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Positioner and Clothing Artifact Can Affect One-third Radius BMD Measurement

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Abstract

This report identifies a radius DXA confounder and technical approach to avoid this inaccuracy. Initially, a precision study revealed substantial differences ($p < 0.001$) in radius BMD least significant change (LSC) ranging from 0.038 to 0.073 g/cm^2 between three technologists that each performed assessments in 30 men and 30 women. Subsequently, visual examination of all 360 forearm DXA images, including bone, soft tissue, neutral and air point typing was performed. Errors in automated "soft tissue" identification were observed; compared to the manufacturer's ideal depiction, suboptimal soft tissue point-typing was present in 30/360 scans (8.3%) involving 27 individuals. These point-typing deviations appeared to result from inclusion of forearm positioner slots at the scan field edges or clothing covering the forearm. Twenty-four individuals had a paired scan appropriately point-typed, thus allowing evaluation of the effect on BMD measurement. In those with incorrect point-typing associated with positioner slots, the mean one-third radius BMD was ~7% higher. In conclusion, positioner slots at the edges of the distal scan field can lead to automated soft tissue identification inaccuracies, and consequent erroneous one-third radius BMD measurement. DXA technologists should avoid slot inclusion in forearm scans and evaluate point-typing as part of routine analysis.

Keywords

bone density; forearm; densitometer; Lunar; radius

INTRODUCTION

Radius bone mineral density (BMD) measurement is a valuable clinical site for bone mass evaluation, especially in patients with hyperparathyroidism.(1–3) It is often important in older adults in whom DXA measured lumbar spine BMD is frequently elevated due to degenerative changes.(4–7) Additionally, osteoarthritis may be associated with increased hip BMD.(8,9) Thus, the ISCD recommends one-third radius BMD measurement when the spine or hip cannot be measured(2) as it may identify otherwise unappreciated low BMD with attendant increased fracture risk.(10–12

Given the well-defined anatomy of the radius, it seems reasonable to anticipate excellent BMD measurement precision and agreement between DXA technologists. However, in our clinical practice, we have previously noted quite large BMD least significant change (LSC) values at the radius. Consistent with this, large LSC values, and in addition, substantial

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variability in BMD LSC was noted at the one-third radius region of interest in a recent precision study, conducted at our facility. Why such imprecision and variability occurs has not been clear.

Upon visual review of point-typing in some scans with substantial BMD variability, it was recognized that soft tissue point-typing errors were present in some scans. This observation led to formal review of 360 forearm scan images from the aforementioned precision evaluation. As duplicate scans were performed, this review also allowed evaluation of the effect of point-typing errors on one-third radius BMD measurement. Following identification of soft tissue point typing errors and their effect on one-third radius BMD, a second cohort of 62 women in whom forearm DXA had been performed was evaluated to confirm the presence of soft tissue point-typing errors in a second cohort. These observations, and suggested technical interventions to recognize and avoid this inconsistency, are reported here.

METHODS

Subjects

A cohort of 180 community-dwelling research volunteers (90 women/90 men; age 65+) was recruited for a research study evaluating the effect of gender on lumbar spine, proximal femur, total body and one-third radius BMD precision.(13) As part of this study, two non-dominant forearm DXA scans were obtained on all participants. Study volunteer demographic data is presented in Table 1. Within the male and female group, no between technologist differences in age, BMI or BMD were present.

Following identification of soft tissue point-typing inaccuracies, forearm scans from a second cohort of women were reviewed. This cohort consisted of 62 postmenopausal women without osteoporosis recruited for a research study evaluating forearm MRI measurement; data for this group are reported in Table 1. Both research studies were reviewed and approved by the University of Wisconsin Health Sciences IRB. All volunteers signed an approved informed consent document prior to the conduct of any study procedure.

DXA Acquisition

Three International Society for Clinical Densitometry (ISCD) certified technologists, all with more than two years experience in DXA scan performance, conducted a precision assessment. Following ISCD recommendations(2) each technologist scanned 30 men and 30 women twice with repositioning between scans. Two scans of the non-dominant forearm were completed at the same study visit using a GE Healthcare (Madison, WI) Lunar iDXA densitometer. All forearm scans were acquired using a manufacturer-supplied Plexiglass positioner. As demonstrated in Figure 1, this positioner has slots for straps to secure the arm during a scan. enCORE™ software version 13.31 was used for all scan acquisition and analyses. Identical forearm acquisition and analysis was performed for the confirmatory cohort, except that only a single scan was obtained.

DXA Review

All scans were visually evaluated through the enCORE™ software by one of the technologists (NVA). All point-typing (bone, soft tissue, air and neutral) was visually compared with the manufacturer's ideal (Figures 2a–d). Point-typing was considered to be incorrect when air or clothing was identified as soft tissue, or soft tissue was identified as bone. Each scan was visually assessed for presence and location of positioner slots in the scan field. Visual identification of the positioner slots was enhanced by use of the contrast feature, the enCORE™ "image" tool, as noted in Figures 3–4d.

Statistical Analyses

Student's T-test was used to compare group demographic characteristics. The BMD least significant change (LSC) was calculated using the ISCD precision calculator(14). Mixed effects linear regression models were used to estimate the precision error and LSC for subgroups based on technician and gender. P-values for equality of precision error across subgroups were calculated using likelihood ratio tests and 95% confidence intervals for precision error and LSC were calculated using a Satterthwaite chi-square approximation. Statistical analyses were performed using PROC MIXED in SAS version 9.1 (SAS Institute Inc., Cary, NC).

RESULTS

One-third Radius BMD Precision

Substantial between-technologist differences in least significant change ($p < 0.01$; 0.038 to 0.073 grams/cm^2) were observed for both men and women (Figure 5). As no difference in subject characteristics, BMD or bone image was apparent between the groups of people scanned by the three technologists, this unexpected difference in BMD reproducibility prompted the review of point-typing described above.

Point-typing Review and Effect of Errors on BMD (Precision Cohort

In this cohort of 180 volunteers, 27 (15%) were found to have visually evident soft tissue point-typing inaccuracies. Technologist #3 performed the scans in 19 of these 27 individuals, contributing to the difference in precision observed between technologists. Overall, soft tissue point-typing inaccuracies were observed in 30/360 (8.3%) of these scans. Examples of soft tissue point-typing errors are demonstrated in Figures 3–4c/d.

During the course of scan review, it became apparent that almost all observed soft tissue point-typing errors could be categorized into two types: those associated with long forearm positioner slots located at one of the distal corners of the scan field (14 scans; Figure 3) and those related to clothing covering the forearm (15 scans; Figure 4).

Specific characteristics of forearm positioner slot location that appeared to affect soft tissue point-typing include a slot opening (i.e., no Plexiglass) located at either the very distal left or right corner of the scan and with no human tissue overlay. Tissue typing errors were also dependant on the length of this opening that was included in the scan; the slot must be included in at least the first and second scan swipes to produce the point typing error. In this regard, "backwards" positioner placement (Lunar logo under the elbow rather than wrist, Figure 1c), thereby locating the longer slots near the wrist, makes it more likely this error will occur. It was also apparent that inclusion of only minimal slot width (e.g., a few millimeters), or the presence of even an entire large slot located in the scan field but at a location other than on the scan corner, did not alter soft tissue point-typing.

In the 27 individuals in whom soft tissue point-typing errors were identified, the "paired" scan from the precision assessment was correctly point-typed in 24. This allowed evaluation of the impact of point-typing errors on BMD result (Table 2). Incorrect soft tissue point-typing due to slot inclusion increased the measured one-third radius BMD in all but one person. The mean BMD increase was 6.8% ($p < 0.01$; Figure 6). In contrast, incorrect soft tissue point-typing due to clothing variability affected BMD; overall, one-third radius BMD was numerically, but not statistically higher; the mean difference was +2.4% (Figure 6).

As noted above, and depicted in Figures 2–4a, these tissue typing errors were typically not evident when evaluating the bone edge detection. However, bone point-typing errors were

evident on two scans. Additionally, a soft tissue point-typing error of unknown cause was observed in one scan.

Point-typing Review (Confirmatory Cohort; n = 62

In an effort to determine if these observations were unique to this precision assessment cohort, a second "confirmatory" group was evaluated for the presence of radius point-typing errors. This confirmatory group consisted of 62 post-menopausal women participating in an MRI study of low-trauma fracture. Entry criteria required normal bone mass or osteopenia (T-scores between −1.0 and −2.5 at the spine, hip and one-third radius). Demographic data are presented in Table 1. Apparent soft tissue point-typing anomalies were observed in 7/62 scans (11%). These errors were associated with positioner slots in 5 and with clothing in 2 volunteers. Similar to the prior precision group, bone edge detection of these 7 scans was correctly identified by auto-analysis in all but 1 subject.

DISCUSSION

Technical pitfalls of bone density measurement by DXA are well recognized.(15–17) Here we report a previously unappreciated technical error in point typing when measuring forearm bone density on a GE Lunar densitometer. Recognition of these point-typing errors resulted from substantial differences in 1/3rd radius BMD precision results being observed between experienced DXA technologists. Further investigation demonstrated that these errors where due to incorrect automated soft tissue identification by the software. It seems probable that these errors have not previously been appreciated due to the fact that bone edge detection is appropriate. Specifically, since only bone edges are typically visualized when analyzing and interpreting DXA scans, technologists performing the scan analysis, and clinicians reporting the scan results, may not appreciate this technical error. Consequently, it is necessary that DXA technologists specifically evaluate soft tissue point-typing on GE Lunar forearm scans. As DXA determines BMD by comparison of radiation absorption of bone in comparison to soft tissue,(18,19) it is not surprising that these soft tissue point-typing errors cause miscalculation of 1/3rd radius BMD.

These soft tissue point-typing errors appear to result from incorrect positioner placement and/or from clothing covering the arm. Thus, technologist attention to the placement of these slots is indicated. Specifically, it is important to ensure that positioner slots are not in the upper corners at the distal end of the scan. It seems likely that these slots create less than necessary photon absorption in critical areas of the scan field by removing the soft-tissue simulation resulting from the Plexiglass. This explanation seems plausible based on our observation that to consistently cause a tissue typing error, the slot needs to be at the very distal scan corner and extend a substantial distance along the edge. A way to reduce the likelihood of this circumstance occurring is to correctly place the positioner under the forearm as recommended by the manufacturer, with the "Lunar" logo at the distal end of the arm. The shorter slots at this end of the positioner are less likely to extend very far down the scan and, in our experience, do not result in tissue point-typing errors. It is noted the change in 1/3rd radius BMD with the positioner error is quite substantial, whereas tissue typing errors due to heavy clothing are less remarkable. The clothing artifacts included plastic buttons on sleeves, folded over cuffs, heavy material or simply wide sleeves. Due to the lack of consistency in BMD effect due to clothing, it seems appropriate to avoid any clothing over the forearm when acquiring a DXA scan.

Bone point typing errors were rarely observed in these cohorts. Only bone edges are routinely visible on the images used for clinical interpretation. Importantly, the soft tissue point-typing errors noted here are not visually evident on such images. As such, it seems

probable that clinicians will not appreciate these occurrences, thereby leading to an incorrect reading.

Limitations of this report include the fact that these data were compiled at one center using only a GE iDXA densitometer; as such it is difficult to assess the scope of this confounding acquisition error. However, anecdotally, we have been informed of similar observations by other technologists. Additionally, all data reported here were only obtained using only one model of GE Lunar densitometers. However, as the cause of these soft tissue point typing errors appears largely to be due to positioner slots, and as this positioner is used on all Lunar densitometers, it seems reasonable that such errors may confound scans obtained with other instruments. Consistent with this, we have observed similar errors in clinical care with Lunar Prodigy densitometers. Whether such errors occur with other densitometer manufacturers is unknown.

In conclusion, DXA technologists should utilize care to avoid inclusion of the positioned slots and assure that no clothing is covering the arm during forearm scan acquisition. Additionally, it is recommended that DXA technologists using GE-Lunar densitometers evaluate forearm scan point-typing prior to accepting a scan as valid; if suboptimal tissue point-typing is identified, an immediate scan reacquisition is necessary.

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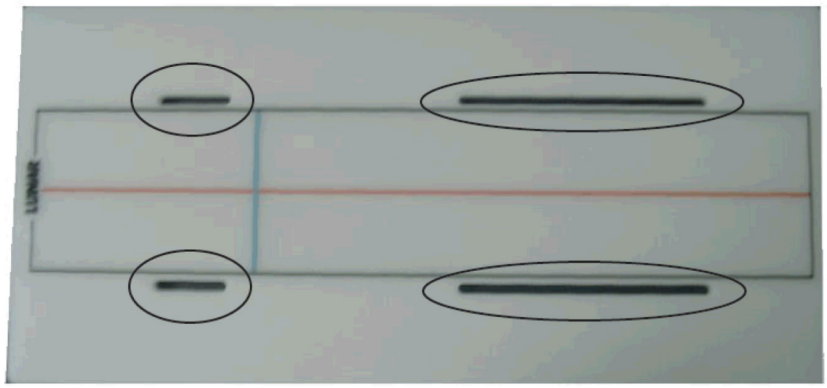

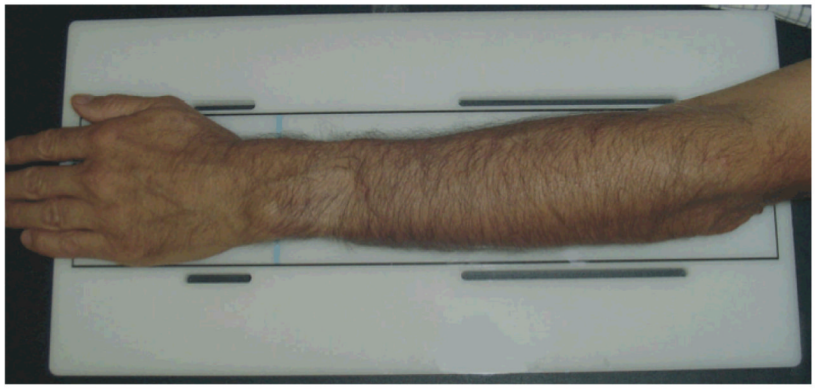

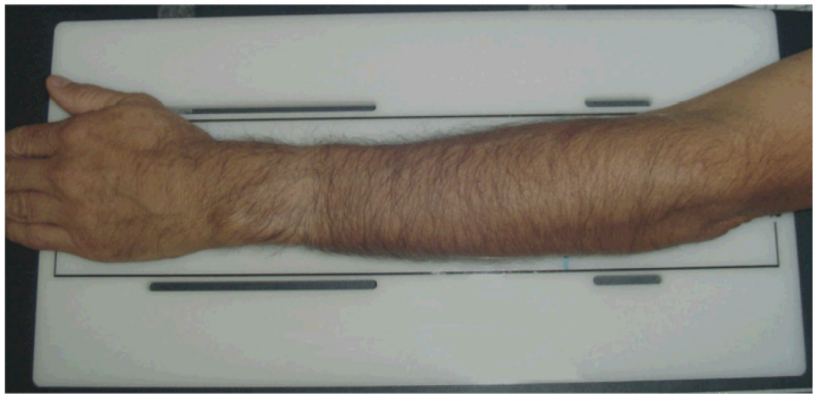

Figure 1. Positioner Used for Forearm Scan Acquisition

The manufacturer-supplied forearm positioner is noted in Figure 1a. Slots in which Velcro straps could be placed to assist with positioning are noted by the circles. Correct patient and positioner placement for forearm acquisition is demonstrated in Figure 1b. Incorrect placement of the positioner is depicted in Figure 1c in which the larger slots are located near the wrist.

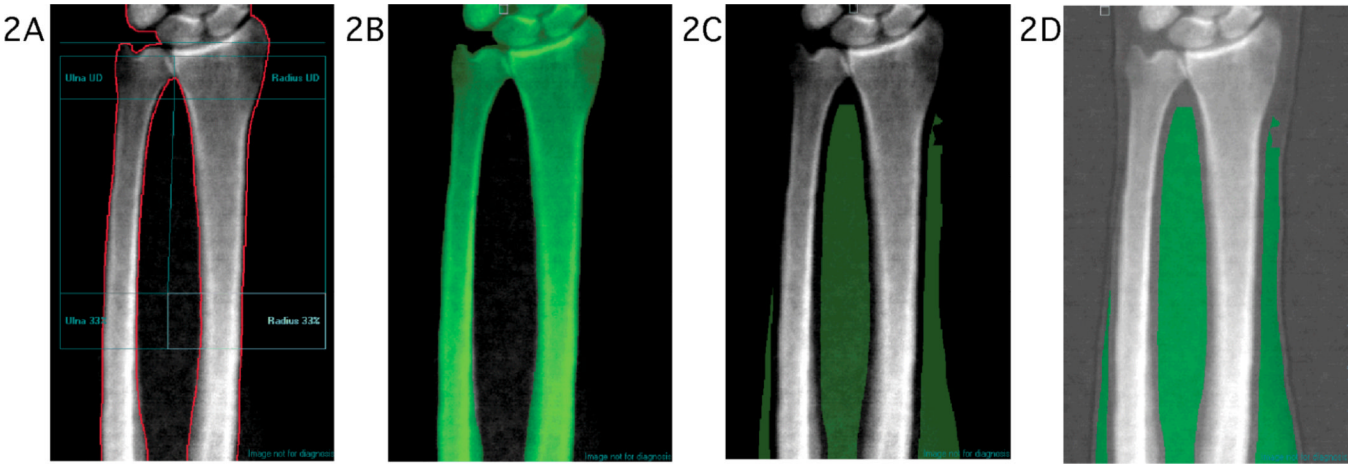

Figure 2. Examples of Forearm Scans with Correct and Incorrect Point-typing

Figures 2a–d demonstrate a correctly acquired and analyzed scan. Figures A represent a usual print-out with the bone edges identified. Such scans are typical of those that an interpreter would review. Figures B and C respectively depict bone and soft tissue identification or "point-typing." Figures D represent alteration of image contrast which was used to evaluate potential causes of soft-tissue point-typing errors. As demonstrated in Figures A and B, errors in soft tissue point-typing are not readily identifiable by reviewing the print-out or validating bone point-typing. Soft tissue point-typing errors due to inclusion of a positioner slot at the distal corner of the scan (Figure 3C) or clothing (Figure 4C) are depicted here. Utilizing the software contrast alteration feature can help identify these unappreciated confounders, noted by white arrows, positioner slots (2D) and clothing (3D). Note: Figures 2 and 3 are the same person; the 1/3rd radius BMD in Figure 2 was 0.907 grams/cm^2 vs. 0.997 grams/cm^2 in Figure 3.

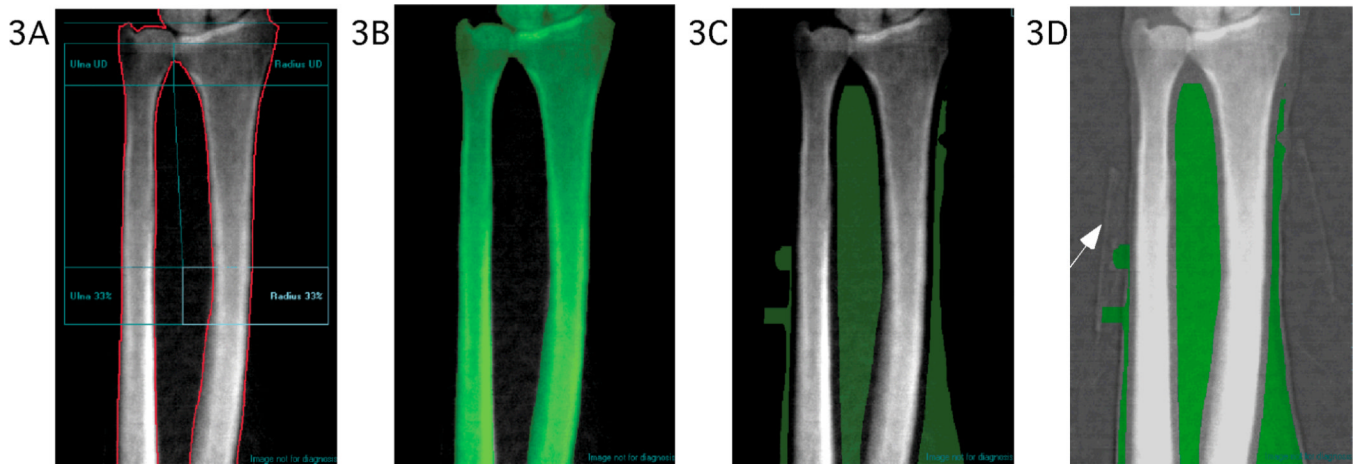

Figure 3. Examples of Forearm Scans with Correct and Incorrect Point-typing

Figures 2a–d demonstrate a correctly acquired and analyzed scan. Figures A represent a usual print-out with the bone edges identified. Such scans are typical of those that an interpreter would review. Figures B and C respectively depict bone and soft tissue identification or "point-typing." Figures D represent alteration of image contrast which was used to evaluate potential causes of soft-tissue point-typing errors. As demonstrated in Figures A and B, errors in soft tissue point-typing are not readily identifiable by reviewing the print-out or validating bone point-typing. Soft tissue point-typing errors due to inclusion of a positioner slot at the distal corner of the scan (Figure 3C) or clothing (Figure 4C) are depicted here. Utilizing the software contrast alteration feature can help identify these unappreciated confounders, noted by white arrows, positioner slots (2D) and clothing (3D). Note: Figures 2 and 3 are the same person; the 1/3rd radius BMD in Figure 2 was 0.907 grams/cm^2 vs. 0.997 grams/cm^2 in Figure 3.

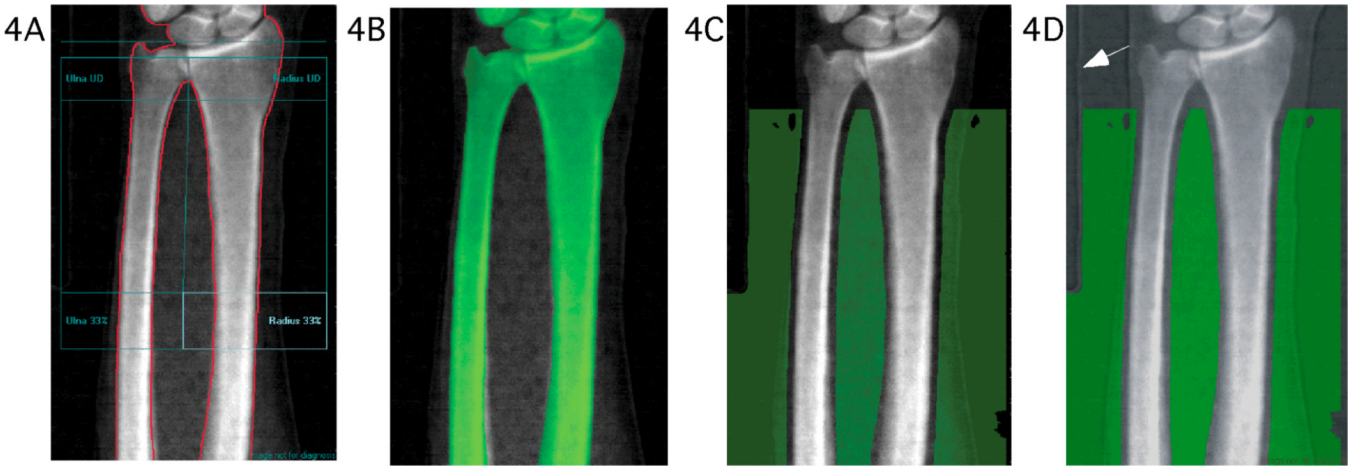

Figure 4. Examples of Forearm Scans with Correct and Incorrect Point-typing

Figures 2a–d demonstrate a correctly acquired and analyzed scan. Figures A represent a usual print-out with the bone edges identified. Such scans are typical of those that an interpreter would review. Figures B and C respectively depict bone and soft tissue identification or "point-typing." Figures D represent alteration of image contrast which was used to evaluate potential causes of soft-tissue point-typing errors. As demonstrated in Figures A and B, errors in soft tissue point-typing are not readily identifiable by reviewing the print-out or validating bone point-typing. Soft tissue point-typing errors due to inclusion of a positioner slot at the distal corner of the scan (Figure 3C) or clothing (Figure 4C) are depicted here. Utilizing the software contrast alteration feature can help identify these unappreciated confounders, noted by white arrows, positioner slots (2D) and clothing (3D). Note: Figures 2 and 3 are the same person; the 1/3rd radius BMD in Figure 2 was 0.907 grams/cm^2 vs. 0.997 grams/cm^2 in Figure 3.

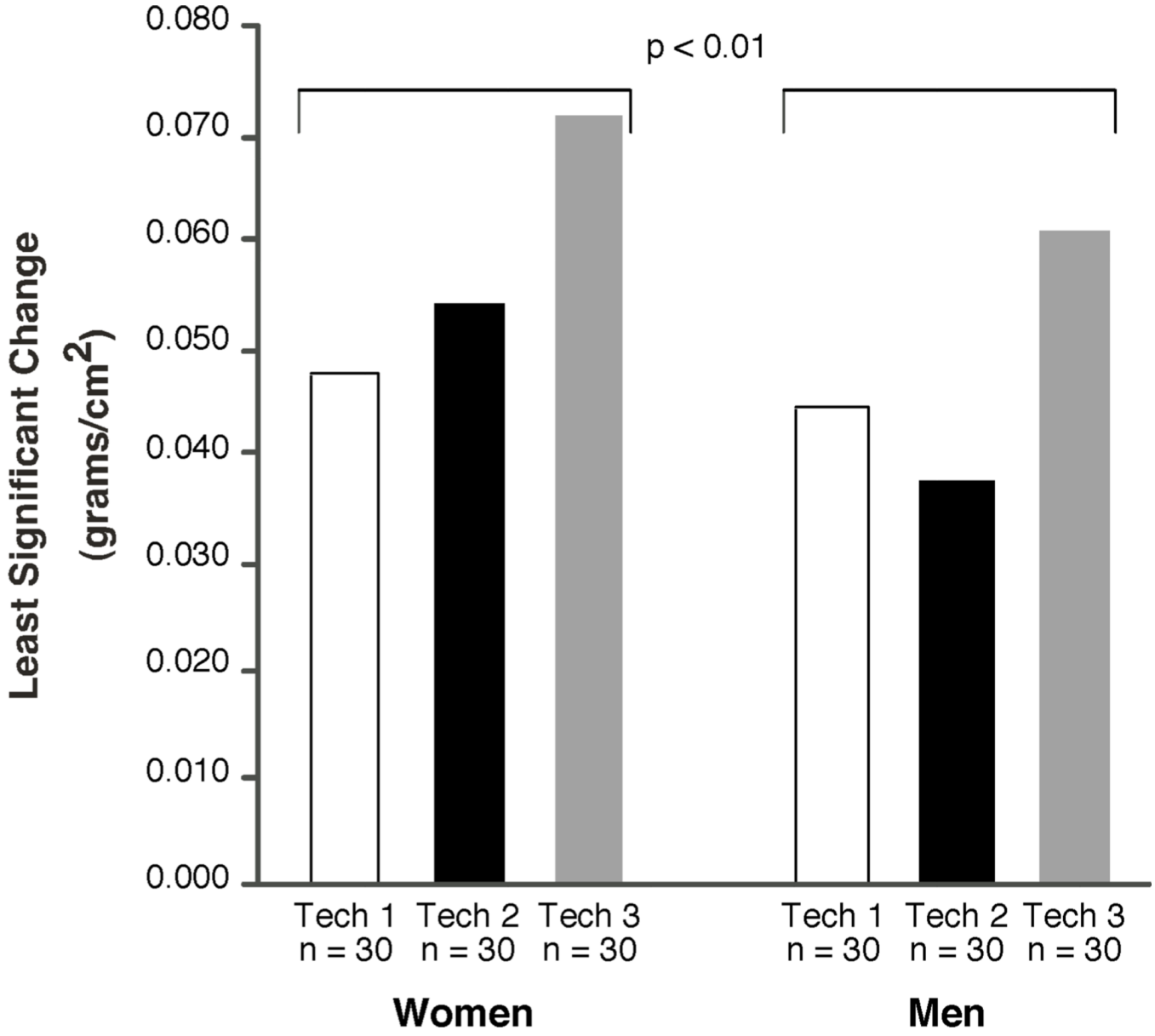

Figure 5. One-third Radius BMD Least Significant Change

A substantial difference ($p < 0.01$) in least significant change (LSC) was observed between technologists. The LSC was larger for technologist #3 in both men and women. It was this observation that prompted investigation which ultimately led to the identification of the soft tissue point-typing abnormalities reported here.

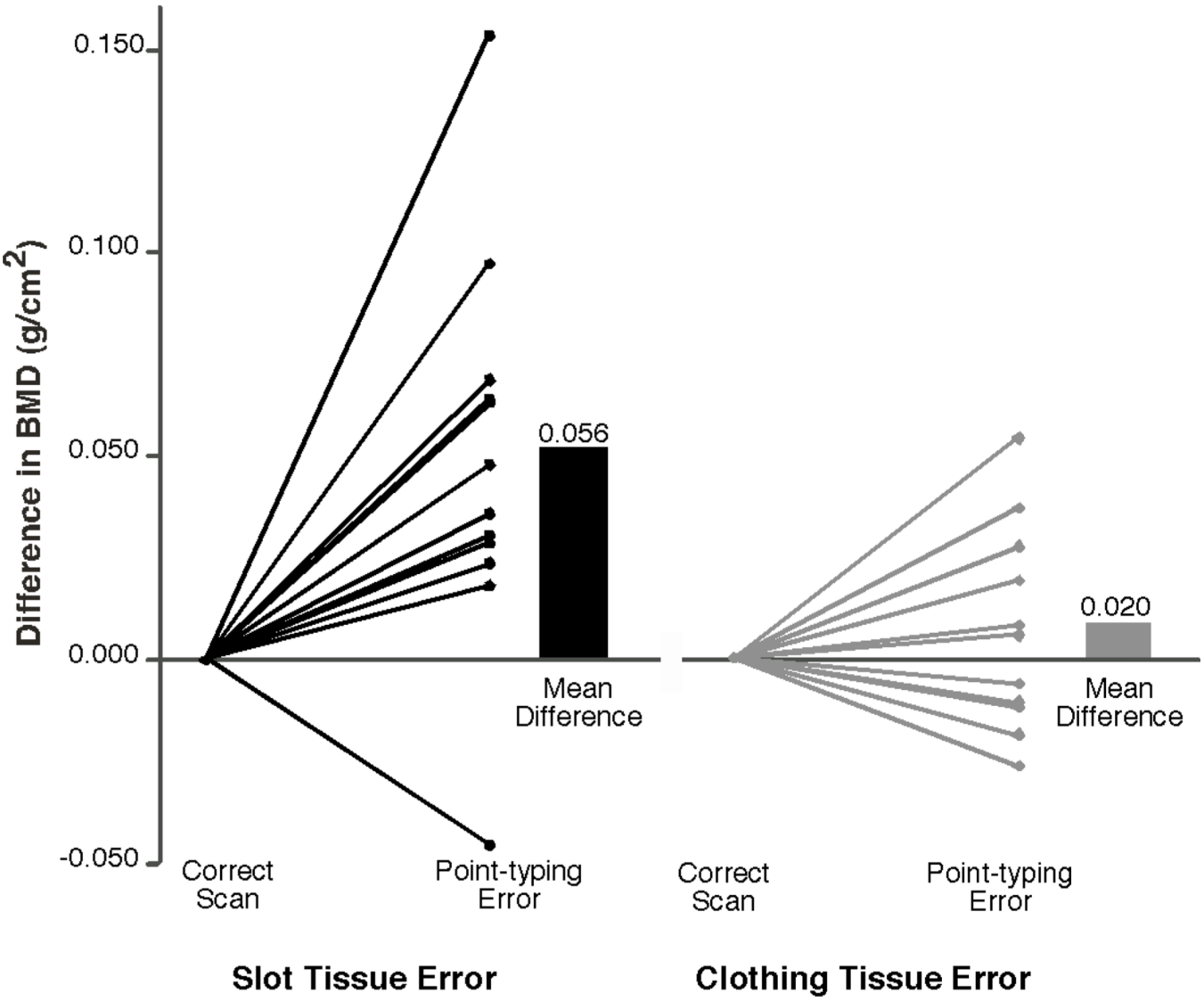

Figure 6. Effect of Soft tissue Point-typing Errors on One-third Radius BMD Measurement

When soft tissue point-typing was altered by the presence of a positioner slot, the 1/3rd radius BMD was virtually always higher (left). The mean increase ($p < 0.01$) was 6.8%. Incorrect soft tissue point-typing due to clothing had a variable and less pronounced effect on 1/3rd radius BMD (right). The mean difference of 2.4% was not statistically significant.

Table 1

Subject Demographic Data

	Tech 1 Male n = 30	**Tech 2 Male n = 30**	**Tech 3 Male n = 30**	**Tech 1 Female n = 30**	**Tech 2 Female n = 30**	**Tech 3 Female n = 30**	**Confirmatory Cohort n = 30**
Age (years)	76.4 ± 8.1	75.9 ± 7.4	75.1 ± 6.5	74.6 ± 6.4	74.4 ± 6.4	72.5 ± 6.0	60.3 ± 6.8
BMI (kg/m^2)	27.9 ± 3.5	26.4 ± 3.5	25.9 ± 2.9	26.5 ± 5.7	26.4 ± 5.6	27.1 ± 4.6	26.2 ± 5.3
One-third Radius BMD (g/cm^2)	0.955 ± 0.096	0.952 ± 0.124	0.935 ± 0.116	0.710 ± 0.123	0.719 ± 0.129	0.722 ± 0.100	0.820 ± 0.080
Percent with Osteoporosis	10%	10%	17%	43%	37%	30%	N/A

Table 2

Soft-tissue Point Typing Error and Effect on One-third Radius BMD

Subject	Type of Error	BMD Difference from Correct Scan
1	Positioner Slot	0.153
2	Clothing	0.027
3	Clothing	0.037
4	Clothing	−0.019
5	Clothing	0.054
6	Positioner Slot	0.018
7	Clothing	0.019
8	Positioner Slot	0.068
9	Unknown	0.104
10	Positioner Slot	0.023
11	Positioner Slot	0.063
12	Clothing	−0.012
13	Positioner Slot	0.097
14	Clothing	−0.026
15	Clothing	−0.011
16	Clothing	−0.006
17	Positioner Slot	0.035
18	Positioner Slot	0.063
19	Positioner Slot	0.028
20	Positioner Slot	0.030
21	Positioner Slot	−0.046
22	Positioner Slot	0.047
23	Clothing	0.006
24	Clothing	0.008