Nanocrystalline silver foam dressing use in diabetic foot ulceration

Alistair Bielby

The development of a foot lesion is a pivotal event for any individual with diabetes (Edmonds et al, 2004a). The insidious pathophysiological and pathomechanical consequences of diabetes coupled with the demanding functional role of the foot creates conditions in which achieving incident-free healing of foot lesions is problematic. This article includes a case study describing how a nanocrystalline silver foam dressing was successfully employed in the treatment of a diabetic foot ulcer that had deteriorated from a seemingly innocuous abrasion to a limb-threatening wound. This case illustrates how the dressing was effective in exerting an antimicrobial effect while simultaneously maintaining moisture balance at the wound–dressing interface, such that conditions for wound healing were optimised.

Article points

1. The management of diabetic foot ulceration requires a holistic approach.
2. The moisture balance at the wound–dressing interface is critical in the management of diabetic foot ulceration.
3. Microbial control is problematic but essential in diabetic foot ulceration.
4. Nanocrystalline silver foam dressing effectively combines antimicrobial and moisture managing properties.

Key words

- Wound bed preparation
- Moisture balance
- Infection
- Nanocrystalline silver

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The healing of any wound can be complicated. Both intrinsic and extrinsic factors influence the wound so that orderly and predictable progression through the healing cascade cannot be standardised between individuals. In the case of the diabetic foot ulcer (DFU), intrinsic pathobiological abnormalities coupled with detrimental extrinsic influences (such as poor glycaemic control and weight-bearing forces) combine to create circumstances in which linear progress through the normal phases of healing can be difficult to achieve (Falanga, 2005). Thus, in order to optimise the possibility of lesion resolution it is necessary to adequately address those intrinsic and extrinsic influences to which the wound is sensitive and which, if left unopposed, are liable to interfere with and complicate the healing process.

This calls for a holistic approach to wound management where intervention at the level of the wound bed is teamed with adequate consideration of biomechanical, systemic, circulatory, behavioural and metabolic elements.

Managing the wound bed

Wound bed preparation involves consideration of the principles required to stimulate healing

Page points

1. The TIME framework considers tissue, infection and moisture management as well as monitoring wound edge advancement.
2. Creating the optimal moisture levels in a diabetic foot ulcer means the wound is sufficiently moist to promote epithelialisation and prevent eschar formation.
3. Diabetic foot ulcers are vulnerable to infection, and should infection occur immunopathy can increase the severity.
4. The recognition of infected diabetic foot ulcers can be obscured by neuropathy and ischaemia.

and the removal of barriers to healing (Moore, 2005). The principles embodied in wound bed preparation are formalised within the TIME framework (Schultz et al, 2003) which comprises of:

- Tissue non-viable
- Infection and/or inflammation
- Moisture imbalance
- Edge of wound non-advancing or undermining.

The TIME framework dictates a clear and concise format to wound assessment. It directs practitioners in the systematic evaluation of the wound environment, aids identification of factors intrinsic to the wound which are impeding healing and thereby informs the selection of wound care products and treatment interventions.

When applying the TIME framework the first three components – T, I and M – should be assessed in a logical and step-wise manner. The impact of manipulating these components within the wound bed is then evaluated via examination of the fourth component of the framework: E. The four components thus complete a circular feedback of care where practitioners are directed to continually review the elements of the TIME framework until healing is achieved (Dowsett and Claxton, 2006).

TIME management

It is impossible to consider the management of wound bed infection and moisture balance in isolation since the two are inextricably linked to one another and to the other components of the TIME framework.

- **T**: the presence of devitalised tissue within the wound bed serves as a growth media for bacterial pathogens thereby encouraging infection.
- **I**: wound infection results in increased quantities of wound exudate which impede the maintenance of an optimal wound moisture balance.
- **M**: ineffective moisture management can lead to maceration and resultant compromising of the skin barrier function, increasing the risk of infection.
- **E**: keratinocyte migration and hence epithelial advancement is impaired both when the wound environment is too dry or too moist (Winter, 1962; Morison, 2005).

I is for infection

The pathological triad of arteriopathy, neuropathy and immunopathy coupled with the location and function of the foot render the DFU extremely vulnerable to infection.

The initial risk of infection is increased by immunopathy. This also makes the infection both more severe and refractory to treatment (LeFrock and Joseph, 1995). In addition, the reduction in tissue perfusion associated with arteriopathy is accompanied by a decline in tissue viability – hence, the detrimental consequences of infection are increased.

The anatomical location of the foot and its functional role requiring repeated surface contact and weight baring means that foot lesions are at elevated risk of contamination and harbouring subsequent infection (Marshall et al, 1987; Tytiun et al, 2005). Diabetes-related changes in foot function, such as reduced joint mobility and resultant elevated foot pressures, may also play a part in the development of infection since bacterial growth is enhanced in tissues subject to high forces of compression (Falanga, 2005).

Although the harmful consequences of infection can be limited by prompt recognition and intervention, the presence of neuropathy and ischaemia can both mimic and obscure the cardinal signs and symptoms of infection, confounding timely diagnosis and treatment (Cavanagh et al, 2005; Edmonds, 2005). The foot in diabetes is thus at increased susceptibility to infection, yet recognition of infection is reduced and the consequences of infection are more severe. As a result, although not all DFUs become infected, when infection does occur the consequences may be limb threatening (Cavanagh et al, 2005).

M is for moisture

Although the advantages of moist wound healing have been established for over four

Page points

1. Dressings for diabetic foot ulcers should manage the microbial and moisture management issues.
2. The ionic form of silver has powerful antibacterial properties which have been utilised in nanocrystalline silver dressings which incorporate a layer of foam to draw off excessive moisture.
3. Appropriate and informed action can be taken to facilitate, potentiate, rectify or nullify processes within the diabetic foot ulceer wound bed.
4. Nanocrytalline silver foam dressing provides an efficient means of addressing the moisture balance and infection elements central to the TIME framework and successful wound healing.

decades and are widely advocated (Winter, 1962), in the context of the DFU the concept cannot be uniformly applied (Edmonds et al, 2004b).

In some situations, such as neuroischaemic ulceration, mummification and the establishment of dry gangrene is more appropriate than hydration of the wound (Edmonds et al, 2004b). In addition, glabrous plantar skin is prone to maceration – this reduces its effectiveness as a barrier to microbial ingress and thereby increases the risk of infection (Vowden and Vowden, 2005).

As such, a very subtle balance is needed so that maceration of tissue is avoided while conditions sufficiently moist to promote epithelialisation and prevent eschar formation are maintained (Falanga, 2005). Attaining the optimal moisture balance also results in the appropriate level of proteolytic activity in the wound bed, thus facilitating autolytic debridement and reduced inflammation (Bishop et al, 2003).

In consequence, DFU management frequently necessitates a dressing which can fulfil differing yet complimentary functions, most frequently those of microbial and moisture management.

Nanocrystalline silver foam dressings

The antimicrobial properties of silver have been exploited for medicinal purposes for well over a century (Masson, 2005). It is now understood that it is the ionic form of silver (Ag^+) that exerts this effect (Masson, 2005). The antibacterial properties of silver dressings are therefore dependent upon the amount of Ag^+ made available and the time scale of this release.

Nanocrystalline silver dressings have been developed as a means of achieving the release of Ag^+ to maximise therapeutic benefit. The surface of the dressing has a coating of extremely small (~15 nm) silver nanocrystals – making it highly porous with a large surface area. This structure means that in contact with water Ag^+ is released rapidly, at therapeutically effective concentrations and in a sustained manner (Masson, 2005).

The nanocrystalline silver foam dressing comprises a nanocrystalline silver-coated wound contact layer laminated to highly absorbent polyurethane foam. Thus, the antimicrobial effects of nanocrystalline silver are combined with a moisture-balancing foam that draws excess exudate away from the wound surface. In this treatment, the I and M of TIME are addressed simultaneously. *Appendix 1* contains a case study that describes the use of such a dressing in a non-healing wound.

Conclusions

In terms of wound bed management, the TIME framework provides an effective means by which clinical observations may be interpreted in terms of the underlying cellular abnormalities (Morison, 2005). Appropriate and informed action can then be taken in an attempt to facilitate, potentiate, rectify or nullify processes within the wound bed, in order to aid progression through the healing cascade and achieve wound closure.

At presentation Mr H was correctly regarded as extremely high risk, having already lost a toe digit just weeks earlier due to the presence of infection. Given this history it was essential that his initial infection was rapidly and effectively addressed. It was also vital that the wound environment be carefully managed in order to achieve closure within an optimum time period, avoiding further incidents which might rapidly necessitate admission or amputation with all of the associated costs – both financial and emotional – that would be incurred as a result.

The case study presented above illustrates how a nanocrystalline silver foam dressing provides an efficient means of simultaneously addressing the moisture balance and infection elements central to the TIME framework. By concurrently exerting an antimicrobial effect while maintaining the necessary delicate moisture balance at the wound-dressing interface, conditions for healing are optimised. ■

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Case points

1. Mr H had an area of painless grade 2 ulceration to the space between first and third toes following the amputation of the second toe.
2. Mr H's ulceration was classified as neuroischaemic in nature.
3. Mr H was diagnosed with type 2 diabetes diagnosed approximately 12 years ago. Blood glucose control had been poor since diagnosis.

Appendix 1. Case study.

The patient, Mr H, a 75-year-old male, self-referred to the diabetic foot clinic (DFC) with an area of painless grade 2 ulceration (Wagner classification) to the space between first and third toes of his left foot following the amputation of the second toe (see *Figure 1*).

Doppler ultrasound assessment revealed posterior tibial and dorsalis pedis pulses to be weak and monophasic bilaterally. Sensory testing with a 10 g monofilament elicited inconsistent responses to the stimuli. Given the Doppler findings, the absence of pain and insensitivity to the 10 g monofilament, Mr H's ulceration was classified as neuroischaemic in nature.

Mr H had a varied medical history including type 2 diabetes diagnosed approximately 12 years ago. Blood glucose control had been poor since diagnosis and remained sub-optimal on the current regimen of pre-mixed short- and intermediate-acting insulin.

Other medical conditions included:

- rheumatoid arthritis
- two previous episodes of deep vein thrombosis in the right leg
- renal failure
- hypertension.

He was familiar with the DFC service having, attended for treatment during an episode of digital ulceration which had been resolved successfully 5 months previously.

Case points

1. Neuropathy prevented the early detection of a foot wound, which resulted in digit amputation.
2. Following hospital discharge, exudate recommenced and wound assessment was carried out according to the TIME framework.
3. Wound edges were sharp debrided and the wound was dressed with appropriately shaped nanocrystalline silver foam. Antibiotics were also administered and a stiff soled rocker-bottomed sandal worn during weight-baring activities.

Wound history

The emergency amputation of Mr H's second digit had taken place 20 days previously in Spain where Mr H had been holidaying. Prior to departing for his holiday, Mr H had noted a small abrasion on his left second toe but had deemed it insignificant and failed to seek medical advice despite prior episodes of foot ulceration. While on holiday this apparently trivial lesion began to deteriorate. The wound increased in size, yielding a discharge which was evident on Mr H's socks, and the digit became dactylitic. Owing to the presence of extensive sensory neuropathy, Mr H did not perceive any of the discomfort that would otherwise have accompanied such tissue damage.

The soiling of Mr H's socks with exudate was noticed by his wife and, coupled with the obvious and visible deterioration in the digit, prompted him to seek medical advice.

Inpatient care

Upon visiting the local hospital Mr H was immediately admitted as an inpatient. Systemic antibiotic therapy (levofloxacin) was commenced to limit the further spread of infection and warfarin was discontinued in anticipation of the need for surgical intervention. On the sixth day of admission Mr H underwent surgery to remove the digit which had become necrotic and unsalvageable.

Following the removal of the digit and suturing of the wound inpatient care, including systemic antibiotic therapy and daily dressing changes, continued for a further 15 days. At this point the amputation site appeared to be closed and Mr H was discharged. Mr H discontinued antibiotic therapy, recommenced warfarin and returned home 2 days later, some 36 days since departing on holiday.

Diabetic foot clinic care

One day after Mr H's return he noticed that the wound had re-opened and was discharging once again (*Figure 1*). Concerned by the 'gunky' appearance of the wound Mr H contacted the DFC the following morning and was seen that afternoon.

At this time the wound surface comprised of a mixture of thin, non-adherent slough and unhealthy, pale, friable granulation tissue which bled easily – features suggestive of infection (Cutting and Harding, 1994). Further evidence of local infection was to be found around the wound, where a peri-wound erythema was apparent, and in the seropurulent nature of the wound exudate. Given the presence of infection, a wound swab was taken and amoxicillin and flucloxacillin were commenced pending the swab results.

The following elements were identified and prioritised as treatment objectives at this time.

- T: removal of the macerated peri-wound tissue and devitalised tissue within the wound bed.
- I: reduction of the bacterial burden within the wound.
- M: achieving an optimum wound bed moisture level to prevent maceration and facilitate healing.

At review, the advancement of the epithelial edge of the wound (E), or a lack of, would reflect the adequacy to which T, I and M had been addressed and the effectiveness of the chosen treatment strategy.

The devitalised, macerated tissues at the wound margins were sharp debrided, thereby removing a potential growth media for infective microorganisms. The wound was then dressed with carefully shaped nanocrystalline silver foam. The dressing could be readily cut to a shape to fit the wound site and its soft texture prevented damage to the adjacent digits. This dressing was selected as it allowed the following objectives to be achieved.

- Effectively manage the wound exudate.
- Prevent further peri-wound maceration.
- Exert an antimicrobial action to compliment the antibiotics before further tissue damage and wound deterioration occurs.
- Limited abrasion between digit

inner surfaces.

Mr H was also given a stiff soled, rocker-bottomed sandal to use when weight-bearing. The sandal prevented dorsiflexion at the metatarsophalangeal joints during the propulsive phase of gait which might be detrimental to wound healing. Within the DFC Mr H also received input from the diabetologist and diabetes specialist nurse to optimise medical and blood glucose management – and thereby healing potential.

Outcome

Review of the wound 24 hours later revealed significant improvement. The wound bed appeared markedly more healthy in appearance with less slough reduced peri-wound erythema. This suggested that the choice of dressing coupled with antibiotic therapy was effective in addressing the moisture imbalance and infection within the wound, thereby facilitating healing events.

Mr H was reviewed daily for the next 2 days and the wound was re-dressed with nanocrystalline silver foam. At each review the wound continued to improve.

The wound swab result was returned after 48 hours and indicated a heavy growth of *Staphylococcus aureus*. The antibiotic regimen was therefore left unchanged.

After 14 days, antibiotic therapy was discontinued as there was no longer any evidence of infection. The use of nanocrystalline silver foam was continued as a prophylactic measure for 30 days, during which time the interval between dressing changes was progressively increased up to a maximum of 5 days. The wound maintained constant improvement: the wound bed became granular and slough free, wound edges were epithelialising and wound size decreased (*Figures 2–4*).

Following the removal of the nanocrystalline silver foam dressing, Mr H's wound proceeded to complete resolution without further incident (*Figure 5*).

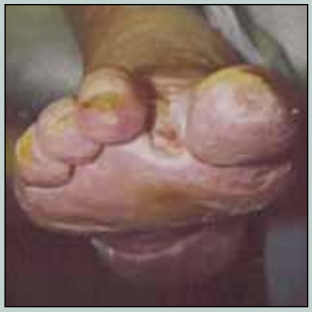

Figure 1. Infected ulceration at the time of initial presentation: day 1.

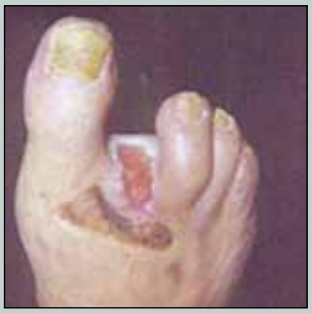

Figure 2. Ulceration resolving following the use of nanocrystalline silver foam dressing: day 16.

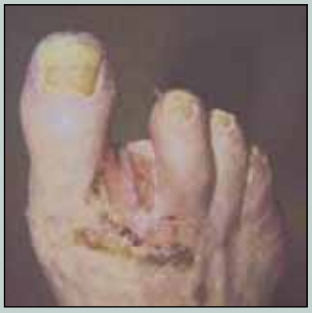

Figure 3. Day 21.

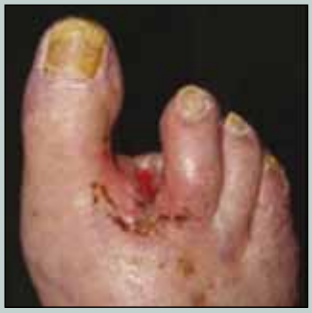

Figure 4. Day 30.

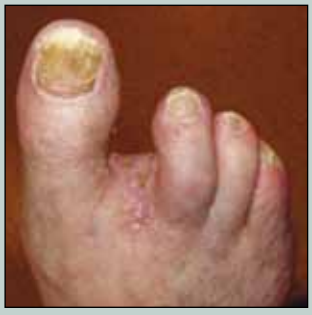

Figure 5. Complete resolution of ulceration: day 56.

Case points

1. Twenty-four hours after treatment the wound had begun to show improvements.
2. After 2 weeks the wound bed became granular and slough free, wound edges were epithelialising and wound size was decreasing.
3. The wound continued to heal without further incident.