The adversarial relationship between wounds and biomechanics in the lower limb

KEY WORDS
- Biomechanics
- Gait
- Mobility
- Sickle cell
- Ulceration

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There has been a growing acceptance that there is a link between abnormal biomechanics and lower limb wound healing. What is not always clearly articulated is what the link is and how to recognise the changes that occur because of these abnormalities. This article looks firstly at how the gait cycle relates to venous return. It then presents a clinical scenario to illuminate the impact the abnormalities have on a patient. While the focus here is on the link to wound healing, it also highlights the link to loss of mobility, which, in turn, may lead to psychosocial changes.

Since the release of Guest et al's work on the cost of wounds to the NHS, there has been an increased focus for many on the burden that wounds pose and how to mitigate this (Guest et al, 2015). This study centred on the cost of dressing and did not address the wider costs, including the psychosocial impact on the individual. The accounting of lost human potential is challenging, with lost work days, social isolation and pain just part of the picture. Altered or reduced mobility is a key player in this but it is difficult to measure. When an individual loses the ability to move freely, it impacts on employment and social choices. And it may become too painful, frightening or logistically difficult to go out.

Loss of mobility is part of the impact of a leg ulcer. One component of this loss of mobility is due to physical changes that occur in response to altered biomechanics. Pain changes the way individuals walk and how confident they are to go out and be exposed to potential trauma. There is an increasing acceptance of the role of gait biomechanics in lower limb ulceration (Araki et al, 1995; Dix, 2003; Smika, 2007). This in turn has spawned a spate of small studies around the use of exercise in ulceration, in particular those defined as venous ulcers (Davies et al, 2007; Kan, 2001; Padberg, 2004).

Some of the biomechanical changes seen in individuals with wounds of the lower limb are seen as normal biomechanical changes related to ageing, e.g. slower steps, wider base of gait and loss of heel-toe pattern. The preconception that leg ulcers are predominantly the remit of older patients may have camouflaged these wound-related changes. However, there are other changes that have been observed clinically that cause a loss of range of motion at the ankle — the most commonly recognised change. It is the impact that this loss of range of motion has on the lower-limb muscle pumps, which is commonly touted as having an adverse impact on wound healing (Araki et al, 1994; Back et al, 1995; Dix, 2003). One such gait adaptation to the pain of a leg ulcer is to walk on the ball of the foot in an unconscious attempt to reduce the pain or pull across a wound.

While this has been seen in wounds of several aetiologies, it has been clinically observed to be particularly common in wounds related to sickle cell anaemia (SCA), which is possibly due to the high levels of pain these individuals consistently experience from their wounds. This article discusses the biomechanical changes seen with any lower limb wound, however, the SCA cohort present these changes in the extreme so are helpful to illustrate them. The true incidence of SCA in the UK is unknown but it is recognised as the most common serious genetic condition in England. Current available information indicates there are about 14,000 people with SCA in the UK (Dormandy et al, 2017). The biomechanical changes that this group undergoes are helpful to

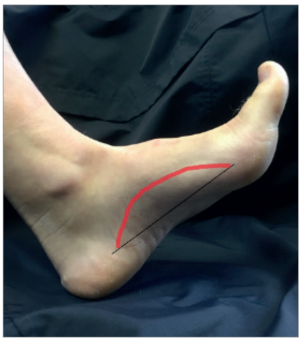


Figure 1. Heel strike: The arch is concave with the hallux and is generally in a dorsiflexed position

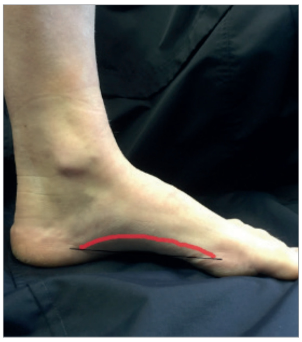


Figure 2. Foot flat: The weight of the body and gravity force is bearing down on the plantar pump of the foot with the arch elongating and flattening

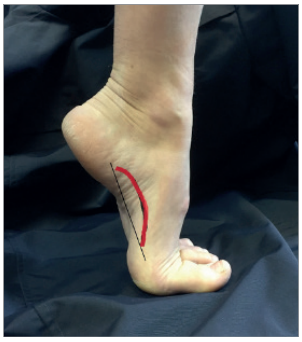


Figure 3. Toe off: The arch is high as the plantar muscles contract to aid the calf muscle and exert maximum force on the medial portion of the plantar pump, emptying the medial portal vein

look at in light of the argument that the changes observed may be age-related as ulceration in this group usually starts to appear from the age of 10 (Centers for Disease Control and Prevention, 2013).

Research indicates that the incidence of ulceration in the SCA population relates to the intensity of haemolysis — the rupturing of the red blood cells. Haemolysis allows the contents of the cell to spill into the surrounding plasma and lymph fluid. This release of cellular matter impacts on the biological structure of nitric oxide. Nitric oxide within the body has a role in relaxing vascular smooth muscle and causing vasodilation. The release of plasma haemoglobin from the rupturing red blood cell absorbs the nitric oxide creating an imbalance so that there is more vasoconstriction than desired. This increased oxidative stress and microvascular obstruction from sickled red blood cells causes deterioration of the muscle function. The knee flexors, which are part of the calf pump, are particularly at risk from this deterioration (Kato et al, 2007; Goncalves et al, 2018).

Both the venous and the lymphatic system rely on the rhythmic pattern of muscle contractions that occur in normal gait to massage fluid from the plantar foot up the calf and thigh and back into the trunk of the body. The system consists of three muscle pumps, which are situated in the plantar foot, calf and thigh with the focus on the calf and foot as the primary mechanisms.

These function slightly differently, as the plantar foot pump relies not only on muscle contraction but body weight as the foot weight bears down and everts or pronates the foot to move fluid from lateral to medial and into the medial ankle. There is an expectation of normal range of motion at the associated joints, in particular the ankle, so that the muscles can contract fully. The calf pump needs the ankle to have a full range of motion so that it can contract at heel lift to move the fluid upwards against gravity (Araki et al, 1994; Lattimer et al, 2017). In order for the pumps to function optimally, movement in all planes is necessary as would be expected in normal gait. So in order for both the plantar foot and calf pumps to function, the foot must move through cycle of heel strike *(Figure 1)*, foot flat *(Figure 2)* and toe off *(Figure 3)*. During these phases, the foot is also pronating and then re-supinating. If there are changes in the way an individual walks, perhaps due to pain as is often the case with lower limb ulceration, these phases disappear. Over time, soft tissue contractures occur that cement these changes in place. In order to highlight the negative impact of these changes, two individuals with SCA have been chosen to illustrate the typical biomechanical changes as well as the concomitant physical ones. The biomechanical changes displayed by both these women are ones commonly seen within our clinic and require no specialised knowledge to recognise. These changes are not SCA specific but individuals with this condition develop them quickly and to the extreme.

Box 1. Similarities between the two patients

- Females
- Ethnic background — African
- Site of ulcers — bilateral ankles posterior to the malleoli
- First episode of ulceration occurred in the their teens
- Functional leg length discrepancy
- Tall slim build
- Fixed ankle equinus (initial causative agent was soft tissue contractures)
- Stiff scar tissue over healed wound sites
- SCA crisis episodes

CASE REPORTS

At the time, Patient A was 26 and Patient B 59 years old. Despite the age gap, they shared a lot of characteristics *(Box 1)* and commonly observed biomechanical changes *(Box 2)*. The ankle restriction developed due to changes in gait. Both walked on the balls of their feet to relieve pain from the wounds. In each case, one ankle lost more movement than the other, so in conjunction with the ankle restriction they also developed a leg length discrepancy as well as lower back pain. Patient A, a student, was mobile but did occasionally require a crutch. She was experiencing tight hip flexors, back, hip and foot pain. Patient B had been awaiting a hip replacement since 2011 but had not been considered well enough for the operation. Her

Box 2. Commonly observed biomechanical changes in lower limb ulceration

- Leg length discrepancy
- Calf muscle atrophy
- Loss of ankle range of motion
- Fixed into a position of pronation or supination
- Valgus or varus ankles
- Hallux limitus
- Genu valgum
- Genu recurvatum (hyperextension at the knee)

mobility was severely restricted, needing two elbow crutches and assistance to leave her home.

Their treatment centred on healing the ulcers, which had been painful with scores moving for 4/10 to 10/10 depending on infection, heat and energy requirements. Another component of the treatment focused on mobility. Both patients were given Theraband Gold, the firmest resistance excercise band. These are used to increase ankle range of motion in soft tissue contractures. Both reported using them but admitted to some inconsistencies. Both patients also used GEKO devices to increase the range of motion of the ankle. The GEKO is a small device that is adhered to the skin, providing electrostimulation to the peroneal nerve. The resulting muscle contractions attempt to replicate calf pump action. Patient B enjoyed the device in particular, finding it helpful to manage pain. Unfortunately, she had a skin reaction to the adhesive so use was discontinued. There was a slight increase in dorsiflexion in both patients caused by using the device but this was minimal.

The average time for the Timed up and Go (TUG) test for individuals between 60 and 69 is 8.1 seconds; the norms for younger than 60 do not exist (Mathias et al, 1986). So both women were slower than the norm and have marked small calves *(Table 1)*.

Table 1. Mobility measures

	Patient A	Patient B
Timed up and Go (TUG) test	8.6 No aids	45.50 2 elbow crutches
Calf circumference at largest point	Right = 235 mm Left = 240 mm	Right = 263 mm Left = 268 mm

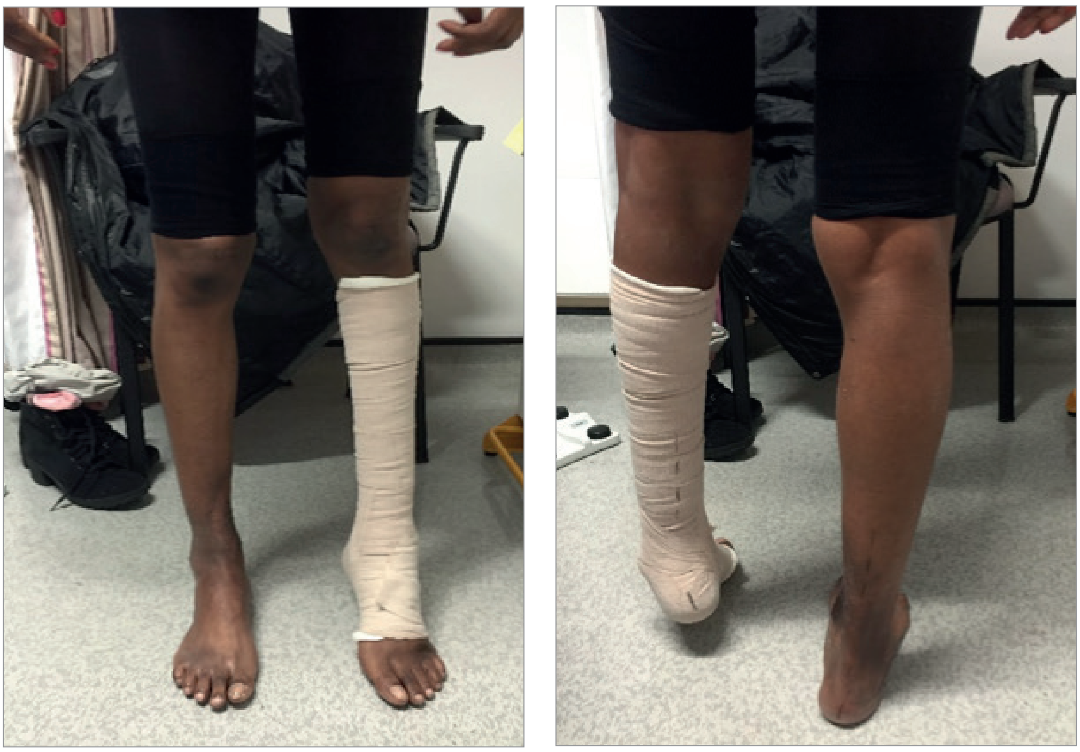


Figure 4. Patient A in stance

Table 2. Goniometer measurements of the dorsiflexion at the ankle

Appointments	**1**		**2**		**3**		**4**		**5**		**6**	
Dorsiflexion measurement at the beginning and end of appointment	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
	Pre -40°	Pre -10°	Pre -30°	Pre -10°	Pre -25°	Pre -7°	Pre -25°	Pre -2°	Pre -24°	Pre 4°	Pre -20°	Pre 5°
	Post -30°	Post -8°	Post -22°	Post -6°	Post -17°	Post 0°	Post -22°	Post 0°	Post -17°	Post 8°	Post -10°	Post 6°

Pre = At the start of appointment Post = At the end of the appointment

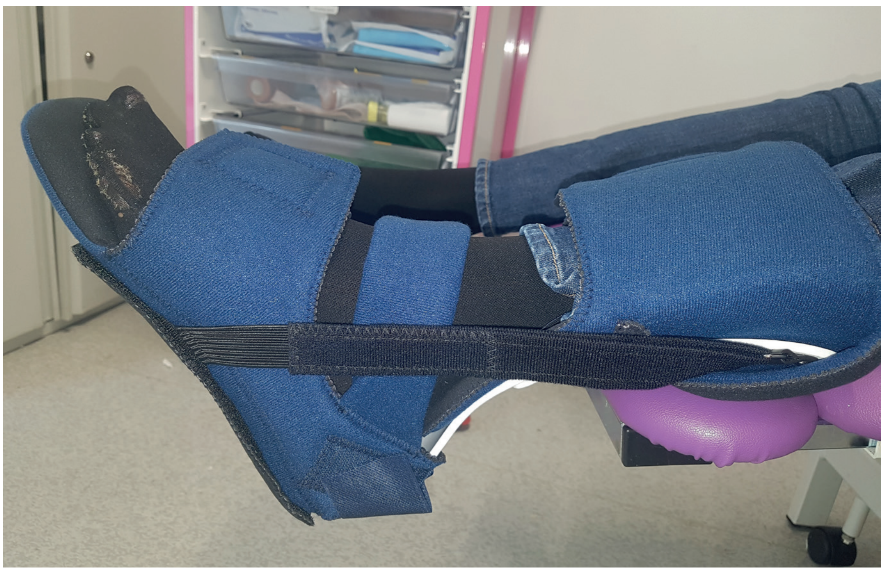
Figure 4 reveals Patient A's normal stance. Note the degree of inversion at the heels and the disparity between the levels of the patella. The equinus at the left ankle is quite fixed but the right ankle is also unable to dorsiflex past a 90°-position. In order to relieve tension around the hip area she is always slightly bent forward, causing tight hip flexors.

While Patient B's foot remains in a positon of plantarflexion (that varies -12 to -5 degrees) and she has had constant encouragement to stay mobile and use the Theraband, as well as shoe adaptations to better support her feet, her degree of pain limited more aggressive musculoskeletal interventions. The ankle equinus of Patient A was getting worse and she agreed to a short programme of appointments focused on increasing her ankle range of motion and decreasing her equinus. She attended weekly appointment for six weeks.

This program consisted of ankle mobilisation by the clinician, a Neurotec safe boot brace *(Figure 5)* to maintain changes during the night and GEKO to be worn during the day. A home exercise programme of Theraband use focused on the ankles and Pilates exercises to stretch the hip flexors. The dorsiflexion at the ankle was measured at the beginning and end of each appointment with a goniometer *(Table 2)*.

Measurements are taken when the clinician dorsiflexes the foot to a position of resistance with the knee extended. Zero indicates the foot is at a position of 90° to the leg, replicating the normal positon of a healthy foot when weight-bearing barefoot. Dorsiflexion, the movement of lifting the forefoot, and plantarflexion, the pointing of the foot, is measured in degrees from this neutral positon. Therefore if dorsiflexion is reported as -40°, the person is unable to get the heel to the ground and is in a position of plantarflexion.

Figure 5. Neurotec safe boot brace to mobilise ankle



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During these appointments, the patient focused on the worse foot, the left, with home exercise. It was not until after appointment three, that she started to apply the exercise in a more balanced way, that an improvement on the right was seen. This was driven by the improvement in the left foot's ability to dorsiflex, a reduction in pain and generally feeling more stable. After the third appointment, she was able to reduce the heel height of her footwear by 2 cm. She also reported a reduction in hip and back pain.

She has now been referred to her local physiotherapy service to continue a programme to improve her mobility. With the 20^0 improvement on the left ankle and a 12^0 improvement on the right, this indicates that even severe deformity can be reduced if caught early. At 26, Patient A has hopefully not sustained the permanent damage to her joints that patient B had, however, permanent change will rest on her ability to continue with unsupervised exercise. Both women's wounds have now healed and are in compression hosiery.

DISCUSSION

Both these individuals have received prolonged treatment for ulceration. The link between their wound pain and altered mechanics, and its associated musculoskeletal degeneration and pain, had never been discussed with them prior to attending our clinic. As these changes become more chronic they become increasingly difficult to reverse and cause more concomitant damage.

With the development of an ankle equinus, the ability to heel strike or gain foot flat in the gait cycle disappears. This means that the first of the lower limb muscle pumps, the planter foot, cannot function. There is also an impact on the calf pump. If the heel is constantly off the ground, as is the case with an equinus, the muscles of the calf cannot shorten from a relaxed state as they are constantly contracted or semi contracted.

At normal heel strike the foot is inverted or supinated and moving into eversion as part of pronation to reduce the amount of force moving up the limb and prepare the foot for adapting to whatever terrain it has to deal with. This is a triplanar movement of weight and force across the foot rather than a simple flexion extension of the foot. This triplanar movement is part of normal gait and provides a more accurate ejection volume measure than the classic tip toe movement (Lattimer et al, 2017). This would support that the failure to pronate and supinate as in normal gait will reduce the ejection volume of the lower limb.

For some time there has been an acceptance of the importance of reduced ankle range of motion on wound healing in the lower limb. What has not always been articulated completely is the interplay between normal gait mechanics with its triplanar motion and ejection volumes.

CONCLUSION

Clinically, measuring the link between improved mechanics and wound healing is challenging not least because these patients have multiple interventions including dressings, compression and medication making the measuring of a single intervention challenging. There is also a strong reliance on the consistence of patient involvement. There are several studies around the effect of exercise on impaired calf muscle pumps with favourable results in increasing functioning and healing (Smith et al, 2018). This appears to be a low cost, low risk intervention that provides control to a patient group that can often feel powerless.

The overall drawback of these studies is that they tend to use smaller groups of patients with some variation of measurement techniques. The results of these studies do appear consistent in providing physical improvement. Every patient with a lower limb wound would benefit from even the most rudimentary mobility assessment. A simple TUG requiring no special equipment or training can help identify people at risk of falling but also highlight those struggling to mobilise.

Assessment by a clinician skilled in biomechanics is extremely beneficial in identifying these issues and creating a treatment programme. The impact of which can include but is not limited to reduced pain, improved functionally of the muscle pumps and safer improved mobilisation. In turn, this can lead to less social isolation and a saving to the health economy by quickly reducing patient transport cost. But until all clinicians understand and emphasize the importance of these changes to patients this will be an intervention that many would benefit from but few will receive. Wuk