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A Hip Analysis Protocol for Pediatric Bone Densitometry: The Iowa Bone Development Study

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Abstract

Pediatric proximal femur dual-energy X-ray absorptiometry (DXA) scans present analytic challenges due to lack of standard points of reference in the growing skeleton. The Iowa Bone Development Study (IBDS) developed a modified pediatric-specific proximal femur analysis protocol using Hologic software. Serial DXA measurements were obtained for 214 children at approximate ages 5, 8, 11, and 13 years. Standard analysis procedures as described by the manufacturer (Hologic default) were compared to the IBDS protocol. The IBDS protocol yielded lower but more stable results for bone area, bone mineral content and bone mineral density for total hip, femoral neck, trochanter, and intertrochanter as a result of more precisely controlling the regions of interest. Linear regression models with body size, age and gender as predictors were developed to examine variation in measurements. Coefficients of variation (R^2) with the IBDS protocol were greater for each time point, demonstrating that the modified protocol was better aligned with body size. Similarly, Spearman correlation coefficients between total hip and hip sub-regions were consistently higher for bone mineral content and bone area with the IBDS protocol with differences more notable among younger children. The IBDS protocol provides a reproducible method for evaluating pediatric proximal femur DXA scans during growth.

Keywords

Bone densitometry; pediatrics; proximal femur; DXA; pediatric growth and development

INTRODUCTION

Dual energy X-ray absorptiometry (DXA) is used to diagnose osteoporosis and to assess fracture risk. More recently, DXA has been used to assess bone development in children (1–

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3). In adults, its application for clinical assessment of bone loss has proven to be practical and efficient; however, interpretation of pediatric bone scans has presented new challenges. DXA software was originally designed for the analysis of completely mineralized bone, stable in size and shape. The analysis of DXA scans relies on standard points of reference for proper region identification (4). In addition, most DXA systems provide a software analysis feature, “compare,” that is intended for adult serial comparisons. It allows for the overlay of a current scan image upon a previous one and provides a mechanism for duplicating anatomical regions in serial analyses to monitor changes in bone over time.

Whole body, lumbar spine and hip (proximal femur) are the sites most commonly imaged in children for clinical and research purposes. In contrast to children, whole body DXA is not commonly imaged in adults for clinical purposes. When standard DXA analysis is used for the pediatric skeleton, special considerations are required due to the growth and ongoing accrual of mineralized bone (5). Machine and software limitations are particularly evident in region selection and replication of those regions. In children, who exhibit great variability in size and shape between serial scans, the “compare” feature is either nonfunctional, or simply a crude guide. In addition, this feature has limitations when analyzing scans that have been obtained with different scan modes, i.e., pencil vs. fan beam modes.

The pediatric hip is both immature and growing, precluding serial scan comparability. Two points of reference necessary for proper region identification for the total hip and its sub-regions are the greater and lesser trochanter. Because these landmarks are either non-existent or undergoing mineralization, standard analytic schemes developed for adults, are inadequate for most children. The specific challenges that immature bone presents to standard DXA technique and interpretation are well substantiated in several publications (5–7).

Despite its complexities and limitations, DXA remains the most commonly used, non-invasive and broadly available quantitative bone measurement tool for both clinical and research settings. It provides quick assessment at minimal cost, with low ionizing radiation doses; however, measurement validity of the pediatric proximal femur continues to be a source of debate among research and clinical investigators. Following the 2007 International Society for Clinical Densitometry (ISCD) pediatric position conference, ISCD reaffirmed its position that lumbar spine and whole body (WB) are the preferred sites for reporting of bone densitometry in children (8,9). ISCD advocates whole body less head (sub-cranial bone mineral content (BMC)) for bone densitometry in children. ISCD further recommends that any deviation from standard adult protocols for scan acquisition or scan region identification be stated in the research report.

Despite inherent errors in applying adult analysis techniques to the pediatric hip, measurements derived with this analysis technique have been reported (10–14), and are critical to understanding how mechanical loading influences hip development during childhood. Behavioral interventions related to nutrition and physical activity have been evaluated for efficacy of enhanced bone accrual. They appear to produce site-specific improved bone outcomes that include the hip and its sub-regions. Some studies report on the use of a special analysis protocol utilized for investigation of the hip, but many do not (15,16).

The clinical value of the pediatric hip scan remains controversial. Since it is primarily the long bone of the femur that fractures in children, most clinicians consider proximal femur evaluation unimportant. Yet there are clinicians who defend the hip as an important measurement site because its proportions of cortical and trabecular bone are different from other sites (17). Furthermore, hip analysis provides an additional regional assessment when

scans at the spine and WB sites cannot be obtained due to artifact or, if measurable, would benefit from corroboration of measurement from multiple sites. Moreover, specific medications or medical conditions predominantly affect either cortical or trabecular bone. For example, children with glucocorticoid-sensitive nephrotic syndrome have significantly less bone mineral content of the spine than controls; however, the predominantly cortical whole-body bone mineral content of patients is significantly higher than controls after adjustment for body size. Similarly, in adults trabecular bone is more susceptible than cortical bone to the effects of glucocorticoids (18). Deficits may be detected more readily at one site over the other, due to the unique composition of bone at each site thus lending credence to measuring multiple sites.

Total hip BMC and geometry are associated with greater physical activity in children, with particularly prominent relationships seen at very young ages (14). When trying to understand the contribution of mechanical loading to bone health, the hip is a particularly important site due to the magnitude and variation of loading incurred at this site via physical activity and its major role in ambulatory movement, the most common type of physical activity through out the life cycle. Cross-sectional and longitudinal assessment of associations seen between physical activity and the hip and dose-response relationships examined during interventions could be enhanced with more precise DXA measures.

This paper describes a reproducible, anatomically relevant, pediatric-specific hip analysis protocol. The analysis protocol was developed because of the need to evaluate bone growth in a cohort of healthy children, after standard analysis techniques proved inadequate. An extensive literature review (1–14) and consultation with a number of pediatric bone researchers and DXA technologists revealed that recommendations varied considerably, without a clearly accepted approach, and convinced us of the need to devise a new approach for standardizing the analysis of proximal femur scans in growing children.

MATERIALS AND METHODS

Study population

This report focuses on a subset of boys ($n = 96$) and girls ($n = 118$) age 4 to 14 years who have received four serial DXA measurements to date as a result of their participation in the longitudinal Iowa Bone Development Study (IBDS). Briefly, the IBDS is a longitudinal observational investigation of fluoride and other factors concerning bone development. Participants were recruited from the Iowa Fluoride Study (IFS), an ongoing investigation of fluoride and other factors associated with dental fluorosis and caries in a cohort followed from birth. Descriptions of this cohort are provided elsewhere (19,20). The IBDS has followed children beginning at age 4, collecting demographic, dietary, genetic, physical activity, and bone outcome data at clinic visits and via mailed questionnaires and accelerometers (21–23). All components of the IFS and IBDS were approved by the Institutional Review Board at the University of Iowa. Prior to participation in each clinic visit involving DXA, informed consent was obtained from parents and assent was obtained from children, as appropriate.

Data collection

Children were seen in the General Clinical Research Center for clinic visits at approximate ages 5, 8, 11, and 13 years. DXA scans were acquired using the Hologic QDR 2000 densitometer (Bedford, MA) for children at the age 5 and 8 year clinic visits. DXA scans at the age 11 and 13 year clinic visits were acquired using the Hologic 4500A densitometer (Bedford, MA). Hip scans were acquired in the pencil beam mode with system software V7.20 for the QDR 2000 and in the fan beam mode using analysis software V12.3 for the

QDR 4500A. All scans were acquired and analyzed at the time of the visit by one of three trained technicians using standard analysis procedures as described in the Hologic Users Manual.

The data set was subsequently reanalyzed by one ISCD-certified technician over a time span of three weeks, utilizing a single software version (Hologic V12.6). This version of the software is 100% backwards compatible for all scans acquired on both machines, and provides a consistent analysis protocol for all measurements.

Scan analysis using the IBDS modified protocol

The analysis of the previously acquired hip scans began with selection of the area to be analyzed, called the region of interest (ROI). The first step in ROI selection was accomplished with the software-specific Global ROI to designate the general boundaries of the hip image to be evaluated. The Global ROI appears on the hip image as a box with four adjustable sides. The properly positioned hip Global ROI box includes the proximal femur in its entirety, the lesser trochanter, the top of the femoral head and the lateral side of the greater trochanter. Typically the upper edge of the Global ROI box is set at 10 mm above the head of the femur; the lateral edge 5 mm from the greater trochanter and the lower edge 10 mm below the lesser trochanter. Within these borders, results can be obtained for the total hip region, as well as the three sub-regions which constitute the total: femoral neck (FN), trochanteric and intertrochanteric regions. Bone analysis results for the total hip and its sub-regions consist of area (cm²), BMC (g) and bone mineral density (BMD, g/cm²). Figure 1 provides pictorial guidelines for pediatric hip ROI identification through interpretation of standard points of reference for adult hip analysis as suggested by the manufacturer (manufacturer's recommendation from user's guide).

After appropriately defining the top and sides of the Global ROI box to include the appropriate points of reference as indicated above, a review of the entire hip region included within the ROI box was required. This step determined whether any bone should be excluded or any excluded bone should be added. The process of proper bone identification and inclusion is called bone-mapping, or bone-edge detection. It is performed by the software and evaluated by the operator, with bone manually added or deleted using Hologic's Bone Map Toolbox functions. For example, it may have been necessary to delete ischium located too close to the femoral shaft where it interfered with placement of the femoral neck ROI. Likewise, any gaps in bone edges left undetected by the bone-mapping process needed to be bridged and filled. Adding or deleting bone was performed only when necessary as operator manipulations challenge reproducibility and measurement errors can occur if too much bone is added or deleted.

Following confirmation of the bone map, the FN sub-region was selected. This was accomplished through the utilization of a rectangular box, called the Neck Box (NB), situated with its long sides perpendicular to the FN and a symmetry axis within the neck called the femoral midline. The short sides of this rectangular box run parallel to, but do not touch, the FN. The NB should include bone solely from the FN and exclude any bone from the femoral head, ischium or greater trochanter. To ensure that only bone from the femoral neck was included in the NB, a formulaic size adjustment was initiated by the operator. A measurement of the FN width was obtained for each scan by reducing the length of the NB until the two short parallel lines touched the sides of the FN at its narrowest point. The width of the FN is displayed in the software analysis window and recorded by the operator for further use in the analysis process. The length of the NB was returned to its original size because it was necessary for the box to contain an adequate portion of soft tissue from both sides of the FN to ensure no bone was left out and to allow proper determination of BMD. The width of the NB was then manually adjusted to be half the width of the FN

measurement and the altered box was centered over the narrowest portion of the FN, with all four corners in soft tissue. Region selection and positioning of the NB served two purposes: the FN sub-region was defined by the box and the proximal edge of the box defined the upper edge, or top, of the three sub-regions that constitute the total hip region.

Sub-region selection involved placement of the trochanteric line. This line originates at the intersection of the bottom lateral edge of the NB and femoral midline. The point of origin cannot be altered, but the lower end is adjustable for placement at the trochanteric growth plate (TGP) on the lateral side of the femoral shaft. This differentiates the trochanteric region, which contains the greater trochanter, from the intertrochanteric region, containing a portion of the femoral shaft.

Region selection was concluded by manipulating the inferior border of the global ROI box until it overlaid the TGP on the lateral side of the femoral shaft. From there, the operator lowered the horizontal line the length of the previously recorded FN width to define the lower edge, or bottom, of the total hip region, as well as define the lower edge of the intertrochanteric sub-region. Once region selection was complete, the software performed the analysis and generated a report of the results.

Figure 2 illustrates the placement of the global ROI, NB, and trochanteric line for a representative study participant at ages 5, 8, 11, and 13 years. For this participant, the anatomical landmark (lesser trochanter), necessary for placement of the inferior border of the global ROI when utilizing software default settings, is not evident until age 11 years

Data analysis

Means and standard deviations are reported to describe the sample and scan results obtained using the original (Hologic default) and IBDS modified protocols. Linear regression models with height, weight, age, and gender as predictors were used to evaluate coefficients of determination (R^2) for total hip BMC, using both the Hologic default and IBDS modified protocol at baseline and each follow-up assessment referred to as Waves 1 – 4. Mean change per year between the Wave 1 and 2 assessments (ages 5 and 8 years), and between the Wave 3 and 4 assessments (ages 11 and 13 years) were calculated as estimates of growth to eliminate the influence of variability in the time interval between assessments for different children on the value of change. Spearman rank correlation coefficients were estimated to characterize the association between skeletal mass and total hip mass (WB BMC vs. total hip BMC), total hip size and hip sub-regions size (total hip BMC and area vs. hip sub-regions BMC and area), and skeletal growth and hip growth (mean change in WB BMC vs. mean change in total hip BMC; and average growth (mean change per year) in total hip BMC and area vs. hip sub-regions). Coefficients of variation ($CV = SD/mean \times 100$) were calculated for average changes in hip measures to evaluate and compare relative variability of change for the Hologic default and IBDS modified protocols. To account for differences in instrumentation, comparisons were made for: 1) Wave 1 and Wave 2 (QDR 2000) and 2) Wave 3 and Wave 4 (QDR 4500A). All analyses were conducted using procedures from the Statistical Analysis System for Windows, version 9.1.3, 2002 – 2003 (SAS Institute Inc., Cary, NC, USA). A p-value < 0.05 for any single analysis was considered statistically significant.

RESULTS

Two hundred fourteen children with longitudinal data for the 4 assessments (118 girls and 96 boys) are included in this report. A summary of their age, height and weight for the baseline and follow-up examinations is presented in Table 1. To determine how the body size of our participants compared with other U.S. children, we used the National Center for

Health Statistics clinic growth charts as a reference (24). At each examination period, the mean heights of the children were between the 50th and 75th gender-specific percentiles, and the mean weights were between the 50th and 90th gender-specific percentiles compared to the national standard.

Descriptive statistics for hip data (total and sub-regions) for the Hologic default and IBDS modified protocols are shown in Table 2. Notably, the modified protocol yields lower area and BMC values for the hip and sub-regions than the Hologic default protocol due to the shorter ROI for the proximal femur. As a result of less femoral cortical bone in the ROI, the BMD values are less than those obtained using the default analysis.

To examine the variation in hip measurement results from the 4 examinations, coefficients of determination (R^2) for data obtained using the Hologic default and IBDS modified protocols were calculated (Table 3), with body size (height and weight), age, and gender serving as predictors. The R^2 was greater at each examination for data obtained using the modified protocol. For example, for hip BMC at Wave 1, $R^2 = 0.57$ for the Hologic default protocol and $R^2 = 0.62$ for the IBDS modified protocol. R^2 was consistently greater for the modified protocol at each of the follow-up analyses. These findings suggest that the measurements obtained using the modified protocol for hip assessments are better aligned with body size.

Correlation coefficients for WB BMC and total hip BMC; total hip BMC and FN, trochanter, and Intertrochanteric BMC; and total hip area and FN, trochanter, and Intertrochanteric area are displayed in Figures 3 and 4. The associations between the pairs of bone measures obtained using the modified protocol are consistently stronger. The correlation coefficients are consistently higher and more stable than those estimated using measures obtained using the Hologic default protocol, particularly for very young children. The largest overall differences for all examinations in correlations are seen with area measures (Figure 4). These results are expected since area is the variable that is under the operators' control when determining the ROIs.

In order to compare how the IBDS and default protocols follow growth of the hip and hip sub-regions, we calculated the average change per year for time intervals between Wave 1 and 2, and Wave 3 and 4. Coefficients of variation and Spearman correlation coefficients for average change per year in WB BMC vs. total hip BMC; total hip BMC vs. hip sub-regions BMC; and total hip area vs. hip sub-regions area are displayed in Table 4. CVs for hip measures were comparable for both protocols at each time point (data not shown), but in all cases, CVs for average change were substantially lower with the modified protocol, especially for young children (Table 4). For example, the CV for total hip BMC decreased from 31.2 to 28.7%, the CV for FN BMC decreased from 47.7 to 32.3%, and the CV for FN area decreased from 59.6 to 32.3% when comparing average changes between Wave 1 and 2. In general, the largest decreases in CV were seen for hip sub-region BMC and area. The associated correlations for changes in WB BMC, hip BMC and hip area were higher and more stable with the modified protocol.

DISCUSSION

As we began longitudinal analyses of proximal femur measurements for the Iowa Bone Development Study cohort that had been analyzed using standard DXA analysis techniques, inconsistencies in measurement results were discovered. A few children seemed to implausibly lose BMC as they aged and operator variability in analysis techniques was evident. These discoveries prompted us to evaluate the appropriateness of using the manufacturer's default protocol for pediatric DXA analyses.

A subsequent quality control review of the scans revealed that automatic software analysis did not produce the expected results. The necessary landmarks needed for region selection often were either nonexistent or immature, thus, requiring the operator to manually place ROIs while facing the same challenges as the software. That is, how to place the ROI in the absence of well-defined landmarks. Recognition of the degree of manual intervention necessary for region selection and replication led to our desire to develop additional standardized procedures to increase precision and reproducibility for longitudinal investigation of our cohort.

We recognized the need to establish standard points of reference that would be identifiable from baseline through adolescence, or until standard adult analysis procedures functioned appropriately. Consistent landmarks were imperative to improve the likelihood we were measuring the same part of the anatomy at each evaluation, despite changes in size and shape of the ROI (Figure 2). Specifically, the immature hip is lacking a definable lesser and greater trochanter, particularly at very young ages. It was important to more closely mimic how ROIs were selected for the other two commonly measured DXA sites (spine and WB) and, look to these for general guidelines for ROI selection and replication techniques for the hip analysis.

The optimum method for region selection and reproducibility for serial evaluation of any part of the growing skeleton is to surround a complete bone or group of complete bones with an ROI. The spine and WB are conducive to this method. Both sites permit reproducibility throughout maturation due to consistent structural delineations. At the spine, intervertebral discs lie between adjacent vertebrae, and until severe degenerative changes occur with aging, these areas of fibrocartilage provide stable and unmistakable separation. As the vertebral bodies grow, the intervertebral spaces remain indisputable borders to aid in region selection, as well as reproducibility. The ROI is expanded to match the expanding vertebrae. WB DXA scans in children are highly reproducible for both bone and body composition with CV values ranging from 0.22 – 2.59% (25). Fundamental anatomical features of the skeleton are complete and easily identifiable from birth. Joints provide unambiguous connections between bones and bone groups, affording clear separation of the skeleton into ROIs for analysis.

In contrast, the proximal femur is not a complete bone; rather it is a section of the long bone of the femur, without a definable beginning or end. For adult hip serial evaluation, the problem of how to surround or border a segment of bone is can be solved: the ROIs at baseline are determined using existing anatomical landmarks unchanging in size and shape and follow-up scans utilize the software's "compare" feature to reproduce this segment of bone.

For child hip evaluation, Hologic software relies on anatomical landmark recognition. This approach proves inadequate for baseline scans, and the "compare" feature is ineffective for follow-up scans as well.

Our findings suggest that greater consistency can be achieved following a pediatric-specific hip analysis protocol. Our protocol assumes the proportionality of growth within the proximal femur, which caused us to use a measurable area (FN width) to represent an immeasurable area (proximal femur length). In their instructive article, orthopedic surgeons Lee and Eberson describe post-natal proximal femur development as a coordinated interplay of multiple components, "keeping pace" with and requiring each other for normal growth (26). These concurrent interactions define a relationship of balance, but not necessarily proportionality. In other words, one region of the hip may grow and, in turn trigger another

region's development. The reciprocal relationship of growth and development of the hip is not fully understood.

Our revised protocol does not solve positioning problems such as abduction flaws or anteversion issues, and movement by young children continues to be of concern. Issues pertaining to correction methods for discrepancies in bone size and shape persist as well. Our population is predominantly Caucasian and middle class; therefore, this protocol may not be directly transferable to other population groups. The analyses do not address whether or not the effects are gender-specific or more prominent during certain growth periods (e.g., pubertal growth spurt). Additional research addressing the use of adult DXA software in childhood populations will be useful and important in establishing normative pediatric databases and clinical comparability of DXA results.

Our findings suggest that a pediatric-specific analysis technique has the potential to decrease analysis variability and to improve serial comparability of hip measurements in growing children. We calculated the CV for average change to determine which protocol better followed children's growth. Our results demonstrated that higher CV's for average change in hip measures (BMC and area) with the default protocol were partially due to an inconsistent definition of hip ROI over time. Likewise, the associated correlations for changes in BMC and area were higher and more stable with the modified protocol, again demonstrating that this protocol better follows children's growth. It is important to note that software analysis failure of the pediatric hip using algorithms intended for adults, decreases as landmarks become more clearly demarcated throughout growth and development.

Despite improvement in the precision of change measurements using the IBDS protocol (Table 4), the CV values are still quite high and generally regarded as above the acceptable range for accurate longitudinal comparisons. These values provide further justification to follow the ISCD recommendation not to use DXA hip measurements to assess skeletal changes in children (8). Due to significant variability in skeletal development, the hip is not a reliable site for serial measurement in children.

Accurate measurement of the proximal femur can provide an important adjunct to pediatric DXA research and, potentially, clinical practice. Continued research is necessary to establish appropriate normative data for pediatric databases. It is also imperative that manufacturers continue to improve software for analysis of the growing skeleton and to articulate appropriate uses and limitations of available software.

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Figure 1. Pediatric hip region of interest identification (ROI) through interpretation of adult hip anatomical landmarks.

Figure 2.
Placement of global region of interest (ROI), neck box, and trochanteric line for proximal femur analysis for study participant at ages 5 (A), 8 (B), 11 (C), and 13 years (D).

Figure 3. Spearman correlation coefficients for bone mineral content measurements: whole body BMC and hip BMC, hip BMC and femoral neck, trochanteric and intertrochanteric BMC at ages 5, 8, 11 and 13 years.

Figure 4. Spearman correlation coefficients for bone area measurements: hip area and femoral neck, trochanteric, and intertrochanteric area at ages 5, 8, 11 and 13 years.

Table 1

Mean (SD) Age, Height, and Weight of Study Sample, N = 214.

Time of Scan	Age, years	Height, cm	Weight, kg
Wave 1	5.4 (0.5)	112.0 (5.7)	20.3 (3.6)
Wave 2	8.6 (0.6)	132.8 (7.1)	31.7 (8.4)
Wave 3	11.3 (0.3)	149.0 (7.8)	44.5 (12.9)
Wave 4	13.1 (0.3)	160.6 (8.2)	55.7 (15.1)

Bone Mineral Content (BMC), Bone Mineral Density (BMD) and Bone Area for Total Hip and Hip Sub-region Using Hologic Default (default) and the Iowa Bone Development Study (IBDS) Hip Analysis Protocols, Presented as Means (SD), N = 214.

Table 2

Measurement Site	Protocol	Wave 1	Wave 2	Wave 3	Wave 4
Total hip BMC, g	default	7.2 (1.6)	12.9 (3.2)	21.3 (5.1)	28.8 (6.6)
	IBDS	6.0 (1.4)	11.4 (2.8)	18.8 (4.6)	25.9 (6.2)
Total hip BMD, g/cm ²	default	0.57 (0.06)	0.69 (0.08)	0.78 (0.11)	0.89 (0.13)
	IBDS	0.56 (0.06)	0.66 (0.08)	0.75 (0.10)	0.86 (0.13)
Total hip area, cm ²	default	12.6 (1.8)	18.7 (3.1)	27.0 (3.6)	32.0 (3.9)
	IBDS	10.8 (1.8)	17.0 (2.9)	24.9 (3.5)	30.0 (3.9)
Femoral neck BMC, g	default	1.1 (0.3)	2.0 (0.6) ^a	3.2 (0.6)	3.9 (0.8) ^c
	IBDS	1.2 (0.3)	2.1 (0.5)	3.0 (0.7)	3.9 (0.9)
Femoral neck BMD, g/cm ²	default	0.54 (0.06)	0.64 (0.07)	0.73 (0.09)	0.81 (0.11)
	IBDS	0.54 (0.06)	0.65 (0.07)	0.73 (0.09)	0.83 (0.11)
Femoral neck area, cm ²	default	2.0 (0.5)	3.1 (0.7) ^b	4.4 (0.4)	4.8 (0.4)
	IBDS	2.3 (0.4)	3.2 (0.5)	4.0 (0.6)	4.6 (0.6)
Intertrochanteric BMC, g	default	4.7 (1.1)	8.2 (2.1)	13.3 (3.4)	18.2 (4.3)
	IBDS	3.9 (0.9)	7.2 (1.7)	11.6 (2.7)	15.7 (3.7)
Intertrochanteric BMD, g/cm ²	default	0.61 (0.07)	0.76 (0.09)	0.88 (0.12)	1.00 (0.15)
	IBDS	0.59 (0.07)	0.72 (0.09)	0.82 (0.12)	0.95 (0.14)
Intertrochanteric area, cm ²	default	7.7 (1.3)	10.7 (1.9)	15.0 (2.4)	18.0 (2.7)
	IBDS	6.6 (1.0)	9.8 (1.6)	14.0 (1.8)	16.4 (2.2)
TrochanterBMC, g	default	1.4 (0.5)	2.7 (0.9)	4.8 (1.5)	6.7 (1.9)
	IBDS	0.9 (0.3)	2.2 (0.7)	4.2 (1.4)	6.4 (1.8)
Trochanter BMD, g/cm ²	default	0.48 (0.06)	0.56 (0.07)	0.62 (0.09)	0.72 (0.12)
	IBDS	0.46 (0.05)	0.53 (0.06)	0.60 (0.09)	0.71 (0.12)
Trochanter area, cm ²	default	2.8 (0.8)	4.8 (1.3)	7.6 (1.5)	9.2 (1.5)
	IBDS	2.0 (0.6)	4.0 (1.1)	6.9 (1.4)	9.0 (1.4)

Paired t-test was used to compare Wave 1 – 4 default and IBDS results. All p-values <0.0001, except:

^a p-value <0.01;
^b p-value <0.05;
^c p-value >0.25.

Table 3

Coefficients of Determination (R^2) for Hip BMC with Body Size (Height and Weight), Age, and Gender as Predictors for Hologic Default (default) and Iowa Bone Development Study (IBDS) Hip Analysis Protocols.

	Protocol	Wave 1	Wave 2	Wave 3	Wave 4
Hip BMC	default	0.57	0.68	0.67	0.63
	IBDS	0.62	0.72	0.70	0.67
Femoral Neck BMC	default	0.41	0.50	0.64	0.61
	IBDS	0.58	0.63	0.68	0.66
Trochanter BMC	default	0.33	0.51	0.49	0.53
	IBDS	0.54	0.66	0.66	0.62

Table 4

Coefficients of Variation (CV) and Spearman Correlation Coefficients (r) for **Mean Change per Year** in Bone Mineral Content (BMC) and Bone Area: Whole Body BMC (WB BMC) vs. Hip BMC, Hip BMC vs Hip Sub-region BMC, and Hip Area vs. Hip Sub-region Area using Hologic Default (default) and Iowa Bone Development Study (IBDS) Hip Analysis Protocols.

	Protocol	Wave 1 to Wave 2			Wave 3 to Wave 4		
		CV	Association with Change in WB BMC r		CV	Association with Change in Hip BMC r	
Change in Hip BMC	default	31.2	0.76		43.9	0.68	
	IBDS	28.7	0.83		43.1	0.76	
		CV	Association with Change in Hip BMC r		CV	Association with Change in Hip BMC r	
Change in Femoral Neck BMC	default	47.7	0.41		52.0	0.70	
	IBDS	32.3	0.76		48.6	0.83	
Change in Trochanter BMC	default	49.5	0.58		65.2	0.64	
	IBDS	38.3	0.86		47.8	0.94	
Change in Intertrochanteric BMC	default	39.9	0.85		50.7	0.91	
	IBDS	28.7	0.96		44.0	0.97	
		CV	Association with Change in Hip Area r		CV	Association with Change in Hip Area r	
Change in Hip Total Area	default	28.1	-		48.7	-	
	IBDS	23.3	-		46.4	-	
Change in Femoral Neck Area	default	59.6	0.30		68.2	0.41	
	IBDS	32.3	0.58		63.3	0.67	
Change in Trochanter Area	default	52.2	0.47		78.8	0.40	
	IBDS	32.8	0.83		47.5	0.87	
Change in Intertrochanteric Area	default	48.9	0.64		72.5	0.82	

	Protocol	Wave 1 to Wave 2		Wave 3 to Wave 4	
		24.7	0.89	53.6	0.93
	IBDS				