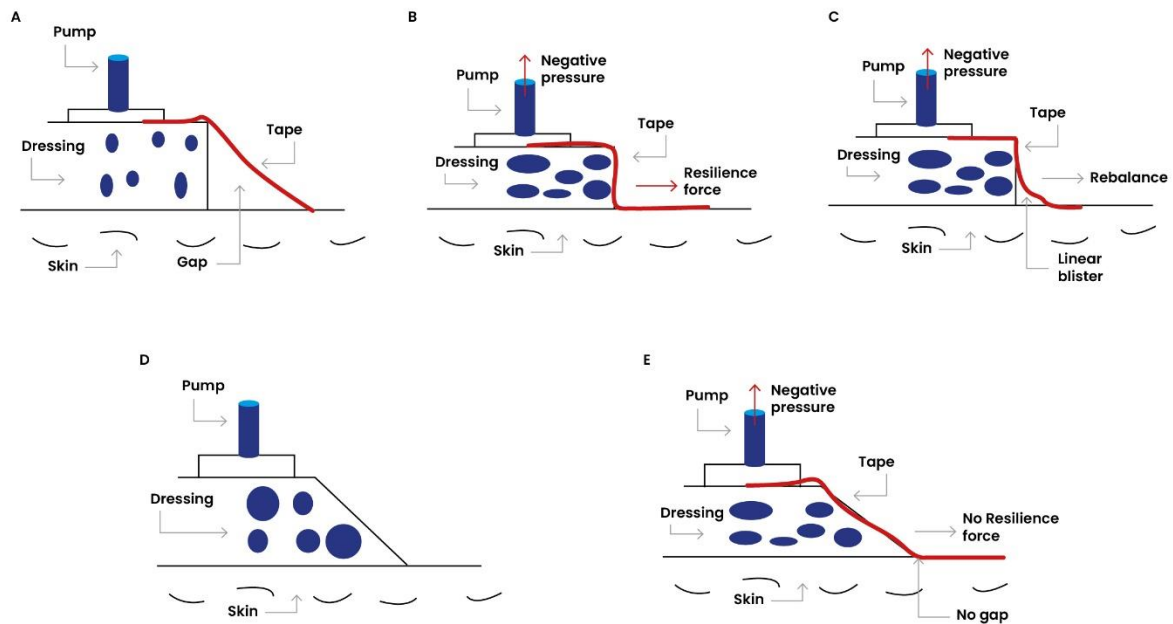


Figure 2: A suggested mechanism of LB formation with NPWT: **a)** before pump operation; **b)** during pump operation; **c)** after pump operation. Recommended modification of dressing structure to prevent LBs: **d)** before pump operation; **e)** after pump operation (adapted from Zhang et al, 2021).

Based on this proposed mechanism, Zhang et al (2021) hypothesised that LB formation occurs due to the gap between the tape and the skin at the edge of the dressing. In addition to exploring LB pathophysiology, Zhang et al. (2021) investigated preventative strategies through a RCT involving 53 patients with Gustilo type II and III open fractures managed with negative pressure wound therapy (NPWT), compared with a modified (trimmed) version of NPWT (**Figure 2d-e**). The findings revealed nine LB formations in the conventional group and one LB formation in the modified group. The infection rate was higher in the conventional group (30.3%) compared to the modified group (25.9%). The length of stay was also lower for patients in the modified group (6-19 days) compared with 5-23 days in the conventional group. These findings suggest that the adapted NPWT technique may effectively reduce LB formation and post-operative complications, while supporting faster recovery and discharge.

In an Australian RCT, Manoharan et al (2016) compared the use of NPWT versus conventional dressings in a sample of 33 patients undergoing TKA. The study aimed to assess the impact of NPWT following TKA on quality of life (QoL), wound complications and cost. Twelve patients had conventional dry dressings (CDD) and 21 patients with bilateral TKA had either side randomised, receiving NPWT or CDD. The findings demonstrated no post-TKA benefit in wound healing or cost, although there were some benefits reported with NPWT relating to QoL factors, such as reduced wound leakage.

From a tertiary care medical centre in the USA, Ruhstaller et al (2017) reported outcomes from an RCT evaluating prophylactic use of NPWT to prevent wound complications in obese women following caesarean section (c-section). The RCT included 480 women; of these, 136 (28%) underwent c-section and were randomised. A total of 69 and 67 women were randomised to standard wound care dressings and NPWT, respectively. Seventeen patients were lost to follow-up during the 4-week period, leaving 58 in the standard wound care dressing group and 61 in the NPWT group for analysis. Four times as many women who received the NPWT system had a skin blister after removal of the device compared with standard wound care (13.1% with NPWT versus 3.6% with standard wound care, respectively; $p=0.10$).

Further research on the effectiveness of NPWT and wound healing by Giannini et al (2018) in Italy compared the effectiveness of wound healing of NPWT with a standard dressing following hip and knee revision surgery in a sample of 110 patients. Although the study outcomes did not support the use of NPWT in all patients undergoing hip and knee prosthesis revisions, NPWT was shown to be beneficial for specific patients (i.e. those at risk of wound complications). In contrast to findings from previously discussed studies (Howell et al, 2011; Suzuki et al, 2014), blister occurrence was lower in the NPWT group (Giannini et al, 2018).

The effectiveness of ciNPWT has also been compared with an occlusive silver-impregnated dressing in a US RCT (Doman et al, 2021) across a sample of 130 post-TKA patients. The findings revealed that the ciNPWT group had fewer incisional wound complications (6.9% versus 16.2%) but significantly more non-incisional wound complications (16.9% versus 1.5%). Among high-risk patients undergoing TKA, ciNPWT reduced incisional wound complications, although an increase in dressing reactions were noted but the clinical impact was minimal.

A meta-analysis of level I studies aimed to determine the effects of ciNPWT on the risk of SSIs and wound complications following total joint arthroscopy (Ailaney et al, 2021). They concluded ciNPWT decreases SSI risk and length of hospital stay when compared to traditional standard dressings; however, use of ciNPWT did increase non-infectious wound complications such as blisters, seroma, haematoma, persistent drainage and wound edge necrosis. In terms of the risk of blistering, ciNPWT was associated with a greater than 12-fold increase of wound blistering post-TKA. No significant differences were detected in rates of overall wound complications, infection, seroma and length of hospital stay. The authors emphasised the need for additional randomised controlled trials to draw definitive conclusions about the use of closed-incision negative pressure wound therapy (ciNPWT) following primary total joint arthroplasty.

See Figure 3 for an illustration of the potential effect of ciNPWT.

Figure 3. Blistering 1 week post-ciNPWT (image courtesy of Sara Carvalhal)



In a literature review exploring risk factors for SSIs, Willey et al (2016) identified obesity, diabetes mellitus, tobacco use and prolonged surgical time as the most common risk factors, and called for surgeons to assess the risks of SSIs alongside other risks of morbidity. Willey et al (2016) recommend selected use of ciNWPT for patients with one or more comorbidity.

Dillon et al. (2007) investigated the mechanical demands of hip and knee surgery wounds by quantifying skin movement during joint flexion. The study compared the extensibility of four dressing types—a hydrocolloid, a traditional adhesive, and two occlusive film dressings—against the strain observed in TKR wounds. Results indicated that TKR wounds exhibited dynamic morphology with strain exceeding 20% during normal knee flexion. While the hydrocolloid and occlusive dressings demonstrated sufficient extensibility to accommodate this movement, the traditional adhesive dressing did not. The authors suggested this may explain the high blister rates with some dressings.

Types of dressings

Ousey et al (2011) recommend that wounds should provide a warm, moist healing environment that does not damage the peri-wound area and result in blistering. This discussion paper emphasises that protection of the peri-wound area is essential and can be achieved through choosing the correct dressing, which does not adhere to the surrounding skin and is flexible, while being easy to apply and remove. Various studies have compared different types of dressings to determine the incidence of blistering on post-operative wounds. A literature review by Collins (2010) to determine how post-operative dressings affect wound healing found that there was no preferred treatment,

and a range of dressings were recommended to reduce the risk of blistering. A further literature review and cross-sectional study (Siddique et al, 2011) evaluating the effectiveness of hydrocolloid dressings for post-operative hip and knee wounds found that hydrocolloid dressings (Duoderm) helped to prevent SSIs and blister formation in patients undergoing lower limb orthopaedic surgery.

In a two-phase study in the UK, Gupta et al (2002) evaluated the incidence of peri-wound blistering to determine whether there was any association with choice of wound dressing. Phase one evaluated three dressing types: Microdon, Mepore® and spirit-soaked gauze held with Mefix® applied to 100 patients following hip and total knee replacement or primary/revision total knee replacement. Of the 41 patients given Microdon dressings, 16 (39%) developed blisters. Five of the 23 patients (21.7%) given Mepore® developed blisters. None of the 16 patients given spirit-soaked gauze held with Mefix® developed blisters (Gupta et al, 2002). The authors assumed that blistering was caused by friction between the skin and dressing during joint movement. As a result, phase two was undertaken with staff being advised not to stretch the dressings pre-application. The same dressings were applied to a further 100 patients who had undergone hip operations and primary/revision total knee replacements. In phase two, Gupta et al (2002) reported 10 of the 58 patients (17.2%) given Mepore dressings and four of the 22 patients (18.2%) given Microdon developed blisters. Again, none of the 20 patients given spirit-soaked gauze with Mefix developed blisters. The authors concluded that not stretching Mefix or Mepore made no significant difference to the development of wound blistering; however, for Microdon, blistering was more than halved.

See Figures 4 and 5, demonstrating blistering following application of a Mepore-like dressing.

Figure 4. Blistering 1 week post-melanoma margin enlargement with a Mepore-like dressing (image courtesy of Sara Carvalhal)



Figure 5. Blistering 1 week post-sentinel node with a Mepore like dressing, with infection (image courtesy of Sara Carvalhal)



Abuzakuk et al (2006) undertook an RCT in the UK comparing a hydrofibre (Aquacel) dressing with a central pad (Mepore) following total hip arthroplasty (THA) or TKA. Among the 61 patients included in this study, there was a significant reduction in the requirement for dressing changes before 5 days in the hydrofibre group (43% versus 77% with central pad) and fewer blisters (13% versus 26% with central pad). This indicated a potential role for hydrofibre dressings in the management of arthroplasty wounds. In an RCT in Germany, Bredow et al (2015) compared the risks of post-operative blistering and wound infections across a sample of 150 patients. Comparisons were made with Mepore Pro, Mepilex Border and Hypafix transparent. Blistering was significantly lower with Mepilex Border (3%) than Mepore Pro (59%) and Hypafix (61%). The time between surgery, blister re-occurrence and the number of dressings used was also significantly lower for the Mepilex Border group. The authors concluded that the dressing with a silicone adhesive (Mepilex Border) significantly reduced the prevalence of blistering following hip surgery.

Other studies have demonstrated the effectiveness of Opsite Post-Op dressings in reducing blisters post-operatively. An RCT in the UK (Cosker et al, 2005) compared three dressings (Primapore, Tegaderm with pad and Opsite Post-Op) across a sample of 300 post-surgical patients (TKR, total hip replacements, hip hemi-arthroplasty, dynamic hip screw, tibial nailing and femoral nailing). The findings reported a significantly lower incidence in blistering with the application of Opsite, despite the patients being older with friable skin. It was believed that this was due to the elasticity of Opsite. The lack of elasticity in dressings has been found to increase the risk of blistering (Blaylock et al, 1995). Jester et al (2000) compared Opsite Post-Op dressings with Mepore dressings across a sample of 169 patients following total hip and knee replacements, revealing four out of 28 patients developed blisters with Mepore compared with eight out of 88 with Opsite Post-Op dressings. This result supports previous findings that a lack of elasticity

of dressings, coupled with oedema, contributes to skin blistering. A later study by Leal and Kirby (2008) also supports the use of Opsite Post-Op dressings in preference over Mepore: in an RCT with 67 women post-hysterectomy, no blisters were found in the patients treated with Opsite dressings, compared with eight in the group treated with Mepore dressings.

Ravenscroft et al, (2006) in their RCT compared Aquacel and Tegaderm dressings with Cutiplast across a sample of 183 patients following hip and knee surgery. The findings revealed that, compared with Cutiplast, Aquacel and Tegaderm dressings were 5.8 times more likely to result in a wound without complications: approximately, 22.5% of patients with Cutiplast developed blistering, compared with 2.4% of patients with Aquacel and Tegaderm.

Hahn et al's (1999) comparative study, determining wound complications following hip surgery in patients treated with compression spica wrap versus those treated with traditional taping methods, revealed a significantly lower incidence of blisters and drainage in the group using the comprehensive wrap dressing. There was no higher incidence of deep vein thrombosis (DVT) or infection associated with the wrap. The authors concluded that compression wraps should be used to reduce wound complications and blistering. However, no further published studies could be located that refer to the use of wraps.

In an Australian RCT, Lawrentschuk et al (2002) compared the rate of wound blisters in two commonly used dressings (non-adherent absorbable [NAA] and paraffin tulle gras [PGT]) among 50 patients following hip surgery. The findings revealed a significant difference within the groups: 64% patients in the NAA group developed blisters, compared with only 8% in the PGT group.

Data reported from Cole et al's, (2020) RCT compared incidence of blistering between post-operative dressings across a sample of post-spinal surgery patients: 92 patients received a post-operative dressing, while 93 patients were given a barrier film underneath the dressing. It was noted 15% of the patients developed erythema, soreness or blistering post-operatively on the skin under the border of an adhesive dressing. Cole et al (2020) called for further research to determine the causes of dressing-related skin blisters in post-operative patients.

A meta-analysis comparing wound dressings after hip/knee arthroplasty demonstrated that an antimicrobial dressing is optimal for preventing infection (Feng-Chih et al, 2021); the authors also warned that, if NPWT is used, surgeons must be aware of the increased incidence of skin blistering. They recommended further research focusing on alginate versus hydrofibre and hydrocolloid dressings to determine the optimal dressing to reduce blisters.

Medical adhesives, which are often used for surgical site dressings, central lines and other catheters, can often cause skin damage when they are removed (Kim and Shin, 2021). Skin damage resulting from the use of adhesive products or devices (e.g. dressings, stoma products, electrodes) is known as medical adhesive-related skin injury

(MARSI), generally defined as erythema and skin abnormalities that last for at least 30 minutes after removal of a medical adhesive (McNichol et al, 2013; Savine and Snelson, 2024). Kim and Shin (2021) state that soft silicone dressings have been proven to provide a gentler option for patients, particularly those with fragile skin at risk of damage, due to less risk of tearing or pain. Savine and Snelson (2024) add that silicone dressings are more cost-effective and easier to use, as no additional products are required, such as adhesive removers.

Responsibilities of healthcare professionals

A two-stage Delphi study (Ousey et al, 2012) reinforced the notion of easy application and removal of dressings to prevent blistering, recommending that dressings remain in place for as long as possible, providing no leakage or signs of infection were present.

Several studies highlight the importance of the knowledge and skill of the healthcare professional managing surgical wounds to ensure the correct technique and dressing choice are used to reduce the risk of blistering. Lumbers (2018) described how appropriate dressings promote wound healing by providing a moist environment to reduce the risk of infection and blistering. This discussion paper recommends that the wound's location, method of closure, level of exudate and dressing wear time should be considered when selecting dressings. A literature review by Eastburn et al (2016) emphasised the need for a multidisciplinary approach to manage wounds effectively, promote rehabilitation and prevent blistering, specifically recommending that physiotherapists collaborate with other members of the multidisciplinary team when managing wounds.

The role of the multidisciplinary team in post-operative wound management and blistering was also highlighted by Heller et al (2015); their prospective study on 135 patients following TKA compared the incidence of blisters in 200 patients with the tourniquet released immediately after wound closure in theatre. The findings revealed that releasing the tourniquet early, prior to dressing application, reduced the incidence of blistering following TKA: the incidence of blistering was 7.5%, compared with 2.2% in the early release group. This emphasises how important it is for all healthcare professionals, including surgeons and theatre staff, to understand the management of wounds and risk of blistering. Following a literature review on dressing choice and outcomes after hip and knee arthroplasty, Tustanowski (2009) called for multidisciplinary action, recommending that wound management commences in theatre with a collaborative approach, while also calling for more large-scale RCTs to determine the effectiveness of dressings. This was later supported by Willey et al (2016), who recommended that surgeons assess the risk of SSI alongside morbidity when considering post-operative wound management.

While most of the literature focuses on blistering following orthopaedic surgery, Sanusi (2011) was the first to publish a report on wound traction blistering following laproscopic cholecystectomy in the UK. This case report, based on a 78-year-old healthy male, described how large vesicles were observed following removal of the dressings around the epigastric port incision. Indentations created by the dressing and skin traction raised questions about the technique of application. This study demonstrated the importance

of the correct application of wound dressings and how incorrect techniques, such as stretching adhesive dressings, can result in extensive blistering, which is otherwise fully preventable. The findings highlight the importance of comprehensive education for healthcare professionals in wound management. Specifically, the study identifies the need for targeted training in appropriate dressing selection, correct application techniques, and the potential risks associated with both material choice and procedural variation.

Limitations

This scoping review is subject to several limitations. While multiple databases were searched, the scope did not extend to all potentially relevant sources, thereby introducing the possibility of missed literature. Additionally, the included studies were not subjected to formal critical appraisal prior to inclusion, which may affect the interpretability and overall strength of the evidence base. The majority of studies were outdated, with many conducted over a decade ago and earlier. Given the substantial advancements in dressing technologies (e.g. modern silicone-based materials), application methods, and peri-operative protocols in recent years, the generalisability of earlier findings may be restricted and may not reflect current clinical practice.

Conclusions

The review highlighted there is a significant lack of data available in the published literature on this topic. A lack of routine follow-up and poor post-discharge data collection makes it likely that this issue is under-reported. The data available are also heterogeneous, with very few RCTs, making meta-analysis impossible. Further data are required, with the addition of better post-operative reporting, perhaps through the use of digital technology, to be able to fully understand the incidence of blistering, the impact on patients' wounds and their overall surgical outcome, and which dressings are protective against both blistering and SSI.

This scoping review examined existing research on the causes and prevention of skin blistering, particularly in post-operative patients. Despite some international contributions, most papers were from the UK. There is a notable lack of recent, high-quality literature, particularly expert opinion pieces, RCTs and case studies. Evidence relating to risk factors and dressing use is inconsistent and often difficult to interpret, suggesting a lack of consensus.

To support clinical decision-making and improve patient outcomes, there is a need for large-scale empirical studies, particularly RCTs, to explore both the aetiology and prevention of skin blisters. Clear, consistent guidance is essential to enable healthcare professionals across settings to implement safe, evidence-based practices. Inadequate blister prevention not only contributes to patient pain and discomfort, but also increases the risk of SSIs, joint infections, and prolonged hospitalisation. Given the rising surgical demand within an ageing population, addressing these knowledge gaps should be considered a research priority.

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The authors declare that they have no competing interests that could have potentially influenced the scoping review process reported in this paper.

References

- Abuzakuk TKM, Coward P, Shenava Y et al (2006) The management of wounds following primary lower limb arthroplasty: a prospective, randomised study comparing hydrofibre and central pad dressings. *Int Wound J* 3: 133-7
- Ailaney N, Johns WL, Golladay GJ et al (2021) Closed incision negative pressure wound therapy for elective hip and knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials. *J Arthroplast* 36: 2402-11
- Banasiewicz T, Banky B, Karsenti A et al (2019) Traditional and single use NPWT: when to use and how to decide on the appropriate use? Recommendations of an expert panel. *Wounds International* 10(3): 56-62
- Blaylock B, Murray M, O'Connell K, Rex J (1995) Tape injury in the patient with total hip replacement. *Orthop Nursing* 14 (3): 25-8
- Bork K (1978) Physical forces in blister formation. The role of colloid osmotic pressure and of total osmolarity in fluid migration into the rising blister. *J Invest Dermatol* 71: 209-12
- Bredow J, Oppermann J, Hoffmann K et al (2015) Clinical trial to evaluate the performance of a flexible self-adherent absorbent dressing coated with a soft silicone layer compared to a standard wound dressing after orthopaedic or spinal surgery: study protocol for a randomized controlled trial. *Trials* 16: 81
- Cole M, Smith I, Vlad SC, Golenbock SW (2020) The effect of a skin barrier film on the incidence of dressing-related skin blisters after spine surgery. *AORN Journal* 112 (1): 39-48
- Collins A (2010) Does the postoperative dressing regime affect wound healing after hip or knee arthroplasty? *J Wound Care* 20 (1): 11-6
- Cosker T, Elsayed SM, Gupta S et al (2005) Choice of dressing has a major impact on blistering and healing outcomes in orthopaedic patients. *J Wound Care* 14 (1): 27-9
- Diaz LA, Giudice GJ (2000) End of the century overview of skin blisters. *Arch Dermatol* 136(1): 106-12
- Dillon JM, Clarke JV, Deakin AH et al (2007) Correlation of total knee replacement surgery wound dynamic morphology and dressing material properties. *Journal of Biomechanics* 40(2)
- Doman DM, Young AM, Buller LT et al (2021) Comparison of surgical site complications with negative pressure wound therapy vs silver impregnated dressing in high-risk total knee arthroplasty patients: A matched cohort study. *J Arthroplast* 36:3437-42

Eastburn S, Ousey K, Rippon M (2016) A review of blisters caused by wound dressing components: Can they impede post-operative rehabilitation and discharge? *Int J Ortho Trauma Nursing* 21: 3-10

Feng-Chih K, Chih-Wei H, Timothy TL et al (2021) Effectiveness of different wound dressings in the reduction of blisters and periprosthetic joint infection after total joint arthroplasty: a systematic review and network meta-analysis. *J Arthroplast* 36: 2612-29

Fleischmann W, Becker U, Bischoff M, Hoekstra H (1995) Vacuum sealing: Indication, technique, and results. *Eur J Orthop Surg Traumatol* 5(1): 37-40

Giannini S, Mazzotti A, Luciani D et al (2018) Postoperative wound management with negative pressure wound therapy in knee and hip surgery: a randomised control trial. *J Wound Care* 27 (8): 520-5

Gupta SK, Lee S, Moseley LG (2002) Postoperative wound blistering: is there a link with dressing usage? *J Wound Care* 11(7): 271-3

Hahn GJ, Grant D, Bartke C et al (1999) Wound complications after hip surgery using tapeless compressive support. *Orthop Nursing* 18(3): 43-9

Heller S, Chen A, Restrepo C et al (2015) Tourniquet release prior to dressing application reduces blistering following total knee arthroplasty. *J Arthroplast* 30: 1207-10

Hoover TJ, Siefert JA (2000) Soft tissue complications of orthopaedic emergencies. *Emerg Med Clin North Am* 18 (1): 115-39

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

Huang C, Leavitt T, Bayer LR (2014) Effect of negative pressure wound therapy on wound healing. *Curr Probl Surg* 51: 301-31

Jester R, Russell L, Fell S (2000) A one hospital study of the effect of wound dressings and other related factors on skin blistering following total hip and knee arthroplasty. *J Orthopaedic Nurs* 4 (2): 71-7

Joanna Briggs Institute (2025) Available at: <https://jbi.global/> (accessed 24.06.2025)

Kim J, Shin Y (2021) Medical adhesive-related skin injury associated with surgical wound dressing among spinal surgery patients: a cross-sectional study. *Int J Environ Pub Health* 18: 1-8

Lambert KV, Hayes P, McCarthy M (2005) Vacuum assisted closure: a review of development and current applications. *Eur J Vasc Endovasc Surg* 29(3): 219–26

Lawrentschuk N, Falkenberg MP, Pirpiris M (2002) Wound blisters post hip surgery: a prospective trial comparing dressings. *ANZ J Surg* 72: 716-9

Leal A, Kirby P (2008) Blister formation on primary wound closure sites: a comparison of two dressings. *Wounds UK* 4(2): 31-7

Liu X, Liang J, Zhao J, Quan L (2016) Vacuum sealing drainage treatment combined with antibiotic-impregnated bone cement for treatment of soft tissue defects and infection. *Med Sci Monit* 22: 1959-65

Liu X, Zhang H, Cen S, Huang F (2018) Negative pressure wound therapy versus conventional wound dressings in treatment of open fractures: a systematic review and meta-analysis. *Int J Surg* 53: 72-9

Lumbers M (2018) Selecting appropriate postoperative dressings to support wound healing and reduce surgical site infection. *Br J Nurs* 27(6): S32-5

Manoharan V, Grant AL, Harris AC et al (2016) Closed incision negative pressure wound therapy vs conventional dry dressings after primary knee arthroplasty: a randomized controlled study. *J Arthroplast* 31: 2487-94

McNichol L, Lund C, Rosen T, Gray M (2013) Medical adhesives and patient safety: State of the science: Consensus statements for the assessment, prevention, and treatment of adhesive-related skin injuries. *J Wound Ostomy Cont Nurs* 40: 365-80

National Library of Medicine (2024) Blister. Available at: <https://www.ncbi.nlm.nih.gov/mesh?Db=mesh&Cmd=DetailsSearch&Term=%22Blister%22%5BMeSH+Terms%5D> (accessed 24.06.2025)

Ousey K, Gilibrand W, Stephenson J (2011) Understanding and preventing wound blistering. *Wounds UK* 7 (4): 50-6

Ousey K, Gilibrand WP, Stephenson J (2012) Achieving international consensus for the prevention of orthopaedic wound blistering: results of a Delphi survey. *Int Wound J* 10(2): 177-83

Ozkan B, Markal Ertas N, Bali U, Uysal CA (2020) Clinical experiences with closed incisional negative pressure wound treatment on various anatomic locations. *Cureus* 12(6): e8849

Peters MDJ, Godfrey C, McInerney P et al (2020) Scoping Reviews. In: Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z, eds. *JBI Manual for Evidence Synthesis*. JBI: 1-481

Ravenscroft MJ, Harker J, Buch KA (2006) A prospective, randomised, controlled trial comparing wound dressings used in hip and knee surgery: Aquacel and Tegaderm versus Cutiplast. *Annals Royal College Surg England* 88 (1): 18-22

Ruhstaller K, Downes KL, Chandrasekaran S et al (2017) Prophylactic wound vacuum therapy after cesarean section to prevent wound complications in the obese population: a randomized controlled trial (the ProVac study). *American J Perinatol* 34(11): 1125-30

Sanusi AL (2011) Severe wound traction-blisters after inadequate dressing application following laparoscopic cholecystectomy: case report of a preventable complication. *Patient Safety Surg* 5 (4): 1-3

Savine L, Snelson K (2024) Medical adhesive-related skin injury (MARSI): Preventing patient harm. *Wounds International* 15 (3): 28-36

Siddique K, Mirza S, Housde P (2011) Effectiveness of hydrocolloid dressing in postoperative hip and knee surgery: literature review and our experience. *J Periop Prac* 21 (8): 275-8

Suzuki T, Minehara A, Matsuura T (2014) Negative-pressure wound therapy over surgically closed wounds in open fractures. *J Orthopaed Surg* 22 (1): 30-4

Tosoundis TH, Daskalakis II, Giannoudis PV (2020) Fracture blisters: pathophysiology and management. *Injury* 51 (12): 2786-92

Tustanowski J (2009) Effect of dressing choice on outcomes after hip and knee arthroplasty: a literature review. *J Wound Care* 18 (11): 449-58

Willey C, Agarwal A, Anderson CA et al (2016) Closed incision negative pressure therapy: international multidisciplinary consensus recommendations. *Int Wound J* 14(2): 385-98

Zhang C, Wang Q, Wang Z et al (2021) Modified negative pressure wound therapy for linear blister formation prevention around foam dressings: technical note and case series. *J Orthopaed Surg Res* 16 (602): 1-8