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High Frequency Ultrasound: Description of sacral tissue characteristics in healthy adults

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Abstract

Objectives—The purpose of this study was to describe selected sacral tissue characteristics in a convenience sample of healthy volunteer subjects.

Design—Descriptive

Sample and setting—50 healthy volunteers in a clinical learning center in a school of nursing

Methods—Sacral scans were obtained using a 20-MHz ultrasound scanning system in three positions: prone, 60 and 90 degree side-lying from the back. The images were analyzed by software in the ultrasound program using quantitative parameters of dermal thickness and density (dermal median intensity and derived number of low-echogenic pixels to total pixel [LEP:TP] ratio).

Results—In general, average values were: dermal thickness between 2.32 and 2.65 mm; median pixel intensity between 102–112; the LEP:TP ratio between 0.39–0.56. There were significant differences in sacral tissue characteristics between measures of thickness and dermal density (median intensity and LEP:TP ratio) by subject side-lying position (60 and 90) versus prone with all p-values less than 0.0001.

Conclusions—Overall, the ranges were consistent across measures of thickness and dermal density except for systematic differences between side-lying and prone. When comparing thickness, median intensity, or LEP:TP it is important to report subject position. To best recognize

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Conflicts of Interest

For all authors no conflicts of interest are declared.

tissue inflammation indicative of pressure injuries before surface changes are seen, it is useful to understand healthy High Frequency Ultrasound (HFUS) sacral tissue characteristics. It is anticipated that quantitative assessment of dermal thickness, density, and LEP:TP ratio could help identify individuals with incipient pressure injury.

Pressure injuries, formerly known as pressure ulcers, are a major health problem associated with pain, risk for infection, increased resource use, and mortality.¹ Hospitalized patients and those in long term care facilities are at especially high risk for pressure injury development.² Currently in the United States, the Centers for Medicare and Medicaid Services do not reimburse health care facilities for pressure injury acquired after admission; therefore, pressure injury prevention or early identification has become a priority in health care settings.³

With the goal of early pressure injury identification, high frequency ultrasound (HFUS) in the range of 20 MHz with high fidelity is a cost-effective and non-invasive method allowing immediate or convenience evaluation of subepidermal tissue.⁴ HFUS images have been recently studied to detect pressure-related skin changes based on patterns of fluid or edema within or near dermal tissues.⁴⁻⁸

In addition to producing HFUS images for visual evaluation, HFUS systems provide quantitative data and image archiving allowing objective measurements and convenience evaluation. Some HFUS systems enable users to access analysis functions to view A-scans (one-dimensional measurements) and B-scans (two-dimensional images) as well as generate quantitative parameters based on the distribution signal intensity of the pixels in the HFUS images. Numerical data produced could show contrast between healthy tissue and tissue with change, assisting in detecting subtle changes over time that may not be identified by visual assessment of images alone.

Studies that have used analysis of HFUS images to extract quantitative parameters to differentiate between normal and damaged tissue can be largely grouped into categories based on the use of patient populations or animal models, the anatomical locations studied, the equipment used, and the ultrasound measurements used. The most common quantitative parameters used were dermal thickness^{5, 9-13} and density, also referred to as echogenicity.^{7, 8, 13, 14} While several of these studies used within-subject designs to compare healthy to normal tissue, these individuals represent people who have already developed a pressure injury or are hospitalized patients at risk of pressure injury.^{4-6, 10, 14} In other words, normal tissue measurements in these compromised individuals may not be representative of healthy tissue on the whole. While normative ultrasound data has been generated in limited studies and some for healthy individuals, dermal thickness was the only quantitative ultrasound measurement taken, position differences were not considered, and the coccyx was not specifically studied.^{12, 15}

As ninety-five percent of all pressure injuries develop on the lower portion of the body with the sacrum/coccyx most frequently affected, the use of healthy tissue data may assist in recognizing differences between healthy and abnormal tissue with respect to pressure injuries. Although the prone position is recommended for HFUS scanning in the intensive

care unit (ICU) environment it can be uncomfortable for patients and may not be feasible for patients using some medical devices/equipment. In our first study regarding the effect of HFUS with respect to position we found that different positions affected quantitative HFUS measurements.¹⁶ We are now describing the relationships fully and reporting a second density measurement currently more widely used in research. It would be useful to fully understand the relationship of position to quantitative parameters obtained by HFUS software as ICU patient position may change frequently and we now know that position affects HFUS data. Without standards for healthy tissue characteristics HFUS evaluation of those at risk for pressure injury, especially hospitalized patients or those in long term care facilities is difficult. Therefore, the purpose of this study was to describe sacral tissue characteristics in a convenience sample of healthy volunteer subjects.

METHODS

The study was conducted in a clinical learning center in a school of nursing. A convenience sample of 50 adult volunteer subjects was drawn from the university and surrounding community using personal contact, electronic mailings, social media, and fliers. 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. Volunteer subjects had to understand English and provide consent. The university institutional review board approved the study.

Measures

High Frequency Ultrasound Image—HFUS images of the sacral area were obtained using a 20-MHz ultrasound dermal scanning system (EPISCAN system, Longport Inc., Glen Mills, PA). This system was used as it was found to have good precision for thickness measurements, with resolution on the order of 0.003 mm for 2 mm thick layers and 0.01 mm for 5 mm thick layers.¹⁷ Settings for the HFUS system on all images were as per manufacturer's recommendation for sacral scans and remained consistent to insure uniformity of measurement between images: size — 512 × 1024; TGC srt = 0%; pos = 16.0; depth = 10.2 mm; TGC = 10%; gain = 20%. Pixels per square millimeter were 3429. The "Bottom Palette" mode was used due to the wider lower spectrum of color allowing superior discrimination of skin layer boundaries for more accurate thickness measurement. The "Mirror Palette" mode (intensities from 0 to 127) was used for number of low-echogenic pixels to total pixel (LEP:TP) determination. Only quality HFUS images (those with at least half of both layers evaluable with the evaluable portions positioned over each other) were selected for analysis based on our previous work which outlined a scale determining quality images.¹⁸

Sacral Tissue Characteristics—Tissue characteristics most likely to indicate healthy tissue in comparison to tissue inflammation (the first indication of pressure damage), were used. Healthy sacral dermal thickness and density data appear the most relevant for comparison in detecting tissue change.^{10,12,15} We used a specific area, the coccyx (within the sacral area), determined by palpation of the coccyx, to further target a smaller area for

consistency of measurements. Inflammatory changes in the dermis with an accompanying increase in fluid could be expected to produce lower HFUS density data as well as increased dermal thickness.⁴⁻⁸

Dermal thickness or sonographic depth index is defined as the measurement of distance from the top to the bottom of the dermal layer in millimeters. The bottom of the dermal layer (inner limit) was identified by a layer of hypoechoic subcutaneous tissue. Healthy tissue would be expected to have less dermal thickness than tissue with inflammatory change with accompanying increase in fluid content. Three equidistant measurements inside an annotated area were collected to report average dermal thickness (Figure 1).

Healthy tissue would be expected to have higher density (higher echogenic values); in comparison, injured tissue with increased fluid from inflammatory processes produces overall lower echogenic values.^{6, 9, 10} Changes in dermal density may suggest inflammation/increased water content or the converse in healing.⁴⁻⁸

Dermal Median Intensity: The one-dimensional A-scan graph is used to extract dermal median intensity data displaying the pixel color values on the horizontal axis and the number of pixels on the vertical axis as intensities. The median intensity is at the center of the sonographic distribution profile with the same number of significant intensities to either side. Both median and mean intensity values are available from the software; however, as the signal distribution is skewed we used the median intensity. Healthy tissue would be expected to have higher median intensity values than tissue with inflammation as discussed above.

Low Echogenic Pixels vs. Total Pixel Ratio: Evaluating the number of low-echogenic pixels (LEP) to total pixels (TP) derived from A-scan HFUS data has been used by others to compare images over time.^{13, 19-21} There is no gold standard for density measurements but the LEP:TP ratio is convenient to use and easily understandable. LEP:TP data is one density parameter but several have been used. Moghimi et al. (2011) used five features commonly used in texture analysis, defining echogenicity as the root-mean-square, or average of the absolute value, of pixel values.⁸ Timar Banu (2001) defined echogenicity as the mean intensity of pixel values divided by the total area of interest, normalized between 0 and 100¹⁴ while Ryan (2001) and others calculated echogenicity by dividing the number of low echogenic pixels (LEP) (intensity values ranging from 0 – 30) by the total number of pixels (TP) (intensity values ranging from 0 – 255).²¹⁻²⁴ Following the process established by others we calculated echogenicity by dividing the number of low echogenic pixels (LEP) (intensity values ranging from 0 – 30) by the total number of pixels (TP) (intensity values ranging from 0 – 255).²¹⁻²⁴ Dermal tissue with suspected inflammation accompanied by higher water content produces overall lower echogenic values. Healthy tissue would be expected to have generally lower ratio values than tissue with inflammation.

The manufacturer recommends the prone position for HFUS scanning; however, the majority of hospitalized patients are cared for in a side-lying position and assuming the prone position is difficult for most. Side-lying patients are usually between 60 and 90 degrees from the horizontal on the back when HFUS scans are obtained. Body angles lower than 60 degrees prevent proper probe placement while body angles greater than 90 degrees

have two disadvantages: the potential to interfere with medical equipment and a prone position can be uncomfortable. Tissue characteristics vary by scanning position. In our recent study evaluating general HFUS thickness and density measurements between prone, 60 degree, and 90 degree side-lying positions, we found significant differences between thickness and density with respect to position.¹⁶ Specifically layer thickness and density were significantly less for the prone position than either the 90 degree or 60 degree positions. Due to significant differences found with respect to position for thickness and median intensity, we further report LEP:TP ratio for all three positions.

Study Procedure

Each participant had an appointment for data collection. Demographic information was provided by each subject (gender, ethnic background, race, and age height, weight, and BMI). Prior to scanning by three operators trained in HFUS data collection as well as study procedures, all subjects were sitting or standing to assure pressure uniformity and consistency of the sacral surface. The healthy volunteer subject was escorted to a hospital bed in a private patient bay, instructed to expose the sacral area for scanning, and assisted to assume the first randomized position. Interrater reliability between operators was generally good and results were previously published.¹⁶ The first position was achieved within about 2 minutes of arrival to the bay.

The positioning/scanning process was performed efficiently to respect volunteers' schedules. As soon as the position was assumed, scanning was initiated. For the prone position, subjects were directed to lie prone on the bed. For the 90 degree 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 degree position, two 30 degree 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. Subjects 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's instructions, approximately one teaspoon of non-irritating hypoallergenic gel was placed on the probe before contacting the subject's skin. The HFUS system creates and captures a series of images at 1-second intervals, during which an operator has the opportunity to adjust the probe to produce an optimal scan. One to three of the highest quality captured images were saved as a randomly generated number in a database for later blinded analysis by one researcher (RSB). For each subject, data collection lasted approximately 15 minutes.

In obtaining measurements from the HFUS images, a shape annotation was added to enclose the dermal layer from which a summary of the distribution statistics are derived (Figure 1). Full dermal layer thickness measurements were obtained in a maximum of 3 equidistant locations inside the selected area for measurement (Figure 1). Density and thickness data were generated by the same researcher (RSB) with significant training and experience in HFUS data acquisition and evaluation.

Data Analysis

Descriptive statistics of the 50 healthy volunteer subjects participating in this study were computed for demographic characteristics such as gender and race and physical characteristics, e.g. weight, height and BMI. For each of the three positions from which HFUS measurements were taken (prone, sixty and ninety degrees) distributional information was computed for median intensity and tissue thickness to include the minimum, maximum, 25th, 50th and 75th percentiles. In addition, the mean and standard deviation was provided. ANOVA utilizing a randomized block design was used to ascertain whether or not thickness, median intensity, or LEP:TP ratio measures differed by position. Statistical tests assumed a 0.05 level of significance.

RESULTS

The majority of the 50 subjects in this study were students and differed significantly by gender and race (both $p < 0.0001$). Study subjects were primarily female ($n=41$, 82%) and white ($n=36$, 72%) (Table 1). Average age was about 30 years and ranged from 20 to 63 years. BMI varied ranging from about 14 kg/m² to 39 kg/m² with a mean of 24 kg/m². See Table 1.

Dermal thickness was between 1.21 and 3.76 mm. Average thickness tended to fall between 2.32 and 2.65 mm. In general, median pixel intensity ranged from a value of about 76 to 124 and averaged between 102–112. The LEP:TP ratio averaged between 0.39–0.56 and ranged as low as 0.18 and as high as 0.90. Correlations between BMI and median pixel intensity, LEP:TP ratio, and thickness were low to moderate, ranging between 0.05 to 0.31.

There were significant differences in sacral tissue characteristics between measures of thickness and dermal density (median intensity and LEP:TP ratio) by subject side-lying position (60 & 90) vs. prone with all p -values less than 0.0001. All Percentile values for tissue thickness and dermal density values are provided by position for accurate description of sacral tissue characteristics (Table 2). Thickness measurements differed by approximately 0.4 mm at the 25th and 50th percentiles between prone and sixty and ninety degrees and approximately 0.2 mm for the 75th percentile. Percentile estimates for thickness measurements at sixty and ninety degrees varied slightly (within about 0.1). See Table 2.

In the prone position (manufacturer recommended position) percentile estimates for median pixel intensity were about 10 units lower than that at sixty or ninety degrees; however, differences between sixty and ninety degrees were minimal (1–2 units). See Table 2.

Percentile estimates for LEP:TP ratio were lower in the prone position than at either sixty or ninety degrees except at the minimum. LEP:TP ratio only differed by about 0.04 between sixty and ninety degrees. However, the minimum value observable for prone or sixty was 0.18 which is 0.02 units lower than that for ninety degrees. Similarly correlations of dermal density varied by position but not thickness. See Table 2.

Correlations of BMI to thickness ranged between 0.22 and 0.28, but were not statistically significant (all $p > 0.05$). Median pixel intensity and BMI were weakly, and not significantly

($p=0.11$ and 0.09) correlated between 0.23 to 0.25 for sixty and ninety degrees. However, in the prone position, median pixel intensity only had a correlation of 0.05 ($p=0.75$). Similarly, the correlation of LEP:TP ratio to BMI was weak to moderate for sixty degrees (0.25 , $p=0.08$) and ninety degrees (0.31 , $p=0.03$), and only 0.07 ($p=0.61$) for the prone position.

DISCUSSION

To best recognize tissue inflammation indicative of pressure injuries in ICU patients before surface changes are seen, it is useful to understand healthy HFUS sacral/coccyx tissue characteristics. We focused on thickness and dermal density (median pixel intensity, LEP:TP measurements).

Average thickness was somewhat comparable to others for our sacral dermal sample. Dermal thickness was previously reported in two studies. A study of 22 body sites of the lower back (middle of the lumbar region) as 1.75 to 2.56 mm with female and male ranges combined.²⁵ Their thickness measurements were lower than our mean but may be due to sacral area location differences as we used a site that was chosen by palpation of the coccyx, a more specific region than lower middle back. No mention was made of body position. Dermal thickness was also reported in a study of 241 healthy participants stratified by age and gender.¹² Their thickness measurements were lower than our mean possibly due to the specificity of location (coccyx) or body position. Body position reported was either standing or the prone position. We have previously reported significant differences in sacral skin thickness by position.¹⁶

We found minimal differences in measurements between 60 and 90 degrees in dermal thickness (within about 0.1 mm) but significant difference between both side-lying positions and prone. Thickness measurements were higher in the prone position. In general, a thickness measurement that would place a subject at the 25th percentile when measured at sixty or ninety degrees corresponds to that for a subject at the 50th percentile when prone. The two other studies found thickness measurements lower than ours in the prone position.^{12,25} Dermal thickness measurements may be subject to variability due to human error - inaccuracies from measurement area based on visual judgment of the location for the scan and image assessment boundaries of the dermal layer. Using good quality HFUS scans plays an important role in the measurement process.¹⁸ Image quality was not mentioned in the two other studies. Subject position is important in determining sacral dermal thickness measurements.

We found minimal differences in measurements between 60 and 90 degrees in dermal median intensity (density) ($1-2$ units) but significant differences, again, between the manufacturer-recommended prone and both side-lying positions. Median intensity was higher in the prone position. An individual at the 25th percentile for median pixel intensity measured at 60 or 90 degrees would be near the 75th percentile in the prone position. Dermal median intensity measurements are also subject to variability from visual judgment of the boundaries of the dermal layer which can be minimized by using only good quality HFUS images.¹⁸ We found no studies reporting this variable for the sacral area.

We found LEP:TP ratio in the prone position was about 0.15 units lower than for 60 or 90 degrees from the 25th percentile up to the maximum. It is important for the LEP:TP ratio to be reported by position also. We found no studies reporting this variable for the sacral area.

In using both visual inspection and quantitative data for serial HFUS scans to investigate sacral tissue change in a side-lying subject it is important to consider that 90 degree positions have slightly lower thickness, median pixel intensity, and LEP:TP ratios than the 60 degree position and that prone positioning produces significantly lowest values of all.

As individual weight differences may affect healthy sacral dermal tissue measurements, we evaluated associations of BMI to our variables. Certain dermal tissue measurements may be higher in the higher BMI population.²⁶ Sacral dermal thickness, median pixel intensity, and LEP:TP were not significantly different (all $p>0.05$) based on BMI and were at best weakly associated. The dermal layer is composed of denser tissue with lower adipose content. The association may have been stronger using hypodermal layer thickness as this layer has both higher fluid and adipose tissue.

There were study limitations common to all HFUS investigations. Changes in density and thickness may also be attributed to gender, race, hydration, and stage of menstrual cycle, not evaluated in this study. We have noted significant differences in thickness measurements by position.¹² To date there has been no study of skin thickness with respect to position. There was lack of diversity in the sample; our convenience sample consisted largely of university students – younger, female, and white. Our sample may not be generalizable to an older population. A greater diversity of sample would assist in understanding differences in healthy sacral tissue characteristics due to age, gender, and race. Future studies would benefit from a larger sample with more heterogeneous demographics and stratification for age, gender, and race as well as other characteristics. There are other HFUS systems in the marketplace; however, it is not known if data acquired from these systems are uniform across different manufacturers.

In the interest of higher quality as well as greater continuity and consistency in HFUS data, retraining of operators at regular intervals would be desirable. We completed this study over a relatively short period of time (3 months); however, retraining during scan quality monitoring or training modules at regular intervals would serve to promote homogeneity in scanning techniques improving image quality. As is well-known, highest quality scans produce highest quality data although we showed that high quality scans are not always possible.¹⁶

It is anticipated that assessment of dermal thickness and density could become a standard of care for at risk individuals, aiding in the identification of incipient skin injury.

CONCLUSION

We report normal ranges for dermal sacral measurements for healthy generally younger individuals. Overall, the ranges were consistent across measures of thickness and dermal density except for systematic differences between side-lying and prone positions. Further

studies need to evaluate the usefulness of the HFUS software-derived parameters in reliably indicating a change in echogenicity associated with the inflammatory process.

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Key Points

1. Overall, healthy sacral tissue normal range measurements were consistent across measures of thickness and dermal density except for systematic differences between side-lying and prone. Side-lying positions produced higher thickness, median pixel intensity, and LEP:TP Ratios.
2. Differences in HFUS software-derived sacral thickness and median pixel intensity in 60 or 90 degree side-lying healthy subjects was shown to be not significant across positions.
3. When comparing sacral thickness, median intensity, or LEP:TP it is important to report subject position. This allows greater confidence in quantitative comparisons.

Figure 1.
HFUS image with enclosed measurement annotation and thickness measurement bars.

Table 1

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)

Table 2

Median intensity and dermal thickness by subject position *

Percentiles									
	N**	Mean	SD	Min	25 th	50 th	75 th	Max	
Prone									
Thickness	50	2.32	0.53	1.21	1.92	2.28	2.72	3.60	
Median Pixel Intensity	50	102.50	9.90	76.00	97.00	102.50	110.00	119.00	
LEP:TP Ratio	50	0.39	0.12	0.18	0.29	0.36	0.48	0.69	
60 degrees side-lying									
Thickness	49	2.65	0.54	1.53	2.31	2.65	2.98	3.76	
Median Pixel Intensity	49	112.29	9.00	80.00	109.00	114.00	119.00	124.00	
LEP:TP Ratio	49	0.57	0.18	0.18	0.46	0.54	0.73	0.90	
90 degrees side-lying									
Thickness	48	2.61	0.54	1.45	2.19	2.55	3.06	3.75	
Median Pixel Intensity	48	110.44	9.09	85.00	107.50	112.00	118.00	122.00	
LEP:TP Ratio	48	0.53	0.17	0.21	0.41	0.50	0.69	0.82	

* The manufacturer estimates an equipment systematic error of up to $\pm 1\%$

** Sample size varies due to availability of quality 16 images