Definitions of the physical properties of pressure ulcers and characterisation of their regional variance

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Key words
Dermis; Pressure ulcer; Undermining formation; Wound deformity

Abstract
A pressure ulcer is a localised injury of the skin and underlying tissue that usually develops over a bony prominence. A decrease in the pressure over the bony prominence effectively prevents pressure ulcers; however, no studies have systematically assessed the physical properties of existing pressure ulcers. To characterise pressure ulcers, we established new terminology that clarifies the physical properties of pressure ulcers: wound mobility was defined as movement using the bony prominence as a predefined specific marker, and wound deformity was defined as a change in the three-dimensional shape of the wound. Observational studies using this terminology showed that the distinct physical properties of pressure ulcers depend on the site of development and the wound depth according to the National Pressure Ulcer Advisory Panel criteria. Most grade IV sacrum pressure ulcers exhibited mobility and deformity. Superficial sacrum pressure ulcers below grade II showed only mobility. In contrast, foot pressure ulcers did not exhibit mobility or deformity. We propose a new concept, ‘wound physical property’, for understanding the unique pathogenesis of pressure ulcers.

Introduction
A pressure ulcer is a localised injury of the skin and underlying tissue that usually develops over a bony prominence. Although the primary cause of pressure ulcers is ischaemic changes induced by pressure-related external forces, including shear force, the clinical heterogeneity of pressure ulcers is critical for proper management (1). Although a number of randomised controlled studies for treatment and prevention have been performed, pressure ulcers are still considered refractory chronic wounds (2).

Key Messages
- a pressure ulcer is a localised injury of the skin and underlying tissue that usually develops over a bony prominence
- the effects of external forces on existing pressure ulcers have not yet been understood
the distribution of skin ligaments is likely an important factor affecting the physical properties of a wound
as pressure ulcers usually occur in elderly patients, we were unable to compare the physical properties of pressure ulcers in different age subgroups in this study
our data also show that most deep pressure ulcers on the feet did not exhibit wound deformity
this finding also suggests that the physical properties of the surrounding tissues are important for maintaining wound shape
a biomechanical study showed that heel skin and subcutaneous tissues are stiff
it can be reasoned that wound deformity causes further damage to wound tissues, leading to subsequent undermining
thus, it is necessary to reduce wound deformity by careful positioning and wound contraction
the physical properties of wounds are apparently altered in the presence of scar tissue
in deep ulcerations, the defect in residential tissues is temporarily replaced by granulation tissue, which is rich in inflammatory cells and lacks fibrous connective tissue elements
granulation tissue may be vulnerable to external forces owing to lower amounts of fibrous components
although a consensus is needed to establish new definitions, our unique concept of ‘wound physical property’ may be useful for future pressure ulcer research and care

Pressure-decreasing mattresses are effective in preventing pressure ulcers (3), and pressure reduction and redistribution are recommended in published guidelines for the prevention and treatment of pressure ulcers (4, 5). However, because patients with pressure ulcers usually have limited body movement (6), it is often difficult to eliminate all external forces acting on existing pressure ulcers.

The effects of external forces on existing pressure ulcers have not yet been clarified. We have seen cases of refractory pressure ulcers in clinical practice and noticed that their wound shape is deformable. Therefore, the physical changes in the wound caused by external forces need to be understood. However, no terminology for the changes in the wound shape has been established in the context of descriptive dermatology (7).

In this study, we established a generic terminology for describing the physical aspects of pressure ulcers. Moreover, we characterised the distinct physical properties of pressure ulcers of the sacrum and foot. Our new concept of ‘wound physical property’ may be a useful tool for understanding the unique characteristics of pressure ulcers.

Methods

Wounds

All the wounds examined in this study were observed in patients at the National Center for Geriatrics and Gerontology. This study complied with the ethical tenets for human experimentation outlined in the 1975 Declaration of Helsinki. All the patients were treated by dermatologists and pharmacists according to the guidelines of the Japanese Society of Pressure Ulcers. The age of the patients ranged from 55 to 100 years, with a mean age of 79.6 years. The detailed characteristics of the patients with pressure ulcers are as follows: foot pressure ulcers (n = 48), mean age 81.6 ± 10.1 years; sacrum pressure ulcers (n = 45), mean age 78.1 ± 9.2 years and total (n = 93), mean age 79.6 ± 9.8 years (±: mean SD value). Wounds complicated with remarkable soft tissue infection (e.g. cellulitis and fascitis) were excluded. The size of each wound, including the undermined area, was measured and photographed at least once a week. The physical properties of the wounds were evaluated after all rigid necrotic tissues were completely removed. The pressure ulcers were graded on the basis of the National Pressure Ulcer Advisory Panel (NPUAP) criteria. The pressure ulcer sites were described according to the site of bony prominences.

Physical examination of the wounds

Physical examinations were performed using the following two procedures without physical intervention. The wounds were examined in the lateral position. First, the wound mobility was examined by manually forcing the surrounding skin

Figure 1 Schematic representation of the physical properties of wounds. (A–C) The direction of the external force is indicated by an arrow, and the predefined bony marker is indicated by an asterisk. (A) A cross-sectional model of wound mobility. An external force moves the wound away from the predefined bony prominence. (B) A cross-sectional model of wound deformity. Wound deformity was defined as a change in the three-dimensional shape of the wound, which may coexist with wound mobility. (C) The wound deformity grades are illustrated. The diameter of the primary wound base is indicated by ‘a’. The undermining portion in the predefined wound base caused by the external force is indicated by ‘c’. The wound deformity grade was estimated as c/a and categorised as follows: c/a < 0·1 non deformed (−), 0·1 < c/a < 0·5 moderately deformed (+) and c/a > 0·5 severely deformed (++).
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(~2 cm from the edge of the wound) in an upward direction. The strength was almost equal to the gravitational force when adjusting the position to the other side. To examine wound deformity, the diameter of the wound and undermining region was measured before and after the application of force. The size of the undermining region was measured using a probe and marked with an oil-based pen.

Definition of the physical properties of wounds

As there is little existing terminology for describing the physical properties of wounds, we created novel terms for these physical properties to better understand them. First, we defined wound mobility as the movement of the wound from the predefined bony prominence. Thus the wound mobility was examined by forcing the surrounding skin in a predefined direction. The predefined force was determined according to the mobility of the individual patient. For instance, in a sacrum pressure ulcer in a completely bedridden patient, the force could only be exerted bilaterally unless the head was lifted. To examine the deformity of a wound, the diameter of the wound was measured before and after applying the force. These concepts are shown in cross sections in Figure 1A. The mobility of a wound was quantified by the distance the wound centre moved from the original bony prominence. Mobility was further graded as moderate (+, from 1 to 3 cm) or high (+++, >3 cm).

Statistical methods

All the pressure ulcers examined in this study were graded using the NPUAP classification. The degrees of wound mobility and deformity were evaluated as described in the Results section. The correlations between the physical properties of wounds, and the site of development and NPUAP classification were statistically analysed using the Cochran–Armitage test using SPSS (version 12.0 for Windows; SPSS, Inc, Chicago, IL).

Results

Evaluation of the physical properties of the pressure ulcers

Using the definitions described in the earlier section, the numbers of cases of each type of pressure ulcer were documented. Figure 2A shows a wound that apparently moved towards the head of the patient. However, the wound was not deformed by an external force towards the left side (dotted arrow). (C, D) A grade II pressure ulcer on the heel of a 78-year-old female patient showing neither mobility nor deformity caused by an external force (dotted arrow).

Figure 2 Clinical findings of the typical pressure ulcers in elderly patients. The direction towards the head of the patient is indicated. The position of the bony prominence is indicated by arrowheads. (A, B) A grade II pressure ulcer on the sacrum in an 80-year-old female patient exhibiting severe wound mobility. However, the wound was not deformed by an external force towards the left side (dotted arrow). (C, D) A grade II pressure ulcer on the heel of a 78-year-old female patient showing neither mobility nor deformity caused by an external force (dotted arrow).
from the primary bony prominence of the sacrum (arrow) owing to external gravitational force. Figure 2B shows a wound located over a bony prominence, indicating that gravity moved the wound. In contrast, the pressure ulcer on the heel shown in Figure 2C and D did not exhibit remarkable mobility.

When the skin on the left side was moved upward, the wound on the coccyx shown in Figure 3A and B became visible, indicating that the shape of the wound was altered by external gravitational force and not by pressure alone. The pressure ulcers on the sacrum also exhibited severe deformity owing to gravitational force (Figure 3C and D). In contrast, the pressure ulcers on the heel were not deformed by an external force (Figure 3E and F).

**Wound mobility of the pressure ulcers in the sacral region**

Next, we analysed the physical properties of the pressure ulcers developing in different locations, particularly the sacrum and the feet. As shown in Figure 4, most sacrum pressure ulcers exhibited wound mobility, whereas those on the foot did not. The statistical analysis showed a significant difference between the sacrum and the feet for all grades of pressure ulcers (Figure 4B).

**Wound deformity in deep sacrum pressure ulcers**

Finally, the deformity of the pressure ulcers was analysed (Figure 5). The statistical analysis showed that the NPUAP grade IV wounds on the sacrum showed severe deformity (Figure 5B) compared with those that developed on the feet. In contrast, the grade II pressure ulcers on the sacrum did not deform regardless of their mobility score (Figure 2A and B).

**Discussion**

Few studies have assessed the physical and mechanical aspects of pressure ulcers. In this study, we established new terminology for describing the physical properties of pressure ulcers and propose a new concept: wound physical property.

Analyses of the physical properties of pressure ulcer wounds showed that the degrees of mobility and deformity are largely dependent on the location of the wound. This finding may be related to the physical properties of the surrounding skin and subcutaneous tissues. Regional variance in the dermis...
and subcutaneous tissues appears to be responsible for the different physical properties of wounds (8). Pressure ulcers usually develop in aged patients, and the physical properties of dermal and subcutaneous tissues around the wound may be different from those of young individuals. The distribution of skin ligaments is likely an important factor affecting the physical properties of a wound (9).

When an elderly patient is lying on his/her side, the wound is not visible because of gravity-mediated drooping of the skin and subcutaneous tissues, as shown in Figure 3A and C. This observation indicates that ageing of the dermis and subcutaneous tissues affects the physical properties of wounds. As pressure ulcers usually occur in elderly patients, we were unable to compare the physical properties of pressure ulcers in different age subgroups in this study.

Wound deformity was frequently observed in deeper pressure ulcers on the sacrum. It can be reasoned that the shape of pressure ulcers less than grade II is maintained by the remaining intact dermis. In contrast, the shape of deeper pressure ulcers may be altered owing to loss of the dermis. Because the dermis consists of mature collagens crosslinked with other extracellular matrices, the remaining dermis of superficial pressure ulcers is still able to mechanically support the shape of the wound. In contrast, subcutaneous tissue is easily compressed by pressure because the physical properties of fat tissue differ from those of the dermis (10).

Our data also show that most deep pressure ulcers on the feet do not exhibit wound deformity. This finding also suggests that the physical properties of the surrounding tissues are important for maintaining wound shape (7). Indeed, a biomechanical study showed that the skin and subcutaneous tissue of the heel are stiff (11). Our preliminary observations showed that even pressure ulcers on the feet varied in location, such as between the heel and the ankle.

It can be reasoned that wound deformity causes further damage to wound tissues, leading to subsequent undermining. Thus, it is necessary to reduce wound deformity by careful positioning and wound contraction. Indeed, the physical properties of wounds are apparently altered in the presence of scar tissue. In deep ulcerations, the defect in residential tissues is temporally replaced by granulation tissue, which is rich in inflammatory cells and lacks fibrous connective tissue elements (12). Granulation tissue may be vulnerable to external forces owing to lower amounts of fibrous components. Although a consensus is needed to establish new definitions,
our unique concept of ‘wound physical property’ may be use-
ful for future pressure ulcer research and care.

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References

1. Mustoe T. Understanding chronic wounds: a unifying hypothesis on
their pathogenesis and implications for therapy. Am J Surg
2004;187:65S–70S.
Treatment of pressure ulcers: a systematic review. JAMA 2008;300:
2647–62.
3. Hofman A, Geelkerken RH, Wille J, Hamming JJ, Hermans J, Bres-
lau PJ. Pressure sores and pressure-decreasing mattresses: controlled
son MC, Rodeheaver G, Thomas D, Stotts N. Guidelines for the
5. Stechmiller JK, Cowan L, Whitney JD, Phillips L, Aslam R, Bar-
bul A, Gottrup F, Gould L, Robson MC, Rodeheaver G, Thomas D,
Stotts N. Guidelines for the prevention of pressure ulcers. Wound
Structure of skin lesions and fundamentals of clinical diagnosis. In:
Fitzpatrick’s dermatology in general medicine, 7th edn. New York:
8. Cichowitz A, Pan WR, Ashton M. The heel: anatomy, blood sup-
ply, and the pathophysiology of pressure ulcers. Ann Plast Surg
ligaments: regional distribution and variation in morphology. Clin
10. Conner LM, Clack JW. In vivo (CT scan) comparison of vertical
shear in human tissue caused by various support surfaces. Decubitus
on the hind foot biomechanics during heel strike. Skin Res Technol
12. Vande Berg JS, Rudolph R. Pressure (decubitus) ulcer: variation in
histopathology – a light and electron microscope study. Hum Pathol