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Effects of Position and Operator on High-frequency Ultrasound Scan Quality

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Abstract

Objectives—High-frequency ultrasound may evaluate those at risk for pressure ulcers. Images may be obtained by clinicians with limited training. The prone position is recommended for obtaining sacral scans but may not be feasible in the critically ill. This study investigated image quality using multiple operators and a variety of patient positions.

Research Methodology—Sacral scans were performed in three randomized positions in 50 volunteers by three different investigators using a 20 MHz ultrasound system. General linear models and ANOVA random effects models were used to examine the effects of operator and position on image quality rating, and measures of dermal thickness, and dermal density.

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Results—The best scan for each position and operator was used for analysis (N=447 images). Image rating varied by operator ($p=0.0004$), although mean ratings were 3.5 or above for all operators. Dermal thickness was less for the prone position than in 90° or 60° side-lying positions ($p=0.0137$, $p=0.0003$). Dermal density was lower for the prone position than for the 90° or 60° positions ($p<0.0001$ for both).

Conclusions—These data show that overall scan quality was acceptable in all positions with all operators. However, differences were found between side-lying positions and the prone for dermal thickness and dermal density measures.

Keywords

skin integrity; high frequency ultrasound; pressure ulcers; position; technology; evaluation

Pressure ulcers are a major health problem associated with pain, risk for infection, increased resource use, and mortality.¹ Hospitalized patients are at especially high risk for pressure ulcer development. The prevalence in adult critical care settings is between 8.8% to 12.1%², and 3.3% of ICU patients developed severe ulcers (Stage III, Stage IV, eschar/unable to stage, or deep tissue injury [DTI]).² Currently, the Centers for Medicare and Medicaid Services (CMS) do not reimburse health care facilities for pressure ulcers acquired after admission.³ Therefore pressure ulcer prevention or early identification has become a priority in health care settings to both reduce adverse outcomes and promote cost effectiveness.

The ability to detect subtle subepidermal edema associated with early onset of tissue injury, prior to visible skin surface changes, has been reported using analysis of high frequency ultrasound (HFUS) images in the range of 20 MHz.^{4–6} HFUS is a cost-effective and non-invasive method allowing immediate or convenience evaluation of subepidermal tissue with image documentation.⁴ Thus, the use of HFUS to identify changes in skin integrity with the goal of early identification and intervention has the potential to identify the presence of underlying pressure ulcers before they appear on the surface. This may be a way to reduce pressure ulcer incidence and reduce hospital costs.

HFUS image analysis requires high-quality images, specific training, and experience. However, the collection of data (images) may be achieved by operators following basic HFUS training. Primary HFUS training typically consists of 8 hours of manufacturer-directed training for advanced practice nurses and wound care specialists who anticipate analyzing HFUS images as well as teaching and/or demonstrating basic HFUS training to others. Therefore once trained, HFUS images may be obtained by a variety of health care providers. Little is known about the consistency in obtaining high-quality images with different operators. Ninety-five percent of all pressure ulcers develop on the lower portion of the body with the sacrum/coccyx most frequently affected.^{7;8} HFUS has been recently used to detect pressure-related skin injury based on patterns of fluid or edema within dermal and subdermal tissues.^{4;9–12}

Ideal HFUS images of the sacrum are obtained when the patient is prone and the ultrasound probe is placed perpendicular to the patient's skin.¹³ In critically ill patients, use of a prone position may not be possible and as a result alternative and suboptimal positions may be

used. These alternative positions may preclude obtaining optimal images due to differences in body position and difficulty in holding the probe in an optimal (perpendicular) position. Although use of a prone position is recommended to obtain a sacral scan, it is not known how a change in position may affect the quality of the image. Therefore, the purpose of this study was to evaluate the quality of HFUS images obtained by multiple operators in different subject positions (prone, left side-lying with 60° rotation, left side-lying with 90° rotation).

METHODS

Setting and Subjects

The study was conducted in a clinical learning center in a school of nursing. A sample of 50 adult volunteers was drawn from the university and surrounding community using personal contact, electronic mailings, social media, and fliers. For this initial study, volunteers were used since repeated repositioning in the critically ill patient may significantly affect patient comfort and safety. Exclusion criteria were: age <18 years, pregnancy, sacral skin disorders (such as psoriasis, eczema, open sores, or open wounds), individuals with chronic, persistent neuromuscular disorders (such as cerebral palsy and Parkinson's disease), and individuals with stroke as these may affect movement and study measurements. Volunteers had to understand English and provide consent. The study was approved by the university institutional review board.

Measures

HFUS Image Quality Components—High Frequency Ultrasound image quality consists of two areas for evaluation; 1) overall HFUS image and 2) dermal / hypodermal layer components. Highest quality HFUS images have specific components: a defined epidermal entry echo and uniform, clearly visualized texture (collagen bundles and ground substance) differences between the dermal and hypodermal layers. The HFUS images of the sacral area were obtained using the EPISCAN system (Longport Inc., Glen Mills, PA), a 20-MHz ultrasound dermal scanning system. Settings on all images were as per manufacturer's recommendation for sacral scans and were consistent to insure uniformity of measurement between images.

Overall HFUS image: The quality of the overall HFUS image was determined using a rating scale (1.0 poor - 4.0 flawless) previously developed by our team¹⁴ and reflects the presence or absence of the components described above (Table 1). Based on these criteria an acceptable quality image has a rating of 3.0 to 4.0.¹⁵ To further delineate image quality between the rating of 3.0 (acceptable image) and a rating of 4.0 (essentially a perfect image), an additional gradation to define specific features of images between 3.0 and 4.0 was included (Table 1).¹⁴ The rating scale was tested using 241 images in 40 subjects, with analysis of expert agreement after 20 subjects (127 images) and again after 40 subjects (241 images).¹⁴

Layer components: Changes in patient position may affect the ability to visualize and measure important image components (dermal and hypodermal layer thickness, dermal and

hypodermal layer density) that may reflect tissue injury. Recent use of HFUS to evaluate tissue injury has indicated that patterns of fluid accumulation or layer edema below the epidermis or within dermal and hypodermal tissue may be early indicators of tissue injury.^{4;9;10} Therefore, dermal and hypodermal layer thickness (in millimeters) would increase as fluid accumulates expanding the layer. On the other hand, dermal and hypodermal layer density may decrease as fluid accumulates and would be reflected as less tissue dense (that is lower signal intensity distribution in the image - hypoechogenicity).^{4;11;16}

In comparing image components, some variability can be expected. In a HFUS scan, for example, sacral skin of a subject in one position may have a different layer thickness and layer density than in other positions although these measurements should be comparable between similar positions. Use of HFUS in the evaluation of tissue injury is dependent on accurate measures that may reflect changes or injury in the dermis or hypodermis layers. However, in this study of normal volunteers, we only used dermal measures, since we were not evaluating for edema reflective of tissue injury in these healthy subjects, but rather to identify changes in these measurements based on operator or subject position. Therefore, HFUS image components, with respect to subject position, included only dermal layer thickness (in millimeters), and dermal layer density (median signal intensity distribution) and were both obtained using the HFUS system software analysis functions. It is not known if position changes could induce significantly different layer thickness or layer density measurements, affecting uniformity of image components.

Horizontal layer orientation—To obtain optimal images, the HFUS probe should be held perpendicular to the skin and lightly touching the skin ideally resulting in images with a horizontally-oriented (0°) epidermal entry echo.¹³ However the orientation of the HFUS probe may vary based on patient position, ease of obtaining the perpendicular angle, and the title of the probe which may attenuate the epidermal echo affecting the ability to obtain a quality image. Evaluation of image layer orientation from the horizontal was obtained for each image using a protractor during image evaluation to identify differences among subject positions.

Subject position—Three body positions were chosen based on manufacturer's recommendations and typical positions of critically ill patients: 1) prone (manufacturer's recommendation); 2) left sidelying with 90° rotation; 3) left side-lying with 60° rotation. To ensure position consistency between subjects only the left side was arbitrarily chosen. Two degrees of rotation (90° and 60°) were used as they simulate usual critically ill patient positions. Degree of rotation less than 60° for obtaining HFUS images would not be possible due to probe location, i.e. inability to place the probe on the sacral area in a patient who is barely turned to the side. Thus, 90° and 60° degrees were selected as the most common and practical positions for obtaining sacral scans. Therefore, including all three positions (prone, 90°, 60°), allowed us to compare the positions most likely to be used in the critically ill (90°, 60°) with the manufacturer-recommended position (prone). Up to 9 images per patient were selected for analysis – one image by each operator (3 images) in 3 positions.

Procedure

After obtaining consent for the study and subject demographic information provided by each subject (height, weight, gender, ethnic background, race, and age) three operators trained in obtaining HFUS images (RSB, APB, MBR) obtained scans in all three positions for each subject. The first randomly chosen operator escorted the volunteer to a private patient bay with a hospital bed, instructed the subject to expose the sacral area for scanning, and assisted the individual to assume the first randomly assigned position.

For the prone position, subjects were directed to lie prone on the bed for scanning. For the 90° position, subjects were directed to lie on their left side with hips flexed and stacked; visual evaluation and body adjustment was used to refine the position. For the 60° position, two 30° 3-foot long hospital patient wedges were placed together, wedged along the subject's back and head, one end just above the sacrum to allow sacral scanning. Patients were directed to lean firmly against the wedges. Again, visual evaluation and body adjustment was used to refine the position.

The location of the HFUS probe site was based on palpation of the coccyx. Per manufacturer instructions, approximately one teaspoon of non-irritating hypoallergenic gel was placed on the probe to provide a good ultrasound path between the transducer and the skin. The operators' scanning procedures were done in privacy with the patient bay blinded to other operators. At 1-second intervals, the HFUS system creates and captures a series of images after which operators have the opportunity to adjust the probe to produce an optimal scan. Operators were directed to identify from 1 to 3 of the highest quality captured images to retain for documentation. Images were identified by a random number and entered into a database for blinded analysis. Once the first operator had completed scanning and labeling the images, the second and third operators completed their scans using the same method. The procedure lasted approximately 15 minutes for all operators to complete the data collection for the three positions in one subject. The three trained study personnel performed all sacral ultrasound scans in each position for each volunteer.

Data analysis

After all data collection was completed, the expert HFUS image analyst (RSB) assessed the images. The expert analyst, blinded to the operator and subject position, evaluated the quality of each image using the rating scale (1.0 to 4.0), selected the best image for each operator and patient position for analysis. Dermal layer components (layer thickness and layer density) were obtained using the HFUS system software analysis functions and horizontal layer orientation was measured using a protractor.

Demographic and sample characteristics were described using means and standard deviations for continuous variables, and frequency counts and percentages for categorical variables. Three response variables of interest were identified: overall image quality, dermal layer thickness and dermal layer density. Dermal layer thickness was computed as the average of three measurements. ANOVA was used to examine the effects of subject position, operator and horizontal layer orientation on each response variable separately. Horizontal layer orientation in the image (as described above) was collapsed into three

categories based on naturally occurring groups: those with an angle $<10^\circ$, those with angle 10° or higher and those with a varying angle. A varying angle occurred when the epidermal layer was U-shaped and may have been related to greater probe pressure. In addition, a tilt of the horizontal orientation of the image of greater than 10° appeared to effect scan quality supporting the use of these categories. Categories related to position, operator, layer orientation, and all possible interactions between these three predictors were used to model image quality and thickness. Any terms that were not significant in the model, such as an interaction between the position and operator was removed from the model and the model refit. Model adjusted means for each predictor at each level were computed and compared statistically using a Bonferroni adjustment for multiple comparisons between levels of the predictor variables. Since these models were built using subjects from whom multiple measurements were taken (e.g. across operator), the correlation from repeated measurements was included and estimated in the model so that standard errors and inferences would be appropriately adjusted. An experiment-wise alpha level was set to 0.05 and all computations were completed using SASv9.2.

RESULTS

Subjects

Over the data collection period, 50 subjects were recruited resulting in a total of 957 HFUS images. After selection of the best image per subject per position, 447 scans were used for analysis (3 images for either a rater or a position were missing). Subjects' mean age was 30 years (range 20–63) and were primarily female, non-Hispanic, and white (Table 2). Of the 447 scans, 73 (16%) were rated below 3 and considered not reliable for image analysis.

Effects of Position and Operator

There was no significant interactive effects between operator and position on overall image quality ($p=0.5931$), nor were there significant differences in image quality among positions ($p=0.0679$). However, overall image quality did vary by operator ($p<0.0001$). After adjustments for multiple comparisons, average image quality was significantly less for operator M than operator A or R ($p<0.0001$ for both; Figure 1).

There was no significant interactive effects between operator and position on layer thickness ($p=0.5289$), nor were there significant differences in layer thickness among operators ($p=0.1745$). However, layer thickness did vary by position ($p=0.0003$). After adjustments for multiple comparisons, layer thickness was significantly less for the prone position than position 90° or 60° ($p=0.0137$ and 0.0003 respectively), but there were no significant differences in layer thickness measurements between positions 90° and 60° ($p=0.8209$; Figure 2). Model estimated average layer thickness was 2.32 for the prone position (95% CI 2.24, 2.40), 2.55 for position 60° (95% CI 2.47, 2.63) and 2.49 for position 90° (95% CI 2.40, 2.57).

There was no significant interactive effects between operator and position on layer density ($p=0.1018$). However, there were significant differences in layer density by operator ($p<0.0001$) and position ($p<0.0001$). After adjustments for multiple comparisons, average

layer density was lower for the prone position than for the 90° or 60° positions ($p<0.0001$ for both), but there were no significant differences in layer density between positions 90° and 60° ($p=0.1481$). Model estimated average layer density was 106.00 for position 90° (95% CI 104.57, 107.43), 101.14 for the prone position (95% CI 99.71, 102.57) and 108.03 for 60° (95% CI 106.60, 109.46). There was no significant difference in layer density between operators A and M ($p=1.0$), however, operator R had significantly higher average layer density values than either operator A ($p<0.0001$) or operator M ($p<0.0001$; Figure 3).

Effects of Layer Orientation

There were significant differences in the average dermal layer density ($p=0.0049$) and overall image quality depending on layer orientation ($p=0.0007$), but no significant differences in average dermal layer thickness by layer orientation ($p=0.0875$). After adjusting for multiple comparisons, horizontal layer orientation $< 10^\circ$ had significantly higher average overall image quality than either of the other two categories ($> 10^\circ$, $p=0.0005$; variable, $p=0.0383$). There was no difference in the average overall image quality between layer orientation of $>10^\circ$ and the variable category ($p=1.0$). Model estimated average global ratings was 3.69 for horizontal layer $<10^\circ$ (95% CI 3.65, 3.73), 3.59 for $>10^\circ$ (95% CI 3.55, 3.62) and 3.61 for the variable category (95% CI 3.56, 3.66). With respect to dermal density, after adjustment for multiple comparisons, only $<10^\circ$ orientation had significantly lower dermal density than the variable category ($p=0.0035$; Figure 4).

DISCUSSION

This study evaluated the quality of HFUS images, layer components and horizontal layer orientation obtained by multiple operators in different subject positions (prone, left side-lying with 60° rotation, left side-lying with 90° rotation) in a sample of healthy volunteers. We found that although HFUS image quality varied by operator, the vast majority of images obtained were in the acceptable range (i.e greater than 3.0). In our previous work related to evaluation of HFUS image quality,¹⁴ although an image rated as 3.0 was found to be in the acceptable range, images with a 3.5 or greater rating were of much better quality. Our recommendations based on those data were to use images with a 3.5 rating or better to determine any tissue changes. Even though operators in this study varied statistically, the mean rating for each operator was 3.5 or better indicating that a variety of operators, even those who are not highly trained experts, can obtain good images that may be useful for evaluation of changes in tissue.

There were differences in layer components based on position. Layer thickness measures did vary by position, with the prone position resulting in lower levels of thickness compared to the side-lying positions. The skin over the sacral area in the prone position may be more spread out compared to side-lying positions (60° or 90°) causing larger values for tissue thickness. Therefore it will be important when images are repeated over time that similar positions (prone versus side-lying) are used to obtain reliable measures of thickness.

Measures for layer density were lower for the prone position than for the 90° or 60° positions and images from one operator had higher layer density values than either of the other two. Similar to layer thickness measures, the sacral skin may spread out in the prone

position potentially resulting in different skin density values than those found in the side-lying position, where the skin may be “bunched” or pulled by gravity affecting the measurements. Therefore, consistent use of the prone versus side-lying positions will again be important for reliable measurement. There were no differences between the 60° and 90° positions in layer density suggesting that these two types of side-lying positions may be interchangeable and the degree of lateral turn may not be as important as whether the subject is prone versus side-lying. In addition, the images obtained from the operator who had overall lower image ratings also had higher layer density values. This may be related to image quality.

The way the probe was held (horizontal layer orientation), that is, not at a completely perpendicular angle, did affect overall image quality and layer density measurements. When the layers of the image were horizontal or close to it (tilted less than 10°) quality of the image was better. A reduction in image quality may also affect layer density measures, so that more tilted or variably oriented images showed higher density values. It is not surprising, however, that layer thickness was not affected by changes in layer orientation, as whether the image is tilted or not would not affect the actual thickness of the dermal layer or the ability to measure that thickness.

This study is limited in that it included only healthy volunteers who may not adequately represent acutely or chronically ill patients and may not provide enough variation in measures to identify all potential differences. There may be other factors that also affect image quality including the limited scan depth of 20 MHz HFUS systems. Tissue visualization may be variable especially deeper than 15–20mm.^{17;18} precluding reliable examination of the hypodermis, however in this study we focused on dermal layer component measurements only. In addition, there may have been variable experience of the operators. Operator R is an expert in obtaining and evaluating HFUS images, while Operators A and M were newly trained clinicians which may explain the differences among them. However Operators A and M may be more similar to bedside clinicians who are obtaining scans indicating than even without significant expertise, operators can still obtain acceptable images (i.e. above 3.5 rating).

In summary, the purpose of this study was to evaluate the quality of HFUS images obtained by multiple operators in different subject positions (prone, left side-lying with 600 rotation, left side-lying with 900 rotation). The results show that overall scan quality was acceptable in all positions with all operators. However, differences were found between sidelying positions and the prone for dermal thickness and dermal density measures.

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CLINICAL IMPLICATIONS

The development of pressure ulcers is a costly complication of illness and patient care and the best preventive care strategies have been unable to completely eradicate them. Early identification of tissue changes that may eventually lead to tissue injury is critical to further reduce the incidence of pressure ulcers. HFUS technology may identify tissue edema a potential first sign of changes in tissue integrity, however quality scans and accurate measurements are required. HFUS images may be obtained on admission to acute or long term care facilities by multiple clinicians with varying skill to identify those at risk and/or to document the presence of skin integrity issues. Using a variety of clinicians and patient positions may negatively affect image quality and the results presented here should be considered before data obtained from the HFUS images are used for patient care decisions.

Figure 1.
Average Global Rating by Operator

Figure 2.
Average Dermal Thickness by Position

Figure 3.
Average Dermal Density (median intensity) by Position and Operator

Figure 4.
Average Dermal Density (median intensity) and Global Rating by Layer Orientation

Table 1

HFUS Image Quality Rating scale

Rating	Definition
1.0	dermis and hypodermis not evaluable due to poor scan
2.0	at least 1 layer evaluable but other is not or at least 50% of both layers are evaluable*
3.0	at least 50% of both layers are evaluable; no well-defined epidermal entry echo, no defined layer margin between all 3 layers
3.1	approximated epidermal entry echo, no clearly defined layer margin between dermis and hypodermis
3.2	defined epidermal entry echo, no clearly defined layer margin between dermis and hypodermis
3.3	well-defined epidermal entry echo, no clearly defined layer margin between dermis and hypodermis
3.4	approximated epidermal entry echo, also layer margin between dermis and hypodermis can be approximated
3.5	defined epidermal entry echo, layer margin between dermis and hypodermis can be approximated
3.6	defined epidermal entry echo, layer margin between dermis and hypodermis can be determined
3.7	defined epidermal entry echo, well-defined layer margin between dermis and hypodermis
3.8	well-defined epidermal entry echo, well-defined layer margin between dermis and hypodermis
3.9	very high quality image, some minor image defects on lateral areas
4.0	all of both layers are evaluable, no interfering image artifacts present, essentially flawless image, no visible image defects

* at least 50% of the widths of the image of both layers are evaluable with the evaluable portions positioned over each other

Table 2

Demographics and descriptors of sample

Variable	Sample (n = 50)
	n (%)
Gender	
Male	9 (18)
Female	41 (82)
Ethnicity	
Hispanic or Latino	1 (2)
Not Hispanic or Latino	49 (98)
Race	
Asian	5 (10)
Black or African American	5 (10)
White	36 (72)
Other	4 (8)
Variable	Mean (Range, SD)
Age (years)	30.04 (20–63, 10.98)
Height (inches)	66.8 (61–74, 3.19)
Weight (lbs)	155.78 (105–257, 38.51)
BMI	24.39 (14.89–39.54, 4.93)