

EWMA Document: Debridement

An updated overview and clarification
of the principle role of debridement

A EWMA Document



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Introduction

Routine care of non-healing acute and chronic wounds often comprises either cleaning or debridement. Consequently, debridement is a basic necessity to induce the functional process of tissue repair, which makes it a central medical intervention in the management of acute and chronic, non-healing wounds.

The last years many different new debridement techniques have been introduced; primarily applying physical principles and forces to promote the development from acute inflammatory phase to the reparative condition.¹

However, despite the central role of debridement in the field of wound healing, there is still no document that gathers this information. With this document, the European Wound Management Association (EWMA) aims to provide an overview of the various options, including a clarification of the principal role of debridement (why and when to debride, evidence for debridement), the definition of possibilities and limitations for standard and new debridement options with specific potentials in their practical use, health-economic aspects and an algorithm for the clinical routine.

Definition of debridement

The word debridement derives from the French *débridement*, which means to remove a constraint. In clinical medicine this term was first used by Henri Le Dran (1685–1770), in the context of an incision to promote drainage and relieve of tension.² Today, debridement refers to deeply

removing adherent, dead or contaminated tissue from a wound and must be clearly separated from the act of cleansing, defined as the removal of dirt (loose metabolic waste or foreign material).³ Furthermore, debridement does not encompass revision of a wound, resection of functional tissue or amputation. Thus, we define debridement as the act of removing necrotic material, eschar, devitalised tissue, serocrusts, infected tissue, hyperkeratosis, slough, pus, haematomas, foreign bodies, debris, bone fragments or any other type of bioburden from a wound with the objective to promote wound healing.

Debridement is sometimes referred to as a form of wound bed preparation;⁴ however, from a global perspective it becomes clear that not only the wound bed but also the wound edges and the peri-wound skin are important for the successful healing of a wound. This supports a definition of debridement that does not only refer to the removal of bioburden from the wound bed, but also the liberation of wound edges as well as of peri-wound skin. This document will show that this broader view on debridement opens new possibilities and perspectives within the field of wound healing.

When adapting a global approach to wound healing, debridement must be understood as a process, possibly used in conjunction with other treatment approaches, with the aim to create a beneficial situation supporting various clinical goals related to wound management. We believe that this approach increases the

Fig 1. Wound margin covered by dried exudate and hyperkeratosis which may impair the physiological process of wound healing



Fig 2. Lower leg with widely disseminated, adherent crusts of exudate, large skin scales, hyperkeratosis and debris, which may impair the physiological process of wound healing. No defined ulcer.

probability to achieve clinical benefits such as increased quality of life of the patient, fewer odours, improved microcirculation, normalised biochemistry including normalising the matrix metalloproteinase (MMP) balance, decreased access of moisture and stimulated wound edges. A global approach to debridement offers advantages with regards to the possibility to clearly define wound phase targets for debridement and review whether these targets have been achieved. Primary targets for debridement have been summarised in Table 1.

Indications for debridement

As debridement represents a central step in the management of wounds it can be applied to all kinds of wounds, irrespective of their diagnoses and origin. The question arises with regards to the indication for debridement and timing of the procedure. A clear indication can be generated via the diagnosis of different kinds of tissue types and bioburden which cover the wound bed, the state of the wound edges and the peri-wound skin. A tissue type related definition of debridement allows the clinicians to define the right time point for debridement and to

Table 1. Targets of debridement

Remove	Necrosis Slough Eschar Impaired tissue Sources of inflammation Sources of infection Exudate Serocrusts Hyperkeratosis Slough Pus Haematomas Foreign bodies Debris Bone fragments Other types of bioburden/ barriers of healing
Decrease	Odour Excess moisture Risk of infection
Stimulate	Wound edges Epithelialisation
Improve	Quality of life

identify the most appropriate method. Therefore, an appropriate diagnosis must first define the problem (necrosis, eschar, slough, sources of infection) and secondly, define the exudate levels of the wound bed ranging from dry to wet (Fig 3–6).

Many additional parameters exist, which have the capacity to influence the decision for debridement and especially the choice of the appropriate method. Such parameters comprise pain, the patient's environment, patient's choice, age, skill and resources of the care giver, patient's quality of life, regulations and guidelines (Table 2).

To summarise, we understand debridement as an integrated part of the management of an individual with a wound, achieving certain goals and, thus, creating a healthy wound bed, edges and peri-wound skin, with the objective of promoting and accelerating healing. The indication for debridement and choice of technique does not relate to the diagnoses of the wound but to the definition of certain tissue types covering the wound, as well as their state of humidity and relevant factors related to the patient situation.

Method

The methodology of this document comprises of a general literature review with the addition of the authors' clinical expertise. The objective is to provide an updated overview with regard to debridement and its methods together with a suggestion for an overall clinical algorithm which defines the why, when and how of debridement. Thus, this paper is not purely evidence based or evaluating existing products, as this would lead to a compromise with the primary objective: To describe the substantial amount of available debridement technologies, which all have potential advantages and limitations related to the various wound types and treatment settings.

The literature search strategy was instigated to allow for the identification of a broad range of methods and results of using different techniques in the debridement of wounds. Three databases were searched: Medline, Embase and the Cochrane Database. The search was conducted in December 2011 and search terms used are listed in Appendix 1.

The authors responsible for the various sections of the document selected the relevant literature to include in their sections, based primarily on the literature identified in the database search. Literature used includes debridement studies of various types: Reviews, randomised controlled studies (RCTs),

comparative studies and cohort studies were given priority, but in many cases non-comparative studies, case studies, *in vitro* studies and animal studies have been included, as RCTs and comparative studies were not available, with regards to the techniques/topics described in the document.

Fig 3. Dry fibrin; the wound edges show that fibrin represents a barrier to healing.

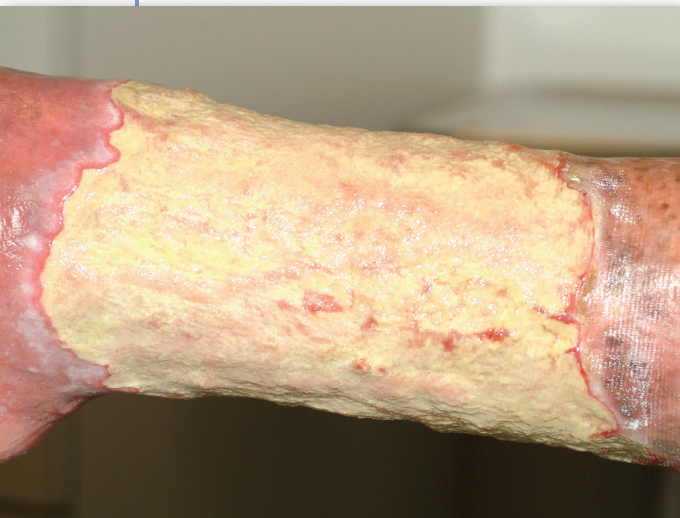


Fig 5. Wet slough



Fig 4. Adherent, dry black necrosis



Fig 6. Local infection of the wound and wound edges, with the potential presence of a biofilm

Table 2. Additional parameters influencing the decision for debridement and the choice of technique

Decision parameters	
Pain	Skill of the care giver
Patients environment	Resources of the care giver
Patients choice and consent	Regulations
Biological age and comorbidities	Guidelines
Quality of life	

A list of references, including information on the study and document type, can be found at www.ewma.org (Appendix 2).

As a general conclusion with regards to the literature search we acknowledge that more high-level evidence is needed to further support the content of this document. However, until this has been provided, we have to rely on existing information and experience to define existing methods of debridement.

Patient consent for debridement

A comprehensive and holistic patient assessment is a necessary pre-requisite to evaluate the most appropriate method of debridement. Patient involvement in the assessment and planning of treatment will optimise success, as the patient will be more informed and more likely to accept and comply with treatment resulting in greater success in removing necrotic tissue.⁵

Informed consent must be obtained before commencing any treatment or investigation, or in providing personal care.⁶ For consent to be valid, the person giving consent must be capable of making the decision or deemed competent. The consent should be given voluntarily, without coercion and the person should be provided with adequate information to make that decision.

Information should be available regarding the type of debridement treatment, including benefits and risks, implications of having treatment and alternatives that maybe available.⁷

It should be noted that a parent or guardian can initiate consent if the person receiving the debridement treatment is too young (<16 years old) or is incapable of making the decision for themselves (due to physical or mental illness).⁸ It is important that parents and their children are informed about the proposed treatment and that children are listened to so that they can be involved in the decision making. Ensuring consent is legally and ethically obtained will reduce risk of litigation and improve patient satisfaction.⁹

Informed consent maybe expressed or implied. Implied consent may be inferred by the patient's actions, for example voluntary attendance to the clinic for larval therapy dressings.¹⁰ Expressed consent can be either written or verbal.¹¹ In the USA and UK, for example, it is common practice for patients to sign a consent form, indicating that they have been given information and that they are consciously giving their permission to receive care, for example, sharp debridement of a necrotic diabetic foot ulcer.

Documentation of consent provides evidence that processes involved in obtaining consent have

been adhered to. It can also provide evidence of information given to patients and clarification of treatment, for example, amputation of lower limb in theatre under general anaesthetic. However, patients do have a right to withdraw their consent at any stage before, or during the course of the debridement technique.¹²

Regardless of debridement technique it is essential that patients are given adequate information in order to reach an informed decision and consent to treatment. Focus should be on all methods of debridement and not just surgical and sharp debridement. Consent is not just a signature on a piece of paper,¹³ it is an active participation of the patient in the decisions about their own health care.

An example of a debridement consent form can be found in Appendix 3.



The objective is to provide an updated overview with regard to debridement and its methods, together with a suggestion for an overall clinical algorithm which defines the why, when and how of debridement



Mechanical debridement

Mechanical wound debridement involves the use of dry gauze dressings, wet to dry gauze dressings, impregnated gauze/tulle dressings or a monofilament fibre pad to remove non-viable tissue from the wound bed.

Following a review of the literature, a large proportion of the articles were excluded, as they did not contain specific information on the ability to debride non-viable tissue (Edsrtom et al., 1979; Xakellis and Chrischilles, 1992; Brown, 2000; Piaggese et al., 2000; Caravaggio et al., 2003; Eginton et al., 2003; Wanner et al., 2003; Allie et al., 2004; Cohn et al., 2004; Mouës, 2004; Brigido et al., 2006; Huang et al., 2006; Yao et al., 2006; Mouës et al., 2007; Koller et al., 2008; Wang and Teng, 2008; El-Nahas et al., 2009; Saba et al., 2009; Martin et al., 2010; Perez et al., 2010; Solway et al., 2010; Brenes et al., 2011; Uccioli et al., 2011; Warriner et al., 2011; Zhen et al., 2011. Full references can be found in Appendix 4).

Wet-to-dry debridement

Background

Mechanical debridement has been reported to be the most commonly used debridement technique in the USA¹⁴ and is a method that has been used for decades.^{15,16} A wet-to-dry method of wound cleansing has also been described,¹⁷ but should not be confused with the traditional wet-to-dry method of debridement.

Action

One technique used to achieve mechanical debridement is the wet-to-dry method. A moist

gauze pad is applied to the wound. As the devitalised tissue dries, it re-hardens and becomes attached to the gauze; when the dressing is removed, the adhered material is pulled free.

Indications

Wet to dry dressings are recommended only as a short-term therapy for infected necrotic wounds.^{15,18}

One case study reports using wet-to-dry as a debridement method in a patient with a category III pressure ulcer.¹⁹ In addition, there is one case reporting success in using wet-to-dry gauze as one component of a debridement regimen.²⁰

Limitations

The wet-to-dry debridement method often results in a lack of procedural concordance, with an increased risk of infection; also, the gauze remnants can potentially act as foreign bodies within the wound bed. The disadvantages of this method are described as injury to normal tissue and pain, along with the necessity for frequent dressing changes.¹⁵ In addition, while cost of the gauze is low, application is said to be time consuming and costly.^{15,18}

Paraffin tulle

Donati and Viganò²¹ provide anecdotal reports of paraffin tulle dressings causing pain and damage to new tissue, bleeding at the wound bed on removal, as well as an increased risk of infection and a delay in re-epithelialisation.²¹ Barnea et al.,²² in a study comparing a Hydrofiber dressing

with paraffin gauze, found patients with split-skin donor sites treated with the latter experienced significantly more pain and a less rapid rate of epithelialisation ($p < 0.01$).

Gauze

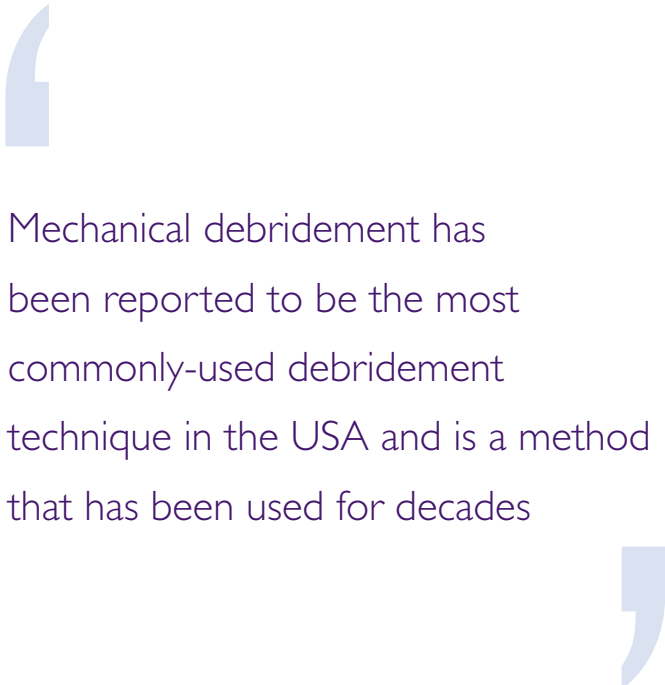
Background

Traditionally, gauze has been used as the basis dressing in wound management and is frequently used as a comparator in wound studies. However, there is limited information and support available with regards to its use as a debridement agent.^{23,24}

Indications

A Cochrane systematic review identified 10 trials in which gauze was used as a comparator, in studies investigating dressings and topical agents for surgical wounds healing by secondary intention. However, they did not use time to debridement as an outcome, instead using time to healing. In four of the trials, gauze was associated with significantly more pain for patients compared with use of other dressings. This finding is compounded by the data from three trials, which identified that patients treated with gauze were less satisfied with their treatment than those receiving alternative dressings.²⁵

Dryburgh et al.,²³ in a Cochrane systematic review on the debridement of surgical wounds, identified three studies that used soaked gauze (with a variety of solutions) as a comparator. However, they concluded that the RCTs were small, evaluated outdated products and were of poor methodological



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quality, and that there was no RCT evidence to support any particular debridement method.²³

The debridement of diabetic foot ulcers was the topic of a subsequent Cochrane review, which identified two studies that use gauze as an intervention.²⁴ The authors concluded that the use of a hydrogel increases the healing of diabetic foot ulcers compared with gauze or standard wound care; however, it is unclear whether this effect is due to debridement.²⁴

Limitations

The primary limitation for use of gauze as a debridement agent is that gauze is associated with significantly more pain for patients than with use of other dressings.

A general limitation related to wound management using gauze is the frequent dressing changes needed, for example to avoid pain. This increases the demand for staff resources.²⁶

Cost effectiveness

A Health Technology Assessment, looking at the clinical and cost effectiveness of debriding agents used to treat surgical wounds healing by secondary intention, reported that modern dressings were found to have lower costs than plain or impregnated

gauze. However, the quality of the cost-effectiveness analyses in the studies was found to be poor.²⁷

However, several studies show that the need for staff resources, in relation to a high number of dressing changes, decreases the cost effectiveness of gauze.²⁶

Monofilament fibre pad

Background

The monofilament fibre product has recently been introduced as a modern, wound-debriding product, designed to mechanically remove slough and devitalised cells from the wound bed.²⁸ Case studies suggest that slough, hyperkeratotic debris and crusts of desiccated exudate are bound in the fibre composite and thereby removed from the wound and surrounding skin.²⁹

Action

The wound-contact side is fleecy in appearance and, once wetted, is gently wiped over the surface of the wound for 2–4 minutes.³⁰

Indications

The monofilament fibre pad has been used in debriding a variety of wound types, including venous leg ulcers, diabetic foot ulcers (neuropathic and neuro-ischaemic), arterial ulcers, mixed aetiology ulcers, pressure ulcers and traumatic wounds.^{29,31}

A number of smaller, prospective, pilot, non-comparative studies and case studies²⁹ suggest good debridement results after one use on a variety of tissue types, such as slough and necrotic, and

effective removal of hyperkeratosis. It is also claimed that the monofilament fibre pad leads to removal of debris, leaving healthy granulation tissue intact, including small epithelialised islands of vital tissue.²⁹

In the case of thick, tenacious slough and hard necrosis it is recommended that the tissue is softened prior to using the pad.²⁸ A larger study of 60 patients with chronic wounds, of which 57 (95%) were included in the analysis, the monofilament fibre pad was effective in 93.4% (n=142) of the debridement episodes.³²

Benefits

The debridement process using a monofilament pad is found to be quick (range 2–12 minutes).^{32,33}

In addition, the monofilament pad is claimed to be easy to use, causing little-to-no pain.³¹

Side effects

Some pain responses following the debridement procedure have been reported.³²

Conclusions

The use of wet-to-dry, plain gauze and paraffin tulle as debriding agents has little to support their use. The limitations should preclude their use in clinical practice; however, the monofilament fibre pad shows the potential to advance mechanical debridement as a viable technique, by providing a rapid, safe and easy-to-use method with limited pain for the patient. However, further research, including clinical use on a variety of acute and chronic wound types, is needed.

Autolytic dressings, enzymatic dressings, absorbptive dressings and honey

This chapter describes various debridement techniques with autolytic, enzymatic and/or absorbptive properties. Many different products are currently available on the market, offering different combinations of components and suitable for different wound characteristics and stages. We will provide an overview of the various product types, defined in four overall categories: autolytic dressings, enzymatic dressings, absorbptive dressings and honey.

Autolytic dressings

Background

The term 'autolytic debridement' describes a natural process in all kinds of wounds, which can be supported by a moist wound-management strategy. Autolytic debridement products can be found in many different varieties, including different properties, benefits and limitations. They can be defined in the following groups:

a Hydrogels, or hydrogel-based dressings, are three-dimensional, cross-linked homopolymers

or copolymers, saturated with water. The proportion of water in hydrogel dressings can vary from 30% to 90%. Different gel-forming agents, such as carboxymethylcellulose, are incorporated into most hydrogels.³⁴

b Hydrocolloids are composed of carbomethylcellulose, gelatin, pectin, elastomers and adhesives that turn in to a gel when exudate is absorbed.³⁵

c Highly absorbptive dressings with autolytic and occlusive properties, such as dressings with a multifunctional polymeric membrane formulation and hydrations techniques (e.g. hydration response technology [HRT]). These dressings are designed for exudation management, aiming to create a moist and physiological environment for autolytic debridement.³⁶

Some dressings comprise a hydrophilic polymer-modified starch in its three-dimensional network with physically-bound iodine.

- d Hydrofibers, including carboxymethylcellulose fibres, which turn into a gel when they come into contact with wound fluid, thereby aiding the removal of nonviable tissue. Hydrofiber dressings are highly absorbent and those with silver content and other antimicrobials are available on the market.³⁷
- e Multi-component dressings. Some dressings combine autolytic, absorptive and antimicrobial features in the debridement process. These include enzyme alginogels, comprising hydrated alginate polymers in a polyethylene glycol (PEG)/water matrix, embedded with an antimicrobial oxidase/oxidase enzymatic complex.³⁸

Indications

Autolytic dressings are indicated for different kinds of acute and chronic wounds with necrotic tissue or fibrin coatings, to rehydrate, soften and liquefy hard eschar and slough.³³ For example, hydrogels should only be used in wounds with moderate or no exudate, while absorptive dressings with autolytic properties, Hydrofibers and combination dressings can be used for the treatment of exudative (low, medium or high) wounds with yellow sloughy surfaces.³⁹ Different products are available for varying levels of exudate.

Autolytic debridement can be used for infected wounds, only if the infection is under control/treatment.

Action

Autolytic debridement products have a dual mode of activity in wound therapies. They can donate water to dry wounds, or absorb fluids from moderately exuding wounds. The idea behind an autolytic debridement is a selective debridement by release of the patients' endogenous proteolytic enzymes, such as collagenase, elastase, myeloperoxidase, acid hydroxylase or lysozymes, and the activation of phagocytes. These enzymes



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will soften, break down and dissolve necrotic or sloughy tissue in wounds, enabling it to be digested by macrophages. Most of these enzymes are produced by leucocytes. Another aspect of autolytic debridement is mediated by the high water content in, for example, hydrogels and the moisturising effect of absorptive dressings, which leads to swelling of necrotic tissue and fibrin coatings, facilitating their de-attachment.

For an autolytic debridement, wound conditions must be created that are optimised for leucocytes and macrophages activity. This is achieved by creating a moist wound milieu using, for example, hydrogels or polymers/sugars, which absorb and physically bind the dissolved material, to maintain a moist environment in the wound.

- c Highly-absorptive dressings absorb and bind wound exudate, which could delay wound healing, and are often combined with moisturisers, which keep dressings from adhering to the wound

and are claimed to support wound healing in some types of wounds (see Contraindications for types and areas to be avoided).

Devices based on HRT combine a glueless mixture of mechanically-treated cellulose fibres and gelling agents. Comparative *in vitro* tests have shown antibacterial and antifungal properties of the dressing, implying that their application could aid treatment of wound infections through entrapment of microorganisms, while wound exudate is being absorbed.⁴⁰

Dressings containing cadexomer-iodine liquid particles, with a hydrophilic polymer-modified starch, can accommodate up to seven times their dry weight in exudate, and then generate a hydrogel. Even if the gel supports autolytic debridement, its primary indication in wound therapy is the antimicrobial treatment of infected wounds.^{41,42}

- e Some multi-component dressings include an enzyme alginate, which is claimed to create a protective film, protecting the wound borders from maceration.³⁸

Administration

For correct use of an autolytic debridement, the dressing is directly applied to the wound surface. As the administration of the available dressings varies according to the properties of the dressings, specific administration guidance apply to different types of products.

For autolytic dressings without absorptive properties, it should in general be mentioned that these may be combined with an exudate-absorbing secondary dressing to allow already-detached, non-viable tissue to be absorbed. For autolytic debridement, it is most common to change dressings once daily. Remains of the gels can be removed with tap water or sterile irrigation solutions.^{34,43}

In addition, it should be mentioned that:

- a For hydrogels, a coating with a thickness of at least 5mm is necessary; smaller or deeper wounds may be completely filled with the gel. Hydrogel sheets should be applied so that they overlap 2cm around the wound edges.
- c Dressings with highly absorptive properties should be applied at a thickness of at least 3mm. The dressing should be replaced after 1–3 days, depending on the level of exudate.

For cadexomer iodine, it is recommended that the total dose should not exceed 150g/week and the overall treatment should not be longer than 3 months, for a single course of treatment.⁴⁴

Benefits

Products for autolytic debridement are fairly well documented as easy to use and causing little-to-no pain. They do not damage healthy tissues (selective debridement) and are claimed to promote the formation of granulation tissue and epithelialisation.^{22,37} Most of these products are likely to require few dressing changes.⁴⁵

With regard to specific groups of products, it should be mentioned that:

- a A further benefit of hydrogel sheets is that they are mostly transparent, thus allowing wound inspection without having to remove the dressing. As well as the debridement effects, certain hydrogel sheets are claimed to provide a cooling effect, which may lead to pain relief, especially for patients with burns. However, for other patients, for example patients with arterial disease, this cooling effect may be unpleasant.³⁴
- c Benefits of the absorptive dressings with autolytic properties include removal of slough, provision of moisture, absorption and

protection.³⁶ These dressings are designed to be used in highly exudative wounds and thus support the exudate management.

Polymeric membrane dressings are claimed to soften tissue and absorb exudate, with the objective to promote healing by combining glycerin and starch.^{45,46}

e By generating reactive oxygen species, the oxidase/peroxidase enzymatic complex included in multi-component products should be effective as an antimicrobial agent. Some multi-component dressings include alginate polymers with a strong absorption capacity and polyethylene glycol/water. These multi-component dressings are claimed to absorb microorganisms into the gel, leading to an oxidative antimicrobial effect.³⁸

Contraindications

General contraindications are known contact sensitisation to ingredients of the dressings. For example, propylene glycol is used as a preserving agent in many autolytic dressings and it is well known that contact sensitisation to propylene glycol exists in up to 14% of patients with chronic venous leg ulcers.⁴⁷

Other product-group specific contraindications are:

- a** Hydrogels and hydrogel dressings should not be used in bleeding wounds, fistulae or body cavities. Moreover, they should not be used when wounds are highly exudative. In addition, these products are contraindicated in infected wounds (this may vary between countries in Europe, depending on the available products) and in those with a high potential for anaerobic infections. It should also not be used in patients with necrotic or ischaemic feet.³³
- b** Hydrocolloids should be used with special precautions in patients with diabetes or infected wounds.

c and **e**: Use of dressings with occlusive properties for highly exudative wounds and/or high temperatures may lead to risk of infection by *Pseudomonas aeruginosa*.⁴⁸

Dressings with an absorptive effect should not be used near the eyes, mucous membranes, in deep wounds with narrow openings, or wounds in body cavities, due to the risk of drying and adhesion. Dressings using hydration technology should also be avoided for dry or drying wound areas, or other areas requiring little or no fluids.

Dressings supporting a moist wound healing environment should not be used in, for example, necrotic digits, because of ischaemia and/or neuropathy. These wounds should be kept dry due to the risk of infection.

Cadexomer iodine is contraindicated in patients with iodine sensitivity, Hashimoto's disease, thyroiditis and nontoxic goiter. Some cases of hyperthyroidism following cadexomer iodine have also been reported and cadexomer iodine may lead to toxicosis, due to a tissue reaction in the peri-wound area when hyperkeratosis is present.⁴⁴

Side effects

Possible side effects related to the various groups of products are:

- a** For hydrogels, excessive use, or use in a highly exudative wound, may lead to maceration of the peri-wound skin. Maceration potentially weakens the skin barrier function and may impede the wound-healing process. Moreover, maceration can be a portal of entry for infections caused by microorganisms, such as bacteria or fungi.
- c** Pain related to cadexomer iodine dressings, such as a burning sensation during application, has been reported.⁴⁴

Moreover, certain topical, antimicrobial agents have been associated with cytotoxicity, delayed healing, emergence of bacterial strains resistant to common antimicrobial agents and contact dermatitis.^{49,50}

Cost effectiveness

Only a few studies have thoroughly evaluated the cost effectiveness of autolytic debridement methods.

A cost efficacy analysis of cadexomer-iodine dressings, compared with hydrocolloid dressings and paraffin gauze dressings, indicate that while material costs were higher in the cadexomer-iodine group, the total weekly costs were similar for all treatments, due to the need for less frequent changes with cadexomer iodine. Primary costs were related to cost of staff resources and transportation, in relation to dressing changes.^{41,44,51}

A randomised clinical study by Caruso,³⁷ including a cost-effectiveness analysis, suggests potential cost benefits related to fewer dressing changes, less nursing time and fewer procedural and opiate medications during dressing changes.

Some general comments with regards to possible cost indicators are:

- Autolytic debridement can be considered one of the easiest and safest methods of debriding wounds. Therefore, it may be appropriate to use in long-term care facilities and in the home-care setting, thereby possibly saving costs.
- However, achieving cost effectiveness may be difficult, as a prolonged period of time may be needed to achieve complete removal of nonviable tissue. Therefore, costs associated with dressings and repeated visits need to be considered.
- Another problem may occur as the hygienic specification for hydrogels are usually

determined for single use. Thus, the tube should be discarded after a single use, regardless of the remaining stock.

Enzymatic dressings

Background

For a few hundreds of years, patients with chronic wounds have been treated topically with proteolytic enzymes, for example in the form of fruit juices. Since 1960, the first scientific records exist on the effective use of proteolytic enzymes in the treatment of patients with chronic wounds (Table 3). Enzymatic debridement is a specific wound-debridement option using proteolytic enzymes in gels or ointments, which should work synergistically with endogenous enzymes.³⁶

Indications

Enzymatic debridement can be useful in patients with wounds where mechanical debridement options are not available or are contraindicated; for example, in patients with bleeding problems.

Mechanism of action

During debridement, proteolytic enzymes are used to hydrolyse peptide bonds, in order to facilitate the removal of non-viable tissue from a wound. These enzymes can be divided in exo- and endopeptidases. Exopeptidases hydrolyse the amino or carboxy terminal protein, whereas endopeptidases degrade peptide bonds within the protein molecules.³⁴

Matrix metalloproteases (MMPs) are zinc-dependent endopeptidases, with a subgroup of metalloenzymes called collagenases. Humans generate endogenous collagenases to facilitate the physiological balance between the assembly and degradation of collagen. Collagenases are the only endoproteases that can degrade human triple helical collagen, but do not attack keratin, fat, fibrin or haemoglobin.

Table 3. Proteolytic enzymes for wound treatment³⁴

Origin	Enzyme	Source
Animal	Fibrinolysin	Bovine plasma
	Desoxyribonuclease	Bovines pancreas
	Krill multienzyme complex	Antarctic krill
	Collagenase	Paralithodes camtschatica
	Catalase	Equine liver
Plant	Papain	Carica papaya
	Bromelain enzyme complex	Pineapple
Bacteria	Collagenase	<i>Clostridium histolyticum</i>
	Streptokinase	<i>Streptococcus haemolyticus</i>
	Streptodornase	<i>Streptococcus haemolyticus</i>
	Suttilain	<i>Bacillus subtilis</i>

Necrotic tissue consists of cellular debris embedded in an extracellular matrix (ECM), mainly consisting of type IV collagen, glycoproteins and proteoglycans. These components are released by the activity of collagenases and can subsequently be degraded by macrophages and other proteases. The resulting collagen fragments stimulate additional fibroblasts and macrophages and thus induce chemotactic effects. Collagen also comprises 70–80% of the dry weight of the skin and is the primary constituent of the human dermis; therefore, it forms a substantial component of the non-viable tissue.

In contrast to the collagenases of mammals, bacterial collagenase breaks the triple helix structure of various collagens at multiple points, thus generating smaller peptides that induce forced further degradation of the collagen. Bacterial collagenase promotes wound healing by digesting native collagen bundles that bind non-viable tissue to the wound surface and by dissolving collagenic debris within the wound. The most commonly used wound products contain the collagenase *Clostridiopeptidase A* from *Clostridium histolyticum*.⁵²⁻⁵⁴

Streptokinase is a fibrin-degrading kinase with a preferred point of attack between arginine–valine bonds. The streptokinase catalyses the generation of plasmin from plasminogen. Plasmin degrades fibrin, fibrinogen, factor V and VIII into polypeptides and amino acids. In addition, plasmin forms a complex with human plasminogen, leading to a conformational change of plasminogen, exposing its active centre. The result is a streptokinase-plasminogen complex that can activate plasminogen. Therefore, streptokinase’s effects require the presence of a plasminogen-containing wound environment.

Streptodornase is a deoxyribonuclease (DNase) with endonucleolytic activity against double-stranded DNA. Streptodornase will contribute a complex with free plasminogen, which catalyses the conversion of plasminogen to plasmin. It liquefies the viscous nucleoprotein of dead cells or pus and has no effect on living cells. Similarly, coagulated blood can be liquefied and then be absorbed. By these characteristics, the streptodornase is particularly suitable when used in combination with other enzymes, such as

streptokinase. A combination of streptokinase and streptodornase is commercially available.

Papain digests necrotic tissue by liquefying fibrous debris across a wide range of pH, from 3 to 12.⁵² For its full activity, it requires the presence of sulphhydryl groups, such as cysteine. Usually, urea is combined with papain. Urea also denatures proteins, making them more susceptible to proteolysis by papain and exposes the necessary activators for papain in necrotic tissue.⁵⁵ It should be noted that papain is not commercially available in all parts of the world.

Krill enzymes (euphauserase) are a complex mixture of endo- and exopeptidases, which are isolated from the gastrointestinal tract of Antarctic krill (*Euphausia superba*). The acidic endopeptidases have a structural relationship to trypsin and chymotrypsin, whereas the exopeptidases are mainly carboxypeptidases A and B. A high molecular similarity to crab collagenase could be found for the serin endopeptidase euphauserase. Krill enzymes assure a nearly-complete breakdown of proteinous substrates to soluble free amino acids.^{56,57}

Administration

To ensure the full effectiveness during the therapy with proteolytic enzymes, the wounds must always have sufficient moisture in the environment. Application of the enzymatic ointment should be performed in a coating of thickness about 2–3mm on the non-viable tissue areas, once or twice daily.

Benefits

The main advantages of the use of proteolytic enzymes in the debridement of patients with chronic wounds are their easy and safe handling. Therapies are bloodless and generally considered rather painless.⁵⁸ Because of the highly-selective mode of action, this type of debridement can be appropriate to use in long-term care facilities and in home-care settings.

Contraindications

It is important to respect the fact that enzymes need a moist environment to be effective. Therefore, dry wounds are a relative contraindication for the use of proteolytic enzymes. The additional use of, for example, antiseptics or soaps should be avoided, as some of the enzymes become ineffective in the presence of these solutions. A contraindication for streptokinase is the acute wound, because the cleavage of fibrin leads to an increased risk of bleeding.

Side effects

Products with proteolytic enzymes can lead to irritation of the peri-wound skin, with clinical signs of inflammation or discomfort. This, in particular, is most important when using papain, as considerable pain induced by inflammatory response has been commonly described.⁵⁹ In an attempt to reduce the occurrence of pain induced by papain, chlorophyllin has been added to these preparations.

Therapy with streptodornase can cause fever, chills, and leucocytosis, due to the absorption of split purines and pyrimidines. Streptokinase and streptodornase are effective as antigens and thus the formation of antibodies may result. In some cases, clinically-relevant contact sensitisation, with allergic contact dermatitis, has been reported.

Cost effectiveness

Proteolytic debridement is an easy-to-handle and safe option for conservative debridement; however, additional costs may occur due to the prolonged period of time needed to achieve complete removal of necrotic tissue, and due to the relatively expensive ointments.

Absorptive dressings

Background

Dextranomer is a hydrophilic, dextran polymer, which is supplied as anhydrous, porous, spherical

beads measuring 0.1–0.3mm in diameter, or as a paste with polyethylene glycol. The product consists of unbranched dextran-polymer chains which are interconnected by glycerol bridges into a three-dimensional network.

Indication

Absorptive dressings are recommended for the treatment of exudative wounds (low, medium or high), with yellow sloughy surfaces.³⁹

Mechanism of action

Absorptive dressings are highly hydrophilic and rapidly absorb exudate from the necrotic, sloughy mass. One gramme of dextranomer can absorb up to 4g of fluid. Prostaglandins, hormones and other small molecules enter the matrix of the absorptive dressings, while larger particles, such as bacteria and wound debris, become concentrated at the surface of the dressing layer. When the dressings are changed, or the beads are washed out, the absorbed and trapped necrotic material is removed.⁶⁰

Administration

Dextranomer should be applied in a thickness of at least 3mm on to wounds that have previously been cleaned with solutions. When the wound is dressed, there must be some room for expansion, as the dressing absorbs a lot of fluid. The absorbent dressing should be replaced after 1–3 days, depending on the extent of exudation. When it assumes a grey–yellow colour, it is saturated and should be removed.

Benefits

Absorptive dressings are easy-to-handle products that can be used even with highly exudative wounds and thus support the exudate management.

Contraindications

As with absorptive dressings with autolytic properties, absorptive dressings should not be used near the eyes, in deep wounds with narrow openings, or wounds in body cavities. Other

contraindications are known contact sensitisation to ingredients of the dressings.

Side effects

Beside some reports of erythema, slightly blistered skin or dehydration of the wound bed,⁶¹ the most important adverse effect is pain on removal of the saturated dressing from the wounds. This effect is the result of the adherence effects.

Honey

Background

The first records of the use of honey in wound management are already more than 4000 years old.⁶² Honey can be characterised as a combination products but is, as a purely natural substance, placed in a separate chapter. It is a viscous, supersaturated, sugar solution, containing approximately 30% glucose, 40% fructose, 5% sucrose and 20% water, as well as many other substances, such as amino acids, vitamins, minerals and enzymes. As well as honey preparations in tubes for wound treatments, dressing pads pre-impregnated with honey are also commercially available.

Indications

Honey has been used to treat a wide range of wound types with necrotic tissue or slough. Other indications are wound infections, even when they are caused by, for example, *Pseudomonas aeruginosa* or methicillin-resistant *Staphylococcus aureus* (MRSA).⁶³

Action

Honey osmotically draws fluid from the surrounding tissue. This reduce wound oedema and, along with the increased exudate, results in autolytic debridement. The claimed antimicrobial effectiveness of honey may be partly explained by an osmotic dehydration, a low pH-value of 3.0–4.5 and the release of small amounts of hydrogen peroxide or methylglyoxal.⁶⁴ Since honey is a



Absorptive dressings are highly hydrophilic and rapidly absorb exudate from the necrotic, sloughy mass. One gramme of dextranomer can absorb up to 4g of fluid.

natural product, effectiveness, depending on the origin of the honey, varies greatly.⁶⁵

It is claimed that honey has anti-inflammatory properties and also stimulates immune responses. Although the exact mode of action remains unclear, it has been observed that reactive oxygen species production is decreased and TNF- α release is enhanced by honey.⁶⁶

Administration

The amount of honey used depends on the amount of exudate from the wound. We suggest

that, in typical cases, 20ml of honey should be used on a 10cm² dressing. The frequency of dressing changes depends on how rapidly the honey is being diluted by the exudate. Honey is water-soluble and easily rinsed out, even if it is inserted to cavities and sinuses. For moderately-to-heavily exuding wounds, a secondary dressing may be needed to contain seepage of diluted honey from the primary dressing.

Benefits

In addition to the suggested autolytic debridement effects of honey, it is also used because of the claimed antibacterial activities and ability to deodorise wounds.

Contraindications

Relative contraindications are dry, necrotic wounds, as honey may cause further drying. Honey products should not be used in patients with known contact sensitisation to ingredients or patients who are sensitive to bee venom.

Side effects

Side effects of honey as a natural product may result from its lack of standardisation and the possibility of contamination with pesticides, antibiotics or viable spores, including clostridia. Allergic reactions to honey are rare but have been attributed, in some cases, to a reaction to specific pollen in the honey.⁶⁷ Pain associated with the use of honey may result due to the acidity and/or the organic chemicals in it. In some instances, the pain or discomfort has been transitory.



Larvae debridement therapy

The removal of devitalised tissue is an essential component of wound care. Larval therapy, also known as maggot debridement therapy (MDT) or biosurgery, is a form of mechanical debridement whereby live maggots, raised in sterile conditions, usually *Lucilia sericata* (common green bottle fly), are placed on necrotic/sloughy wounds. Maggot secretions contain antibacterial substances that reduce bacterial load by exerting a bacteriostatic effect, and proteolytic enzymes cause eschar degradation by disrupting the tissue collagen matrix. These actions promote wound healing and amplify human fibroblast and chondrocyte growth.⁶⁸

Larval therapy has been around for the last 400 years and has been primarily used for debridement of wounds when traditional methods of debridement (autolytic, mechanical or surgical) are unsuccessful.¹⁴ During the First World War, Baer successfully used sterile larval therapy in the treatment of leg ulcers and osteomyelitis.⁶⁹ With the development of antibiotics and advanced surgical technique, the use of larval therapy decreased and it was only used in chronic wounds as a last resort.⁷⁰ However, in recent years, the treatment is re-emerging, due to the rise in chronic wounds and the emergence of antibiotic-resistant strains of bacteria, such as MRSA.⁷¹

Action

The actions of the larvae are threefold:

- Debridement
- Antimicrobial
- Stimulation of healing.

The larvae feed on necrotic tissue and exudate within the wound, thereby debriding it of devitalised tissue. The digestive juices secreted by larvae contain proteolytic enzymes, including trypsin-like and collagenase, and these selectively debride necrotic tissue, leaving viable tissue unharmed.⁷² The movement of the larvae stimulates exudate production, thus increasing irrigation of the wound and assisting in the removal of bacteria;⁷³ the larvae ingest the liquefied tissue, neutralising the bacteria in their gut.⁷⁴ Additionally, bacteria that are not destroyed in the acidic alimentary canal are contained within a tubular structure, known as the peritrophic membrane, thus preventing contamination.⁷⁴ Larvae also inhibit bacterial activity by producing inhibiting secretions.

Steenvoorde and Jukema⁷⁵ argue that adequate numbers of larvae are necessary to eradicate some Gram-negative species such as *Escherichia coli*; however, Van de Plas⁷⁶ contends that the larvae are antibacterial and useful in the eradication of biofilms. The larvae secretions contain alkaline components, thereby altering the PH of the wound and enabling

the growth factors increasing oxygenation and promoting wound healing.⁷⁷ In studies by Gilead et al.⁷⁸ and Sherman,⁷¹ larvae were associated with increased measurements of granulation tissue. Horobin et al.⁶⁸ suggest that this is due to a wider distribution of fibroblasts within the wound bed, a major cellular component of granulation tissue.

The utility of larvae debridement therapy is well documented in the literature.^{71,73,77-88} Markevich et al.⁸⁶ conducted an RCT of 140 patients with diabetic foot ulcers. Participants were randomised into hydrogel or larval therapy groups (each n=70) and 36 (51%) demonstrated a reduction in necrosis compared with 19 (27%) in the hydrogel group. Dumville et al.,⁸² in an RCT of venous leg ulcers of 267 patients randomised into loose, bagged or hydrogel groups, found that the larvae resulted in speedy removal of necrotic tissue.

There is a re-emergence of the use of larval therapy, particularly for patients who have chronic intractable wounds, who may not be suitable for surgery due to the presence of comorbidities. Larval therapy is selective and rapid, it can be performed easily and quickly, eradicating the discomfort of infection, malodour and necrosis, in a safe and effective way.⁸⁹ However, larval therapy is not suitable for all wound debridement and patients need to be holistically assessed before treatment is initiated.

Administration

Larval therapy can be administered by directly applying loose 'free range' maggots to the wound, or using a biobag (maggots contained in a mesh polyvinylalcohol net dressing). On arrival, the larvae or the biobag should be inspected for activity and if there is none it should be reported to the manufacturer and a replacement sought. Information and specialist training is available to ensure practitioners are competent and proficient in the administration of larval therapy. Patient-advice leaflets are also available to assist patients with any queries they may have regarding their therapy.³³

The rate of exudation is relevant for use of larval therapy, as a sufficient amount of fluids is needed for this therapy to be efficient.

Loose larvae

The recommended dose is 10–15/cm² of loose larvae placed directly on to the wound bed. Sterile maggots approximately 24–48 hours old are applied approximately twice a week and left in place for 24–72 hours. The peri-wound is protected with hydrocolloid strips and a sterile net dressing is placed over the wound. This net is secured with tape to prevent escape of larvae. It also allows drainage of liquefied necrotic tissue to be removed on a secondary dressing and gaseous exchange to occur for the larvae.⁷⁸

Biobag

Alternatively, the net bag is available, called a 'biobag', which contains the larvae, prevents escape and reduces the 'yuk factor' for nurses/patients who sometimes are hesitant in using them. Depending on the size of the wound, one biobag, containing live, sterile maggots and foam beads in a net bag, is placed directly on the wound bed. The biobag is placed directly onto the sloughy/necrotic tissue. The peri-wound skin is protected with zinc paste, or a hydrocollid dressing, to reduce irritation to skin.⁹⁰

There is little difference in outcomes between loose or bagged larvae, although for wounds around toes or crevices, loose larvae may be more beneficial.^{75,91} However, Dumville et al.⁸² reported that, although time for debridement was quicker in the loose group, overall time to healing did not differ between loose or bagged groups. Patients demonstrated no preference over loose or bagged larvae,^{75,84} with patients reporting that ulcer healing, and reducing pain, odour and exudate were of greater priority than the choice of larvae. Spilsbury et al.⁸⁴ reported that a minority of females over 70 years old (8/35 women, 23%) had a negative view of larval therapy and would refuse to consider it as a treatment option. However, they argue that information given prior to therapy is of importance and can influence patient acceptance of therapy.

Benefits

Larval therapy is a cost-effective debriding treatment,^{80,92} which can reduce pain, bacteria and malodour, while promoting wound healing with little or no side effects.⁸⁰ One of the major advantages of larval therapy is that the maggots separate the necrotic tissue from live tissue, allowing for an easier surgical debridement.⁷⁸ The therapy can be easily applied in any environment (inpatient/outpatient) and can be left in place for 48–72 hours.⁷⁸ Newer biobags, where larvae



In recent years, larval therapy is re-emerging, due to the rise in chronic wounds and the emergence of antibiotic-resistant strains of bacteria, such as MRSA



are contained in a net bag, may make it easier to contain larvae and may also be more aesthetically pleasing to both staff and patients.³³

Contraindications

Larvae are contraindicated for use near eyes, upper gastrointestinal tract and upper respiratory tract, and patients with reported allergy to fly larvae, brewer's yeast or soy-bean protein.⁹³ In addition, larval therapy is not suitable for wounds with exposed blood vessels potentially connecting to deep vital organs,⁹⁴ patients with decreased perfusion, or in malignant (cancer) wounds.

Caution must be taken that wounds are never allowed to close over larvae, intentionally or otherwise. Care should be taken if the patient has a known risk, or a bleeding disorder, and it may be necessary to use antibiotics in conjunction with the therapy, particularly if *P. aeruginosa* is present.⁸⁴ Larval therapy should not be utilised in areas of the body subject to pressure, as larvae may become squashed and suffocate.³³ There is the potential to drown the larvae in the presence of heavy exudate.

Side effects

The most common side effect reported is pain.^{71,73,77–86,88} This may be due to agitation of larvae in the wound bed, or changes in the pH, but as yet is not fully understood.

Cost effectiveness

Larvae are expensive (UK 2011 price is £58 loose and £98.79 bagged, but prices vary between countries), but they are effective in rapid debridement of chronic wounds.⁹⁵ Wayman⁹² found that larvae were more cost effective than hydrogel (n=12) for treatment of leg ulcers, but the economic analysis was limited. Sherman⁷¹ reports that larvae have traditionally only been used as a last resort and recommends that they should be used as a first or second line of treatment, to save costs.

Larval therapy can quickly debride wounds requiring grafting and the separation of the necrotic tissue from live tissue allows for an easier surgical debridement.^{71,78} Gilead et al.⁷⁸ argue that costs should be evaluated, not only by the cost unit of dressings, but also by costs associated to reduced length of stay in hospital, decreased amputation rates and reduced complications. However, in their

RCT, Dumville et al.⁸³ documented little difference in costs between hydrogel and larvae, indicating a cost of £96.70 on average more per participant with larvae compared with treatment with hydrogel, but patients' quality of life showed an incremental cost effectiveness of approximately £8826 per QALY gained, £40 per ulcer-free day (QALY 0.011; 95%CI –0.067; 0.071). This was slightly better for the larvae group and healing was slightly faster, on average 2.42 days faster than the hydrogel group.⁸²

Conclusions

There is a re-emergence in the use of larval therapy. Patient interest is growing due to the potential benefits and health professionals are becoming more familiar with this treatment method.⁹⁶ The decision to use larval therapy is influenced by knowledge of their efficiency in debridement, disinfection and stimulation of healing in chronic wounds. Once staff are adequately informed, larval therapy can be performed easily and quickly, eradicating the discomfort of infection, malodour and necrosis, in a safe and cost-effective way.⁹² However, the choice for debridement by larvae therapy requires active participation, where possible, of the patient in the decisions about their own health care.

Technical solutions

This section will describe and discuss some of the most widely-used technologies among the different available options, such as hydrosurgery, negative pressure wound therapy (NPWT) and ultrasound.

Among these, some options, such as hydrosurgery and ultrasound, act via a direct debriding action on the wound and may be defined as direct debridement technologies (DDT). Others, such as low-frequency ultrasound and NPWT, act indirectly, activating elements and conditions in the wound that subsequently promote debridement. These may be defined indirect debridement technologies (IDT).

Direct debridement technologies

Jet lavage/hydrosurgery

Background

The principle of jet lavage debridement (hydrosurgery) is basically an evolution of the lavage of wounds, used since the ancient times in acute wounds and, more recently, in chronic wounds.

Mechanism of action

It is related to water irrigation, which can physically remove foreign bodies, debris and any other kind of loose material from the wound. The more intense and fast the irrigation, the more intense are the energies transferred to the tissues and consequently the more extensive the debridement.

Many different technologies have been developed in this area, and many different devices have been produced. Some are gentle, while others are so aggressive that they may be considered similar to certain surgical tools.⁹⁷

The gentler options can be used for removal of necrotic debris, slough and biofilms and all other types of material with a loose structure that have a weak consistence and may be removed easily. The more powerful options, especially those using the so-called Venturi effect, have the capacity to precisely debride dense fibrotic tissues and materials, and may in some cases be used on bone structures, depending on the velocity and intensity of the jet stream passing through the instrument tip.⁹⁸

The precision and the versatility of this kind of device are so flexible that they can be applied in many different conditions and clinical models, from venous leg ulcers to post-surgical diabetic foot ulcers, depending on their settings.⁹⁹

Another interesting aspect of this technology is the possibility to combine it with antiseptic solutions. This may maximise the antimicrobial activity, which is an important part of the debridement procedure.

When used with the new classes of antiseptics, such as super-oxidised solutions or solutions containing polyhexanide (PHMB; these both have a neutral pH, are not harmful, *per se*, on the tissue and are active against all kinds of infectious material); in particular, the hydro surgical devices may act as a physical and biological debrider.¹⁰⁰

Limitations

The principal limitation of this technology is that it may be painful for some patients and for this reason it should only be used when an adequate pain control can be achieved, such as by use of local anesthesia.¹⁰¹

Another issue is that jet lavage has been suspected to disseminate bacteria in the environment because of the formation of an aerosol during the application. This may contribute to the contamination of the setting in which the procedure is carried out.¹⁰²

Although questionable, this objection emphasises the importance of an adequate education of the staff. The clinicians responsible should not only be trained by experienced staff members, but also supported by a system that includes periodical control of the incidence of nosocomial infections. Air contamination can be prevented by using adequate cuffs or protection that may effectively stop, or at least reduce, the diffusion of the aerosol in the environment.¹⁰³

Cost effectiveness

Costs of jet lavage equipment vary according to the different technologies adopted, but are generally higher than other solutions, depending mainly on the costs of the consumables. On the other hand, the advantage of a fast, precise and effective technique make jet lavage interesting and widely indicated for use in the operation-room setting for complex and vast lesions, which can be effectively debrided in a single session, with local anaesthesia. Therefore, indications are the primary issue with regards to cost

effectiveness; when used for the correct indications jet lavage is claimed to be cost effective, due to a reduction in cost of management in the hospital and shortened hospital stay in some cases.

Ultrasound

Background

The most renowned application of ultrasound (US) in medicine is related to the diagnostic-imaging field, in which they reached a level of sophistication considered the golden standard in many areas of medicine and surgery. However, on the therapeutic side, many applications of ultrasound in the range of the megahertz (MHz) have recently been developed. These include surgical cutting and coagulation in laparoscopy or, to the specific interest of this document, in the debridement of chronic lesions.

Mechanism of action

US can, depending on the frequency and intensity of the mechanical energy transmitted, interfere with many different structures, from inert protein material to cellular bodies, exerting a range of effects that may vary from destruction to dislocation and physical modification.

This characteristic makes this technology suitable for application in different conditions and in different clinical settings; primarily for debriding purposes, but eventually also as an adjunct to the reparative phase.

The application of US in the debriding phase of the management of various types of chronic ulcerations has been difficult until relatively

recent times. Technical limitations related to the difficulties with producing reliable and affordable devices that can safely be applied to the patients have been the primary challenge.¹⁰⁴

Due to impressive technological upgrading, ultrasound equipment now populate the clinical environment with a variety of instruments that have been applied to almost all the clinical models of chronic ulceration with satisfying results.¹⁰⁵

A positive feature of the US approach is that this technology may be used for many different types of tissue, from loose connective tissue to tendon and even bones, with a high level of effectiveness.

Limitations

Similar to hydrosurgery, US technology can modulate the debriding activity and can be strictly controlled by the clinician, whose expertise and confidence with the technique is essential to guarantee the effectiveness of the procedure and avoid the possible complications, such as bleeding and disruption of healthy structures.

This is a positive aspect as well as a limitation; the indications for the use of US vary according to skills of the clinician and may range from very simple to complex procedures, based on the frequency of usage, the power of the instrument available and the type of patients treated.

Another aspect that is relevant for some US devices, as well as hydrosurgery, is the nebulisation of material from the wound bed. If not properly managed, this can be substantial and, due to this aspect, the setting in which the procedures are carried out is of crucial importance for the safety of patients and clinicians.

Barriers and cuffs are indicated, as for jet lavage systems, to counteract this negative feature of US, which limits use in outpatient settings.

Cost effectiveness

Based on our experience, the total costs related to the use of US devices are higher than the direct costs related to purchase of the instrument, but lower when one consider that most of the devices use sterilisable probes and not disposable consumables. This may be interpreted as a saving, but also as a limitation, since only a limited number of patients can be treated in each session, depending on the number of probes available.

Indirect debridement technologies

Negative pressure

Background

In wound management, negative pressure wound therapy (NPWT) is probably the most important technological achievement of the last 20 years. It arose as the result of the scientific development of an empiric observation made, in this case, by plastic surgeons, who noted how negative pressure dramatically improved the course of both acute and chronic wounds.¹⁰⁶

NPWT has also been claimed to have certain indirect debridement properties.

Mechanism of action

Negative pressure interacts with the wound environment on a number of different levels. It acts on the macro-structure as well as on the micro-structure of the lesion, integrating all these effects in a complex activity that promotes wound healing in all the phases of the wound development.

On a macro level, NPWT removes secretion and fluids from the lesion, reduces peri-wound oedema, increases local blood flow and reduces the dimension of the ulcer, as well as the risk of contamination of the wound from external sources.¹⁰⁷

On a micro-level, the stimulation that negative pressure exerts on the cell surfaces and on many of the cellular elements present in the lesion (paralleled by a change in nuclear transcription activity) induces positive modifications in both the shape and function of the cells. It has been demonstrated that NPWT promotes angiogenesis, fibrogenesis and the activity of macrophages and leucocytes.¹⁰⁸

A number of studies on NPWT have been carried out on virtually all clinical conditions related to wounds and the management of wounds; acute as well as chronic, from cardio surgery to the diabetic foot, and from venous leg ulcers to pressure ulceration. Its activity has been confirmed for most of the conditions in which it has been tested.^{109–112}

An interesting option with NPWT is that it can be integrated with antiseptic application. This is the case if the antiseptics are instilled in the system, with the objective to rinse the areas of the wound periodically (as has been done with osteomyelitis), or if they are absorbed on the material used to fill the lesion (such as with PHMB on the gauzes used, as is done with many of the devices currently on the market). This adds an antimicrobial effect to the indirect debridement of NPWT, as the new antiseptics have a better profile in terms of effectiveness and safety, and have been successfully tested in a number of conditions.¹¹³

Limitations

A primary contraindication for the use of NPWT in relation to debridement is the fact that this technology cannot be used in an uncontrolled infection, or when necrotic tissue is present in the wound.

In addition, NPWT should not be applied when local ischaemia is present, when there is active bleeding, or when deep structures, such as vessels, tendons, muscles, joints or bones are exposed in the lesion.

However, in cases where one or more of the contraindications to NPWT are present, it is possible to remove these by additional treatment efforts and then proceed to apply NPWT.¹¹⁴

When applying NPWT on a poorly debrided wound, the dressing changes must be altered accordingly, so that they are more frequent, as the foam or gauze will be more saturated with slough and the NPWT-machine will malfunction, causing problems when the patient is at home.

Cost effectiveness

Many different, and sometimes portable or even disposable, NPWT devices are available. A potential cost saving is related to the possibility of discharging the patient with a portable device until debridement is complete, and then prescribing a disposable NPWT device in case further debridement is needed.¹¹⁵ However, when using a portable system at home, the health professional needs to make sure that the patient can manage the treatment and machine by themselves. Otherwise there complications may occur, in the form of negative impact on the patients quality of life and a non-successful treatment result.

The possibility of shortening the hospital stay and prolonging debridement activity in an outpatient setting supports an improved cost-effectiveness profile for NPWT.¹¹⁶

Low-frequency ultrasound

Background

Low-frequency ultrasound is claimed to provide a debridement alternative to, for example, surgical debridement.¹⁰⁵ However, it is more commonly used for therapeutic purposes.

Ultrasonic waves are also claimed to lead to destruction of bacteria and disruption of biofilms.^{117,118}

Mechanisms of action

While high-frequency ultrasound operates in the 1–3MHz range and transmits the mechanical energy directly to the structures to which they are applied, low-frequency ultrasound (LFUS) works in the kilohertz (kHz) range and does not necessarily need direct contact with the tissue to exert its actions.¹¹⁹

The known mechanisms of action of LFUS vary according to the physical and biological modification that they induce at the cellular level, and occur more frequently in the kHz rather than in the MHz frequency range.¹²⁰

Cavitation is the result of the formation of micro-bubbles, which concentrate the acoustic energy and produce a shearing of cellular structures.¹²¹ This should act selectively, for example leading to removal of necrotic tissue, while healthy tissue is not influenced to the same degree. Microstreaming may be a consequence of cavitation, as it consists of a linear movement of macromolecules and ions around the stationary structure of the cells. The combination of cavitation and microstreaming can interfere with the cellular activity.¹²²

A possible alternative mechanism of action, called frequency resonance, is related to the modification in the structure of proteins and the activation of signal transduction at nuclear level. This can lead to a range of effects at cellular level that impact wound healing, such as leucocyte adhesion, increased angiogenesis and increase of nitric oxide (NO) production.¹²³

As in the case of NPWT, all these effects may indirectly promote the debridement of chronic lesions, shifting them towards the healing phase. The actions of LFUS are mediated by a medium of saline, which is vaporised by the US probe and transmits the mechanical energy to the wound bed.

Clinical studies have demonstrated an improvement in the healing process and positive

effects on the microcirculation in many different models for treatment of chronic wounds.¹²⁴

Limitations

Vaporisation of saline solution is probably the most relevant limitation of this technology. However, it can be managed by applying the same protection suggested for high-frequency ultrasound equipment. Another limitation is the great expertise necessary to effectively manage this technology. It is dependent on the user and requires the staff member using the equipment has specific technical knowledge about the device.¹²⁵

Cost effectiveness

There is no clear information available about cost effectiveness of LFUS; however, it has been suggested that the office-based application of this technology may reduce costs related to hospitalisation of patients, as well as the number of surgical procedures required for debridement.

Conclusions

The possibility of using new technologies in the debridement phase of wound healing is now a reality, with a complex structure and an ever-increasing range of possible solutions relevant for any kind of acute and chronic wound typology.

The role of the clinician is to choose the best possible option for each case, taking into consideration the indications and technical characteristics, as well as the cost–benefit profile of the chosen option.

The limitations of this approach are primarily related to the relatively recent development of the technologies. This means that solid evidence has not yet been produced. This commits the scientists and clinicians working in wound healing and tissue repair to design and carry out studies challenging each technology within the indications for which they are suggested by manufacturers.

Surgical and sharp debridement

Surgical and sharp debridement are rapid methods of debridement and have been in use for many years. We define 'sharp debridement' as a minor surgical bedside procedure, involving cutting away tissue with a scalpel or scissors. 'Surgical debridement' is defined as a procedure performed under general anaesthesia, using various surgical instruments.

Despite the major role of surgical debridement in current wound management, there is little evidence available to document the benefits.^{24,126}

Indications

In general, surgical debridement should be considered only if other techniques are ineffective or the condition of the patient requires rapid, major intervention.

Indications for sharp and surgical debridement include a solid layer of necrotic tissue, when excision and immediate grafting are considered superior to other methods of reconstruction, and when there is a clear demarcation line between viable and non-viable tissue.¹²⁷ However, there are some exceptions, which will be described under contraindications.

Presumed involvement of the deep structures and complications are relative indications for surgical debridement; damage of the vessels results in

bleeding, and this may be significant and require a surgical approach to arrest it. Damage of the nerves and tendons result in loss of function and may also require reconstruction. Even minor debridement in distant parts of fingers, approximate to the nail bed and matrix, may result in impaired nail growth that may also require correction in the future.

Surgical debridement may also be a relevant method in severe cases of wound infection.¹²⁸

Action

Sharp debridement is an action that may be performed by any kind of medical specialist, including nurses, family doctors, dermatologists, podiatrists and other personnel without surgical background. Local treatment protocols and regulatory guidelines regarding the permitted functions of different groups of professionals vary from country to country and, naturally, must be followed. Usually, sharp debridement is performed by the patient bed or in the clinic; however, specific facilities, such as a treatment room, may be an advantage.

Surgical debridement is considered a more invasive action, usually performed by surgeons (vascular, general, trauma, plastic etc) in a facility dedicated to surgical interventions, such as an operating theatre or treatment room. Due to the invasive aspects of this procedure,

special education, qualifications, experience and equipment are required before any kind of surgical debridement can be performed. The surgical debridement procedure may be performed as a single procedure, or as the initial phase of a reconstructive surgery, where debridement is followed by immediate or delayed tissue reconstruction, using skin substitute, skin graft or composite micro-vascular flap grafting. Surgical debridement may be limited to dead tissue removal, or excision may be extended to viable tissue level to obtain a vital tissue bed. This is essential for grafting if immediate reconstruction is performed.

Whenever invasive debridement is planned (minor sharp debridement or more extended surgical debridement), the patient's general status and the anaesthesia requirements should be considered. Necessary laboratory tests, such as general clinical and blood coagulation, should be evaluated before the procedure is initiated. These steps are relevant, even if the initial plan for the procedure is a minimal invasion one. Biochemical blood test and ECG should be performed if an extension of procedure is expected; in this case it should be followed by general anaesthesia. Ideally microbiological investigation of the removed tissue should follow the debridement, whenever this is possible and affordable.

Sharp and surgical debridement should be performed under sterile conditions, regardless of the extent of the invasion. The invaded area should be prepared using antiseptic medication for wound and peri-wound skin antiseptics, covered with sterile drapes or textiles, and the tissue removed or excised using sterile instruments (scalpel blade, scissors, forceps) and gloves. Usually an antiseptic solution is used to clean the wound after the procedure and a sterile dressing containing antiseptic is applied.¹²⁹ It is recommended that part of the removed non-viable tissue, including some

healthy tissue from the wound margin (biopsy), is harvested for microbiological examination, in case there are clinical signs of wound critical contamination or infection.

Spread of infection may occur when debridement is performed. This is often caused by not maintaining sterility, an unprepared site, or use of an improper drape or non-sterile instruments. Although these situations are rare, they do occur, especially in institutions with no protocols for this type of clinical procedure.

Disposable sterile instruments and drapes should be used whenever possible, as the majority of the debrided wounds contain a substantial number of microbes. Special procedure sets, including drapes, gauze and disposable instruments, have been designed for sharp excision or surgical debridement, and are widely available on the market, supplied by various producers.

Administration

Pain is a very important issue in the treatment of wounds, as such possible pain increase during the procedures should be monitored closely. Appropriate anaesthesia is essential in all types of debridement. Some wounds are painless (for example diabetic foot ulcers {neuropathy}, frostbite and some pressure ulcers); in these situations sharp debridement may be performed without significant anaesthesia, but the need for oral or systemic pain-killers must be considered before the procedure.

Patient fear is also an issue. Any procedure should be thoroughly explained to the patient, obtaining a written and signed consent form, if needed and possible.¹³⁰ The patient should be forewarned about any manipulations (injection, tracking of tissue, application of the tourniquet). Children and patients with a low pain threshold should be sedated if anaesthesia is contraindicated.

Local anaesthesia should be used with caution, as the application of anaesthetics (ointments, creams) may be insufficient and infiltrate local anaesthesia. In particular, vasoconstrictive agents (epinephrine) may lead to suppression of local immune protection and thus enhance bacterial load and infection.

Benefits

The primary benefit of sharp and surgical debridement is the speed of removal of dead tissue. These procedures allow fast and effective removal, allowing the healing process to start immediately. A further benefit of sharp excision is the low cost of treatment compared with, for example, surgical debridement.

Among the benefits of surgical debridement is that it is possible to remove dead tissue when other alternative methods are ineffective. This method is quick and essential when the presence of devitalised tissue becomes life threatening for the patient. Another benefit is the possibility to close the wound when immediate reconstruction is performed.

There is some documentation available on the benefits of surgical debridement with regard to increased healing rates, improved status of the wound and a reduction in pain related to the wound status after the procedure.^{105,131–133}

Contraindications

Surgical and sharp debridement are non-selective methods, bringing the risk of over-excision into consideration.^{52,134} Over-excised wounds might heal with scarring, lead to a significant delay in healing (when debridement is brutal/not gentle), or cause damage to the deeper structures may occur. However, this is rarely the case for sharp debridement, as this method is usually performed with the intention to remove small amounts of visible non-viable tissue.

Considerations and precautions should be taken in specific areas, such as temporal areas, neck,

axilla, groin and other areas where neurovascular bundles pass superficially and damage to the vitally and functionally important structures (major blood vessels, nerves and tendons) may occur. In these situations, whenever removal of necrotic tissue is indicated, surgical debridement must be performed by an experienced specialist. Usually these procedures take place in a dedicated facility (operating theatre or procedural room) and with use of appropriate anaesthesia.

Although the risk is small, a potential enlargement of the wound in the deeper layers must be considered and pre-procedural planning and proper evaluation must be performed. Pocketing of the wound, involving the deep structures (blood vessels, nerves, tendons or even bones), may require a major procedure, involving removal and replacement of the affected structures.

As sharp and surgical debridement may be very invasive procedures, special precautions must be taken into account when treating functionally and cosmetically important areas, such as the face, hands, perineum and feet. Excessive damage of the tissue should be avoided and alternative techniques should be considered for treatment of these areas.

Contraindications for sharp and surgical debridement are few. The most important are a poor general state of the patient and the disturbance of the blood coagulation. Usually these contraindications are relative, as sharp debridement is a small intervention that drastically improves the patient state in the majority of cases, leading to the release of cytokines and mediators of the inflammation. Debridement will, in all cases, improve the wound healing if over-debridement is avoided.

However, an absolute contraindication for any sharp debridement is refusal from the patient and choice of alternative treatment method should be

considered. Therefore, the consent of the patient should be obtained whenever possible.

Cost effectiveness

There is little evidence available on these methods with regard to clinical efficacy and economic effectiveness in comparison to other methods of debridement. However, the resources needed to perform these procedures may provide an approximate indication of the level of cost.

Sharp debridement is relatively cheap with regard to staff resources and materials. It can be performed by a single staff member. Materials required include a scalpel or scissors, forceps, curette and sterile materials, such as drapes, gauzes, gloves, and containers for tissue biopsy and swabs. In addition, antiseptic medications for pre-procedure site preparation, wound cleansing following the procedure and proper dressings are required. Special procedure packs, containing drapes, gauzes and disposable instruments, are available on the market.

In comparison, costs related to surgical debridement are high. They include, but are not limited to, the cost of the surgical team (surgeon, nurse, anaesthesiologist, anaesthesia nurse etc), labour, and cost of the operating theatre, anaesthesia and materials for surgery. Surgical debridement also requires a set of surgical instruments, usually including various sizes of scissors, scalpels, curettes, saws, drills, osteotomes, forceps, needle holders and others. The need to stop bleeding often occurs and an electrocautery machine is, therefore, an important part of the equipment. Surgery also requires sterile materials (surgical coats and gloves, drapes, gauzes), antiseptic medications and dressings.



Despite the major role of surgical debridement in current wound management, there is little evidence available to document the benefits.



Conclusions

Surgical and sharp debridement are rapid methods of dead tissue removal from the wound, including devitalised, necrotic tissue or fibrin from the wound and peri-wound skin. These methods can be used for all types of wounds. Although clinically effective, both sharp and surgical methods should be used with some precautions, due to the risk of over-excision and wound damage, which might delay later wound healing. Alternative methods to sharp and surgical debridement should be considered, if non-viable tissue demarcation does not extend deeper than the deep-dermal layer, or the wound bed is covered by fibrin or slough. These situations usually require more gentle methods of debridement, to avoid excess wound-bed damage during the procedure.

Health economics: Wound management and debridement

The distinctive feature of an economic approach to the evaluation of health-care interventions is that it involves explicit consideration of both the costs and the outcomes, or consequences, of an intervention. When resources are scarce, it is not appropriate to make choices on the basis of patient outcomes alone, since maximising benefits for one group of patients may mean fewer benefits for others. With a fixed budget, spending money on an expensive treatment that heals wounds faster may simply mean that it is possible to treat fewer patients in total. Economic evaluation takes account of the benefits as well as the costs of an intervention, measured in terms of the value of other opportunities forgone.

During recent years, positive examples have illustrated the possibilities to reduce both resource utilisation and costs, alongside important improvements in health-related quality of life for affected patients. Successful projects are often associated with a broader perspective including, not only the costs of dressings and other material, but also costs of staff resources, frequency of dressing changes, total time to healing and quality of life. Several cases have also focused

on education of physicians and nurses, together with more effective management of ulcers as fruitful actions.

From the resource utilisation point of view it is essential to analyse debridement as an integrated part of wound management to achieve a specific end point, such as healing. Currently these aspects of the various debridement techniques have not been thoroughly examined.

Thus, this introduction to the health economy of debridement will not go in to detail regarding the cost effectiveness of various techniques, but instead focus on the overall structures of costs, with a reference to existing literature on debridement and non-healing wounds.

Health economics and factors related to healing of non-healing wounds

In patients with hard-to-heal diabetic foot ulcers (those with deep foot infections), the dominating factors related to high cost have been identified as the number of surgical procedures, length

Table 4. Resource utilisation and debridement

Surgical procedures (theatre time, clinician time, disposables)	Frequency of dressing changes and by whom (staff, patient, family)
Debridement (material, number of procedures, time, category of staff)	Dressings, drugs, and other disposables and appliances
Inpatient stay (bed-days, clinic)	Antibiotics and other drugs (duration , dosage)
Diagnostic and laboratory tests	Complications and adverse reactions
Facility time and visits (clinic or outpatient setting, category of staff)	Outcome: time to heal, healing rate, time to clean ulcer etc.

of hospital stay and time to healing.¹³⁵ In a prospective study following diabetic patients with foot ulcers until healing, with or without amputation,^{136,137} the highest costs were for inpatient care and topical treatment of wounds. The costs for antimicrobial drugs, outpatient visits and orthopaedic appliances were low in relation to the total costs in both categories of patients. In the same study, the total cost for healing a foot ulcer was strongly related to the severity of the lesion and comorbidities.¹³⁷

When assessing use of resources, it is important not to focus on individual items, such as dressings or procedures, but to adopt a broader view of the total resource use.^{138,139} Table 4 provides an overview of the resource consumption related to debridement.

Additional costs may be related to rehabilitation, transportation, home care and social services, loss of productivity and reimbursement, depending on whether you apply a societal or a private payer's perspective.

Cost of wound management: Existing evidence

As a very limited amount of data exist for the cost effectiveness of debridement, the results from studies of the costs of non-healing wounds may inform cost structures related to debridement.

Total cost of interventions

Product costs are often considered to be synonymous with the cost of care;¹⁴⁰ however, the purchase price of, for example, dressings, rarely forms a significant portion of the actual cost of care.^{141,142} These dressing costs are often negligible in comparison with other factors, such as costs associated with frequency of dressing changes, physician (surgeon) and nursing time, effectiveness in relation to time-to-heal, quality of healing (avoidance of ulcer recurrence), ability to return to paid employment and the cost of the care setting.^{141,142} Cost-cutting exercises that focus on the use of less costly dressings could in fact result in higher overall costs, if dressing-change frequency is increased (necessitating increased nursing time) and time-to-heal is extended.

A number of reports have demonstrated the cost-effectiveness of different technologies and dressings used for the treatment of hard-to-heal wounds. Although many of these products are more expensive than the comparison treatment, the use of them may be cost-effective, if they result in less frequent dressing changes and/or in more effective or faster healing.^{136,143,144} It is important to be aware that a treatment could be cost-effective in one group of patients or for one type of wound, but not in another type. An intervention could also be cost-effective when used in one setting or country but not in another.^{138,139,145}

Time to healing

A key theme in most studies are high costs associated with extended time to healing for hard-to-heal wounds. Most commonly, the size and duration of ulcer have been related to outcome^{146,147} and increased resource utilisation.^{148,149} A study by Tennvall et al.¹⁴⁸ confirmed that leg ulcers with an area of $\geq 10\text{cm}^2$ and of longer duration (≥ 6 months) are the most expensive. The cost, for example, of treatment for a venous leg ulcer of less than 6 months in Sweden was estimated as €1827 (EUR) compared with €2585 for an ulcer of greater than 6 months' duration.¹⁴⁸

Additional costs related to hospital and home care setting

Many health-economic studies in non-healing wounds have focused on reduction in hospital stay and treatment at hospital based specialist clinics. However, a substantial number of resources are used in outpatient facilities in primary care/home care. When analysed according to care setting, home health care accounted for the largest proportion (48%) of the total cost of treating venous leg ulcers in the USA.¹⁴¹ A study in the UK calculated that, in 2000, the mean annual cost per patient for treatment at a leg ulcer clinic was €1205 and by community nurses was €2135.¹⁵⁰ The finding that home health care accounts for a significant proportion of the total medical costs suggests that promotion of high-quality care based in outpatient clinics appears likely to improve cost efficiency. This can be illustrated by a Swedish study in primary care, where a system for early diagnosis of lower leg ulcers and a strategy to reduce frequency of dressings changes resulted in a substantial reduction in resources used and economic cost.^{148,151}

These studies suggest the importance of organisation in wound care, as well as coordination of treatment strategies, to achieve an optimal care, both with regard to outcome and cost.

The health economy of debridement

Debridement is considered an essential part of wound management, but the evidence supporting debridement as a primary treatment regimen to improve healing is sparse. The evidence primarily consists of self reporting from treating physicians and post hoc analysis of RCTs. As a consequence, the health economic data specifically related to debridement techniques are limited.

The literature listed in Table 5 covers the identified studies including a cost-effectiveness analysis of selected debridement techniques.

Need for studies on the cost-effectiveness of debridement

Evidence, including health economic data, will become increasingly important in a situation where the impact of non-healing wounds on society, as well as on the individual, is clarified and the resources of the health-care system are scarce. For approval of new treatment strategies these data may become mandatory in many countries.

However, differences in reimbursement procedures, health-care organisation, salaries of staff members and facilities available in the various European countries, make it difficult to define clear-cut recommendations with regard to health economics. Furthermore, methodological difficulties, which are seen in the existing studies, demonstrate a need to increase the knowledge about economic evaluation with wound management in general. An overview of the methods of economic evaluation is included in the EWMA Document *Outcomes in controlled and comparative studies on non-healing wounds*.¹⁴⁹ For a more complete discussion of economic evaluation in health care see Drummond et al.¹⁵²

Table 5. Existing studies on cost and resource utilisation of debridement

Author(s) & date of publication	Type and results
Wayman (2000) ⁹²	A study including 12 patients with venous leg ulceration and deemed to require debridement. Treatment with larval therapy was compared with hydrogel dressing treatment. Effective debridement occurred with a maximum of one larval application in all six patients in that group. Conversely, two patients (33%) in the hydrogel group still required dressings at 1 month. The median cost of treatment of the larval group was £78.64 compared with £136.23 for the control treatment group (hydrogels; $p \leq 0.05$).
Soares (2009) ⁹³	Cost effectiveness and cost utility was analysed extensively, alongside a 12-month RCT comparing larval therapy with hydrogels, in the debridement of leg ulcers. Treatment with larval therapy cost, on average, £96.70 (GBP) more per participant per year compared with treatment with hydrogels. Healing time was on average 2.4 days shorter with larval therapy ($p = n/s$) and a slightly better health-related quality of life was seen. It was concluded that the treatment strategies were likely to produce similar health benefits and cost; however there was considerable uncertainty regarding outcome estimates in the study, especially due to drop out rate and comorbidities. This ambitious study illustrates the complexity and challenge of performing these kinds of studies.
Caputo et al. (2008) ⁹⁹	In a comparative study hydrosurgery (Versajet; Smith & Nephew) was compared with conventional surgical debridement in lower extremity ulcers. Procedural time and utilisation of consumables were recorded. It was concluded that hydrosurgery resulted in a shorter debridement time, with a reduction in use of pulsed lavage and saline indicating potential cost savings. However there was no difference with regard to median time to healing or healing rate comparing the two strategies.
Lewis et al. (2001) ¹³⁴	In a systematic review of clinical and cost effectiveness of debriding agents in treating surgical wounds by secondary intention, it was concluded that no evaluations compared the cost effectiveness of two different types of modern dressings. All four studies included in the evaluation compared an autolytic debridement method with traditional gauze dressings soaked in various antiseptic solutions. Most studies included suggested positive effects with regard to clinical and cost effectiveness; however, these studies did not support the superiority of one dressing over another.
Graninck et al. (2006) ¹⁵³	Hydrosurgery was found to reduce the number of surgical procedures required to achieve a clean wound bed, in a range of acute and chronic wounds (mean 1.2 vs 1.9 procedures per patient, for hydrosurgery and conventional debridement, respectively). In the study the reduction of number of procedures was estimated to an overall saving in the cost of debridement of \$1900 (USD).
Mosti (2006) ¹⁵⁴	This retrospective evaluation claims that hydrosurgery results in reduction of in hospital stay related to the debridement of hard-to-heal leg ulcers.
Mulder (1995) ¹⁵⁵	In a very small retrospective analysis of gel versus wet-to-dry (moistened saline gauze) for debridement of dry eschar, it was shown that the daily cost was higher with the hydrogel/polyurethane method, but more cost effective taking account of time required to achieve $\geq 50\%$ debridement along with time to change dressings and amount of material needed.

Debridement algorithm

The algorithm included in this chapter reflects the consensus opinion of the authors behind the document, based on their personal experience. The aim is to provide a clear description of the general pathway of debridement, as well as a proposal for a structured approach to choosing between the appropriate techniques.

The suggested pathway of debridement is illustrated in the process cycle, shown in Fig 7.

Fig 8 illustrates a possible pathway to direct the choice of debridement technique. As a starting point we have chosen the time needed for treatment, and availability of the technology in the various treatment settings and situations, with the objective to provide a simple model that is suitable for daily clinical use. However, for any choice of debridement technique, it is important to consider the following parameters that may influence the decision:

- Pain
- The patient's environment
- The patient's choice and consent
- Biological age and comorbidities
- Quality of life aspects
- Skill of the care giver
- Resources of the care giver



... to provide a clear description of the general pathway of debridement, as well as a proposal for a structured approach to choosing between the appropriate techniques.

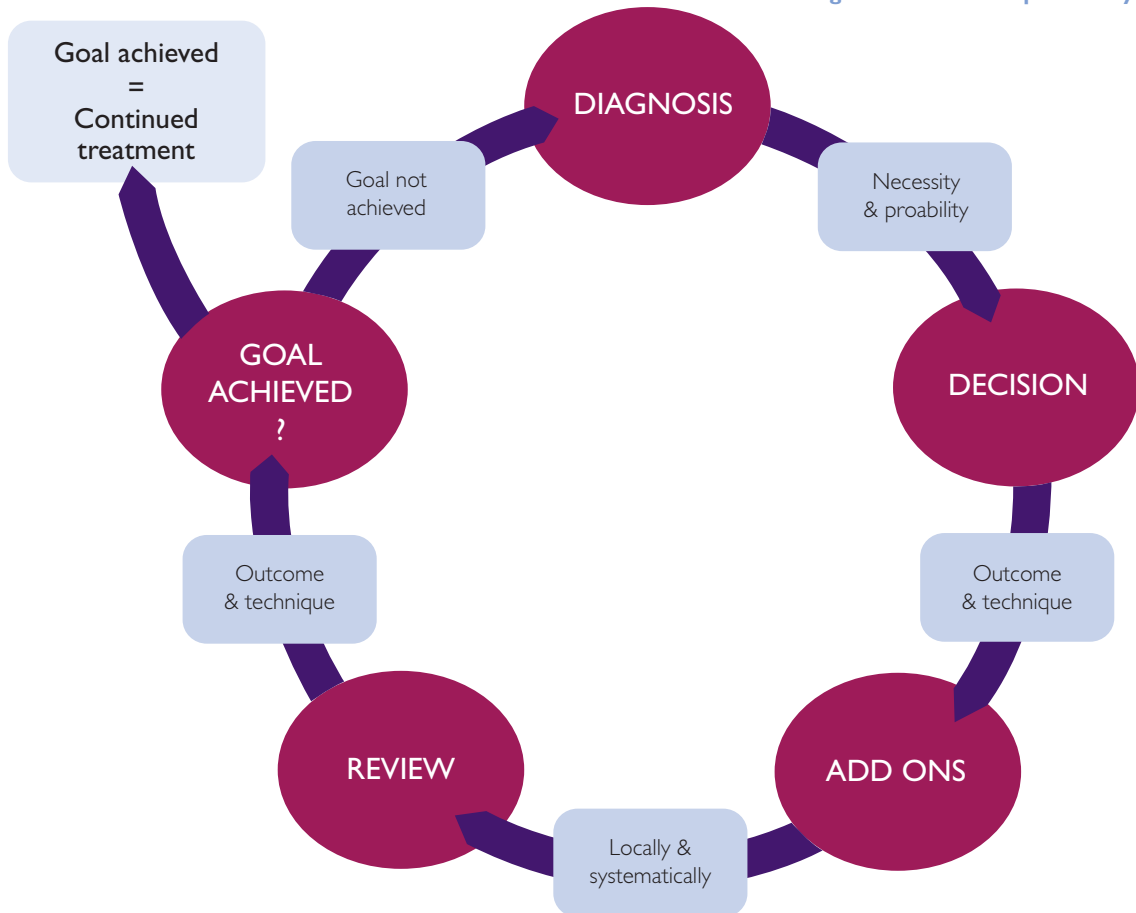


- Regulations and existing guidelines.

In addition, cost efficiency of the various techniques may be worth considering before choosing between different options that are clinically relevant and suitable for the patient. These parameters are described in detail throughout the document, but a short list of the most important aspects related to each of the techniques can be found in Fig 8.

Finally, it should be emphasised that any the listed technologies may be the most suitable option for debridement with regard to a specific patient or treatment situation. ■

Fig 7. Debridement process cycle



Terminology

Diagnosis:

Diagnosis of bioburden, tissue type and factors influencing debridement.

Decision:

Decision on the outcome that should be achieved, the time by which it can be achieved and, depending on this, the techniques that should be used.

Add on:

Additional measures needed to secure a successful debridement process, such as optimising tissue for debridement, locally and additional systemic measures to secure successful debridement, e.g. relieve pressure, treat infection, induce blood flow and optimise comorbidities.

Review:

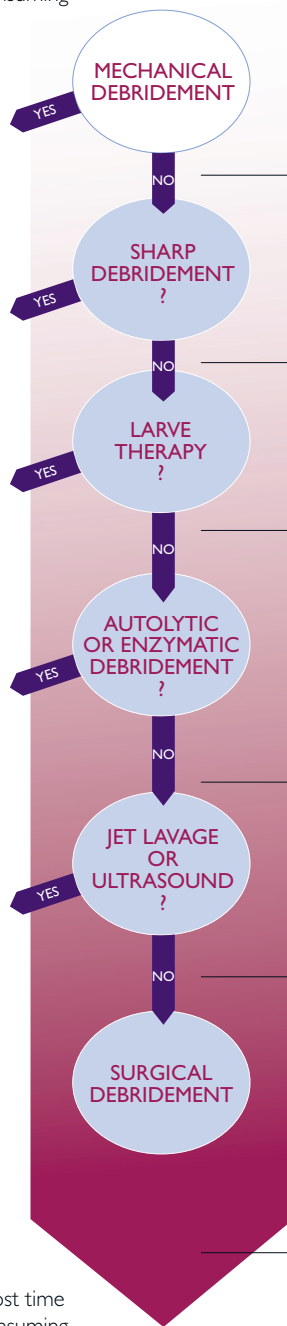
Review whether the outcome has been successfully achieved and whether the chosen debridement technique had proven to be valid in the specific treatment case.

Goal:

If optimal debridement result has been achieved, continue the management of the individual with the wound. If optimal debridement has not been achieved, re-diagnose and repeat the debridement process cycle.

Fig 8. Choice of techniques: Benefits and disadvantages related to various techniques

Least time consuming



BENEFITS

DISADVANTAGES

Very fast method
 No special expertise needed (easy to use)
 Modern mechanical debridement products are claimed to cause little to no pain
 No damage to healthy tissue (selective debridement).

Traditional wet-to-dry debridement may result in increased risk of infection and risk of damage to healthy tissue and pain
 Not efficient in cases of thick, tenacious slough and hard necrosis (demand prior softening).

Fast method
 Cost and resources: few resources needed with regard to staff and materials
 Efficient in wounds with a solid layer of necrotic tissue
 Suitable for exudative wounds and, in some cases, infected wounds.

Risk of infection, if sterile conditions are not ensured.

Reduce pain, bacteria and malodour
 Cost and resources: few resources needed
 Separate necrotic tissue from living tissue.

May be painful
 Contraindicated for some parts of the body, for patients with decreased perfusion, wounds with exposed blood vessels connecting to deep vital organs, and in cancer wounds.

Easy to use
 Cost and resources: may be cost saving due to fewer dressing changes (decrease in staff hours)
 Little or no pain
 No damage to healthy tissue (selective debridement)
 Autolytic: may provide exudation management (if dressing has absorptive properties).

Risk of allergic reactions to ingredients of the dressings and risk of inflammation
 Some dressings are not suitable for highly exudative wounds (enzymatic, hydrogels, occlusive dressings)
Enzymatic: Need a moist environment to work effectively; may lead to excessive production of exudate (not suitable for highly exudative wounds)
Autolytic: The debridement process is time consuming; contraindicated for infected wounds.

Jet lavage: Flexible modes of action (in various types of products) suitable for different wound conditions
Ultrasound: Can interfere with many different structures and has a range of effects, varying from destruction to dislocation and physical modification.

Equipment is not generally available in the various types of treatment settings
 Cost effectiveness: cost of equipment is high
 For hydrosurgery especially, skilled staff, treatment room and anaesthesia are additional costs
 May be painful (if no pain control).

Efficient in wounds with a solid layer of necrotic tissue
 Suitable for exudative wounds and, in some cases, infected wounds.

Cost and resources: need for skilled staff, anaesthesia, treatment room/operation room etc
 May be very time consuming to provide resources needed
 Risk of removing healthy tissue
 Risk of infection, if sterile conditions are not secured
 Not suitable for patients with decreased perfusion
 Special precautions must be taken into account when treating functionally and cosmetically important areas.

Most time consuming

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Appendices

Appendix I. Literature review of debridement methods

This literature was undertaken as a prelude to a Position paper on debridement to be published by the European Wound Management Association (EWMA). In order to achieve this, three databases were interrogated: Medline, Embase and Cochrane Database.

A search strategy was instigated to allow for the identification of a broad range of methods and results of using different techniques in the debridement of wounds

The search terms used were as follows

- 1 Debridement
- 2 Gauze or Wet-to-Dry
- 3 Dressings or alginate or hydrofiber or hydrofibre or hydrocolloid or Granuflex or Tegaserb or Aquacel or Combiderm or Duoderm
- 4 Hydrogel or Intrasite or Sterigel or Granugel or Nugel or Purilon or Vigilon
- 5 Zinc oxide
- 6 Hypochlorite or Hydrogen peroxide
- 7 Malic acid or benzoic acid or salicylic acid or propylene glycol
- 8 Iodoflex or Iodosorb
- 9 Dextranomer or Cadexomer or Xerogel or Eusol or Debrisan
- 10 Dakin
- 11 Collagenase or fibrinolytic or proteolytic or Trypsin or streptokinase or Varidase
- 12 Papain
- 13 Honey
- 14 Maggot or larva
- 15 Jet lavage (Versajet or fluidjet)
- 16 Ultrasound
- 17 Negative pressure or vacuum assisted closure
- 18 Laser
- 19 Electrical stimulation
- 20 Surgical or sharp
- 21 Pain
- 22 Granulation
- 23 Cost

Each search term (2–23) was combined with search term 1 and outputs were identified from the databases. Where there were a large number of outputs (>500) these were restricted to clinical trials.

Method of paper selection

Following the identification of papers in each category as define in the search strategy, the papers were scrutinised to ensure that they were appropriate for the review taking place. A first sift was undertaken to exclude papers that did not fulfil the remit of the literature review. In addition, duplicate citations were deleted. This led to the following numbers of citations. Note that these citations are not mutually exclusive. Some citations may appear in more than one category.

No.	Search term	Citations
2	'Gauze' OR 'wet-to-dry'	64
3	'Dressings' OR 'alginate' OR 'Hydrofiber' OR 'hydrofibre' OR 'hydrocolloid' OR 'Granuflex' OR	204
4	'Hydrogel' OR 'Intrasite' OR 'Sterigel' OR 'Granugel' OR 'Nugel' OR 'Purilon' OR 'Vigilon'	130
5	'Zinc oxide'	14
6	'Hypochlorite' OR 'hydrogen peroxide'	107
7	'Malic acid' OR 'benzoic acid' OR 'salicylic acid' OR 'propylene glycol'	25
8	'Iodoflex' OR 'Iodosorb'	21
9	'Dextranomer' OR 'cadexomer' OR 'Xerogel' OR 'Eusol' OR 'Debrisan'	81
10	'Dakin'	10
11	'Collagenase' OR 'fibrinolytic' OR 'proteolytic' OR 'trypsin' OR 'streptokinase' OR 'Varidase'	231
12	'Papain'	52
13	'Honey'	57
14	'Maggot' OR 'larva'	38
15	'Versajet' OR 'fluidjet'	5
16	'Ultrasound'	25
17	'Negative pressure' OR 'vacuum-assisted closure'	61
18	'Laser'	27
19	'Electrical stimulation'	15
20	'Surgical' OR 'sharp'	68
21	'Pain'	106
22	'Granulation'	62
23	'Cost'	86

Appendix 3. Safety checklist for clinician before commencing debridement procedure

Patient address label	
Hospital no.:	DOB:
Date of procedure:	Time of procedure:
Type of procedure:	
Debridement checklist	
Complete each box: Yes=Y No=N Not applicable=N/A	
Verification of patient	
Holistic patient assessment	
Wound assessment complete	
Method of debridement: Information provided and discussed	
Written informed consent signed	
Equipment set up	
Relevant lab reports available (Hb, Coag etc)	
Vascular assessment (ABPI, toe pressures etc)	
Analgesia documented	
Any known allergies noted	
Procedure to be performed documented	
Site marking, noting patient position	
Procedure documented	

Signature: _____

Appendix 4. Mechanical debridement, excluded articles

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