ORIGINAL ARTICLE

Low-echoic lesions underneath the skin in subjects with spinal-cord injury

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Study design: Criterion standard and survey cases.

Objectives: To assess the utility of ultrasonography for detecting deep tissue injury or incipient pressure ulcers and to determine the patterns of development of pressure ulcers in subjects with chronic spinal-cord injury (SCI).

Setting: Ambulatory setting at public hospital.

Methods: The subjects were 43 men with SCI between C5 and L1 (age: 42.6 ± 11.6 years, mean $\pm$ s.d.). A total of 129 areas (sacral region and bilateral ischial regions in each subject) were examined by inspection, palpation and ultrasonography.

Results: Of the 129 areas, 112 were normal by inspection, palpation and ultrasound imaging. Nine areas were abnormal on ultrasonography alone and six were lesion positive by palpation and ultrasonography. Only two areas were abnormal by all three methods. Ultrasonography always detected a heterogeneous pattern and low-echoic areas directly adjacent to the bone.

Conclusions: Our results indicated that low-echoic lesions, signaling deep tissue injuries or early pressure ulcers, originated in areas near the bone and extended toward the epidermis. The results suggest that ultrasonography is a useful tool for the early detection of deep tissue injuries or pressure ulcers.

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Keywords: pressure ulcer; inspection; palpation; ultrasonography; deep tissue injury

Introduction

Advances in medical management and rehabilitation engineering have improved the quality of life (QOL) and survival of patients with spinal-cord injury (SCI). However, pressure ulcers remain a major problem for these patients as the condition compromises QOL for financial, physical and psychological reasons. Furthermore, pressure ulcers present a significant burden on the national health system; healing one pressure ulcer costs as much as \$70 000.^{1,2}

Pressure ulcers occur almost exclusively over bony prominences that have been subjected to excessive pressure for a length of time, and inevitably resolve once the pressure is removed. Therefore, it is likely that ischemia because of supracapillary pressure is a prime factor in the development of pressure ulcers.³ All patients with chronic SCI have decreased mobility and sensation, and are thus at high risk of developing pressure ulcers. Moreover, patients with SCI have decreased immune function, impaired nutritional

status and depressed cell adhesion, all of which delay wound healing⁴ and impair the body's ability to heal pressure ulcers completely. These factors highlight the need for early detection and rapid treatment of pressure ulcers, particularly in patients with SCI.

Pressure ulcers are staged from I to IV according to the staging system of the National Pressure Ulcer Advisory Panel (NPUAP),^{5,6} based on the depth of the observed tissue damage. In 2007, the NPUAP added two stages of deep tissue injury and unstageable pressure ulcers. From past to present, there are two schools of thoughts regarding where and how pressure ulcers occur, based on visual inspection; the top-to-bottom and the bottom-to-top model.⁷ The former proposes that ulceration occurs first in the epidermis and later in the deeper tissue layers, whereas in the second model, skeletal muscle is injured before damage is evident on the skin surface. In this regard, many physicians, nurses and family members monitor the appearance of pressure ulcers by physical examination of the patient's skin. The first-model pressure ulcer is easily detected by inspection, whereas the second-model pressure ulcer and deep tissue injury are almost impossible to detect by inspection only. Moreover, these ulcers develop at a faster rate than other

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types of ulcers.⁸ Therefore, we advise patients with SCI to self-monitor for pressure ulcers by visual inspection and palpation, although it is difficult to ascertain if such approach is effective.

Owing to the above uncertainty, this study was designed to determine the formation pattern of pressure ulcers in patients with SCI by visual inspection, palpation and high-resolution B-mode ultrasonography. Important assumptions in this study were that increased fluid content would be readily detectable as hypoechogenic area on ultrasonography, and that high-frequency ultrasound can identify the presence of dermal edema and the skin architectural structure.^{9,10} Thus, ultrasonography can detect deep tissue injury and deep tissue necrosis as hypoechogenic area. The study also assessed the utility of ultrasonography for detecting deep tissue injuries or incipient pressure ulcers prior to the appearance of clinical signs.

Methods

Subjects

A total of 43 men with SCI lesions between C5 and L1 voluntarily participated in this study. All subjects were Far East Asian and their skin colors were not brown or dark. Table 1 lists the age, height, weight, and body mass index (BMI) of the subjects. All SCI events occurred at least 1 year before this study. Two physicians independently assessed the neurological injury status of each case (Table 1). Interviews revealed 31 suffered pressure ulcers after the onset of SCI (Table 1). At the time of the study, one subject presented with visually evident pressure ulcers on the sacrum.

The study protocol was approved by the Human Ethics Review Committee of Wakayama Medical University (Wakayama, Japan), and all subjects gave informed consent.

Table 1 Characteristics of individuals with spinal-cord injury

Variables	n	Mean $\pm$ s.d.
Age range (years)		
≤30	6	
31–40	13	
41–50	9	
51–60	14	
>60	1	
Age (years)	43	42.6 $\pm$ 11.6
Body height (cm)	—	169.2 $\pm$ 5.7
Body weight (kg)	—	61.1 $\pm$ 9.0
Body mass index (kg/m ²)	—	21.3 $\pm$ 2.9
Level of neurological injury		
Cervical complete	7	
Cervical incomplete	4	
Thoracic complete	27	
Thoracic incomplete	1	
Lumber complete	3	
Lumber incomplete	1	
Number of patients with history of pressure ulcer	31	

Study protocol

While in prone position, each subject underwent pressure ulcer examination by the following procedures: First, one examiner carefully inspected the skin of the sacral and bilateral ischial regions for the presence of redness, purple or maroon localized area, swelling and/or epidermal fresh wounds excluding old scar(s) and pigmentation due to old wound(s); on inspection, the patient was reported pressure ulcer positive or pressure ulcer negative. Second, the other examiner palpated the same regions to detect local heat or free-floating sensation, and reported that the patient as pressure ulcer positive or pressure ulcer negative. Finally, the sacrum and bilateral ischial tuberosities were imaged by high-frequency ultrasonography using a linear array, 10-MHz transducer of an ultrasound scanner (LOGIQ 500, GE, Tokyo, Japan). Three different aspects were scanned to detect both low- and high-echoic lesions on B-mode imaging from the skin to the bone by one ultrasonographer. The examined parts were classified as positive or negative for pressure ulcer on ultrasonography by another physician blinded to the inspection and palpation findings. The longitudinal diameter, lateral diameter and depth (from skin to the upper border) of each detected lesion were measured.

Statistical analysis

Data were expressed as mean $\pm$ s.d. Analysis of variance was used to determine differences between groups. The *post hoc* Scheffe's test was used. A *P* value <0.05 was considered statistically significant.

Results

A total of 129 areas in 43 subjects were studied. Table 2 summarizes the results of inspection, palpation and ultrasonography. Inspection identified the lowest number of lesions, whereas ultrasound examination detected the highest number.

Table 3 presents the results of classification based on the combination of examinations. The 129 areas examined were

Table 2 Results of inspection, palpation and ultrasonography

Examination	Lesion	n
Inspection	Positive	2
	Negative	127
Palpation	Positive	8
	Negative	121
Ultrasound image	Positive	17
	Negative	112

Table 3 Results of combination of three types of examinations

Inspection	Palpation	Ultrasound	n
Normal	Normal	Normal	112
Normal	Normal	Low-echoic lesion	9
Normal	Free-floating sensation	Low-echoic lesion	6
Redness/wound	Free-floating sensation	Low-echoic lesion	2

classified into four groups; 112 areas were lesion negative by all examinations. Inspection examination identified two areas showing redness or wounding that also demonstrated a free-floating sensation and low-echoic lesions, whereas six areas with free-floating sensation, but no redness or wounding, showed low-echoic lesions. These results indicate that redness of the skin, wounds, or free-floating sensations are likely to be associated with low-echoic lesions under the skin.

Typical ultrasound images of the lesions are shown in Figure 1. Normal areas showed a homogeneous pattern of ultrasound reflections from the epidermis to the bone with a clear muscle layer (Figure 1a). In contrast, echoic lesions were heterogeneous (Figures 1b–d). The diameters of the two echoic lesions associated with redness or wound could not be measured precisely, as the diameters were larger than the

probe. The mean diameter of the lesions detected only on ultrasound imaging was not significantly smaller than that of ulcers detected by both palpation and ultrasonography (Table 4). Low-echoic lesions observed only on ultrasound imaging were significantly deeper than those detected by both palpation and ultrasound studies (Figures 1c and d, Table 4), and all such lesions were directly adjacent to the bone. Eleven (64.7%) of the 17 low-echoic lesions contained a high-echoic area.

Discussion

Our study demonstrated the presence of low-echoic lesions underneath the skin in areas covered with apparently

Figure 1 Typical ultrasound images. (a) Ultrasound image of the normal skin showing a homogeneous pattern of ultrasonic reflections from the epidermis to the right ischial bone (arrow) with a clear layer of muscle. (b) Low-echoic lesion near the left ischial region. Inspection showed redness, palpation yielded a free-floating sensation and ultrasound imaging detected a low-echoic signal from near the bone (arrow) to the skin. The lesion contained high-echoic areas. (c) Low-echoic lesion near the right ischial region that was normal on inspection and yielded a free-floating sensation on palpation. The image shows a low-echoic area near the bone (arrow). The distance to the epidermis exceeded panel b in this image. (d) Low-echoic lesion near the right ischial region. The area was normal by inspection and palpation. The image shows a small area of the low-echoic lesion close to the bone (arrow) and irregular muscle layer.

Table 4 Dimensions and depth of the low echoic lesions

Abnormal	Ultrasound only (n = 6)	Palpation and ultrasound (n = 9)	P-value
Longitudinal diameter (mm)	0.58 ± 0.18	0.81 ± 0.26	0.070
Lateral diameter (mm)	2.20 ± 0.49	2.57 ± 1.51	0.399
Depth (mm)	0.81 ± 0.20	0.31 ± 0.23	0.001

Values are mean ± s.d.

normal skin as well as in areas of red skin or damaged skin. The reverse phenomenon of a normal finding on ultrasound study and unusual findings by either inspection or palpation studies was never observed in this study. Thus, the combinations of results of all three examination procedures produced only four patterns in mathematically calculated eight patterns (Table 3). The depth of the low-echoic lesions correlated with the results of inspection and palpation. These findings suggest that pressure ulcers might form initially under the skin and subsequently extend to the surface. They also indicated that inspection alone is inadequate for detecting pressure ulcers, and that examination by palpation is the preferred method. However, we recommend that ultrasound examination should also be performed to detect pressure ulcers in the early stages.

On the basis of our results, we believe that low-echoic lesions detectable by ultrasonography represent early-stage deep tissue injuries or incipient pressure ulcers. Quintavalle *et al.*⁹ reported that dermal edema was never observed in the absence of subdermal edema. The post-pressure images in their study were similar to our ultrasound imaging of low-echoic lesions in patients with chronic SCI. Lesions found only by ultrasound imaging were small and deep, whereas those apparent by palpation were large and shallow. We could therefore establish a pattern for the low-echoic lesions; they formed near the bone and then developed and grew in size toward the epidermis. Increased pressure from the lesions would finally appear as ulcers on the skin. Nola and Vistnes¹¹ studied the effects of pressure on the skin and muscle in animals and reported that an increased mass of muscle under the skin could diffuse pressure and lessen the incidence of ulceration; however, muscle is not a suitable coverage for pressure-bearing areas because of the extremely high incidence of muscle necrosis in response to pressure points. Moreover, tissue pressure was measured as 3–5 times higher internally near a bony prominence than at the skin.¹² These findings were consistent with the present inspection, palpation and ultrasound results for the sacral and bilateral ischial regions of individuals with SCI. We propose that tissue necrosis in such cases occurs initially in deep muscles near the bony prominence, and that ultrasonography is a sensitive device to detect this early-stage pressure sore. The lesions detected by only ultrasonography were not deep tissue injury defined by the NPUAP because there are no purple or maroon localized areas on the skin. We could consider the possibility that the lesions detected only by ultrasonography may also be very early deep tissue injury or incipient pressure ulcers. This study demonstrated high clinical probability of pressure ulcer formation underneath the skin. However, for ethical reasons, we could not directly prove that the low-echoic lesions underneath the skin would grow with time to reach the skin, and become inspection- or palpation-evident pressure ulcers. It is necessary to examine this issue in the future using a clinically relevant model of pressure ulcers.

It was believed previously that pressure ulcers form in the superficial epidermis.^{9,13} Quintavalle *et al.*⁹ suggested that stages I and II pressure ulcers are superficial in origin and are

the results of friction and shear. However, they did infer that a progressive process for pressure ulcer development from deep sub-dermal layers to superficial dermal then to epidermal layers was possible. Histological examination of cutaneous pressure ulcers by Witkowski and Parish¹³ also concluded that the initial tissue damage was in the upper dermis. However, because the study involved cutaneous tissues only, the findings do not conflict with our results.

Local pressure is one of the most common causes of pressure ulcers, and the distribution of pressure depends to a great extent on the overall functional status. Trochanteric and sacral ulcers are more prevalent in the bedridden patient, whereas ischial ulcers are found almost exclusively in patients who are able to sit for some time.¹⁴ Our subjects with SCI were wheelchair users, but participated in social and sporting activities. Most of the pressure sores found in these subjects (76.5%, 13 out of 17 detected) were located in the ischial regions. The high physical activities in these subjects might have resulted in increased ischial blood flow, decompression of ischial regions and reduction in the overall incidence of pressure ulcers. Therefore, it is possible that the 17 out of 129 areas showing unusual findings in this study is a very small number compared with inactive persons with SCI.

It is extremely important that medical staff advise patients on the prevention of pressure ulcers. Kosiak¹⁴ suggested that the problem with SCI patients is primarily in convincing them on the importance of changing positions frequently, and that these patients do not acknowledge the presence of ulcers if no visual clinical signs exist. As we stated in the Introduction section, we advise patients with SCI to self-monitor the formation of pressure ulcers by inspection and palpation. Our results here showed that six of eight areas detected as unusual by palpation were visibly normal, strongly indicating that palpation is clinically better than inspection in detecting early-stage tissue injury associated with pressure ulcers. On the basis of this study, we will now advise our patients with SCI to self-inspect and palpate for pressure ulcers, and to undergo regular ultrasonography to screen for low-echoic lesions. In this study, we advised the patients who had the lesion by ultrasonography to release compression to the areas of their lesions.

High-resolution ultrasound is a potentially useful tool for improving QOL in SCI patients. Oot-Giromini *et al.*¹⁵ compared the cost of preventing pressure ulcers in an 'at-risk' population with treatment costs for patients with pressure ulcers. The daily ulcer treatment cost was 2.5 times the cost of prevention in the at-risk group. We strongly recommend that all persons with SCI should check the ischial regions both by inspection and palpation on a daily basis to rule out the presence of early pressure ulcers. At this stage, we are not certain whether or not ultrasonography should be used as a screening tool for pressure ulcers, and if used for this purpose, how often such screening should be performed in both the acute or chronic rehabilitation period. Further studies of large numbers of susceptible patients (for example, bed-ridden patients) and subjects with SCI should be conducted to evaluate the role of ultrasonography as a screening tool for deep-seated tissue injuries that are

considered as early-stage pressure ulcers and to discuss the best strategies for the management of such early lesions.

Conclusion

This study demonstrated the presence of low-echoic lesions underneath red, wounded or free-floating palpated skin, as well as in areas with apparently normal skin. On the other hand, a normal finding on ultrasonography and unusual findings by either inspection or palpation studies was never observed. These results suggest that low-echoic lesions, signaling early pressure ulcers, originated in areas near the bone and developed toward the epidermis. Therefore, the use of ultrasonography is highly recommended for the early detection of pressure ulcers.

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