Advanced Body Composition® Reporting and Interpretation

A Technical Discussion

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Introduction

Advances in DXA technology, combined with rising rates of obesity and other musculoskeletal disorders, are driving widespread adoption of DXA scans to evaluate body composition.

Clinical studies have demonstrated that abnormalities in body composition are a key predictor of health risks, including obesity-related diseases, sarcopenia, and lipodystrophy. The ability to reliably and accurately measure body composition, and present the data in a usable format, enables healthcare providers to identify patients at risk for disease and define and manage treatment programs.

Many pathological conditions involving body composition remain unrecognized and undiagnosed. For example, the U.S. Center for Disease Control (CDC) identified sarcopenia as one of the nation's most important health risks with costs estimated to be $12 – $26 billion annually in the U.S. alone. Despite these facts, sarcopenia, a progressive decline in skeletal muscle mass that occurs with aging, still remains widely unknown outside of highly specialized medical and professional working groups.

In 2008 the Centers for Disease Control released NHANES body composition reference data from more than 20,000 U. S. residents measured on Hologic Whole Body DXA scanners. DXA has been shown to provide more detailed and accurate measurement on body composition than the previous clinical standard, body mass index (BMI). Furthermore, DXA body composition is an extremely precise measurement tool with a coefficient of variation (CV) less than 0.5% for lean mass, allowing for routine tracking of lean mass and providing "a high level of precision that will meet the most exacting clinical applications". (Nowitz, M., 2015 ANZBMS abstract). The NHANES database provides a baseline defining healthful levels of body fat and muscle mass. This data is an important tool for healthcare practitioners in identifying patients at risk for obesity-related diseases, sarcopenia, and sarcopenic obesity.

Hologic incorporated NHANES data into its DXA systems, enabling healthcare providers to accurately compare patients' body composition against the NHANES database. Subsequently, Hologic enhanced these capabilities by adding a series of software reporting tools that graphically display the patient's ratio of fat to lean mass, enabling healthcare providers to quickly assess and explain the state of the patient's health. Graphs also chart changes in body composition over time, enabling providers to monitor changes in body composition and thereby evaluate the effects of an intervention or disease.

Mapping NHANES Reference Data to DXA Measurements

It is now possible to compare DXA measures of whole body, bone and body composition, including whole body measures of %Fat, Fat Mass/Height^2, Lean Mass/Height^2, Appendicular Lean Mass/Height^2, Bone Mineral Content (BMC), Bone Mineral Density (BMD) and other direct and derivative measures to gender, ethnicity, and age-specific controls. For a complete list of the DXA measures that can be compared to the NHANES database, see Table 1 below.

Table 1. List of reference curves gerenated from the 2008 NHANES DXA whole body data set.

DXA Measure	Independent Variable	Age Group	Supplemental Table and Figure
Fat Mass/Height2 (FMI)	Age	Adult Only	S1
Total Body % Fat	Age	Adult and Pediatric	S2 and S9
% Fat Trunk/% Fat Legs	Age	Adult Only	S3
Trunk/Limb Fat Mass Ratio	Age	Adult Only	S4
Lean Mass/Height2	Age	Adult and Pediatric	S5 and S10
Appendicular Lean Mass/Height	Age	Adult Only	S6
Total Body BMD	Age	Adult and Pediatric	S7 and S11
Total Body BMC	Age	Adult and Pediatric	S8 and S12
Sub-total Body BMD (excludes head)	Age	Pediatric Only	S13
Sub-total Body BMC (excludes head)	Age	Pediatric Only	S14
Total Body BMD	Height	Pediatric Only	S15
Total Body BMC	Height	Pediatric Only	S16
Sub-total Body BMD (excludes head)	Height	Pediatric Only	S17
Sub-total Body BMC (excludes head)	Height	Pediatric Only	S18
Total Lean Mass	Height	Pediatric Only	S19
Sub-total Body BMC (excludes head)	Total Lean Mass	Pediatric Only	S20

For each whole body DXA measure in column 1, male and female reference curves for White, Black, and Mexican American subjects were modeled against the independent variable in column 2. Adult age range is 20 to 85 years. Pediatric age range is 8 to 20 years.

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Kelly TL, Wilson KE, Heymsfield SB (2009) Dual Energy X-Ray Absorptiometry Body Composition Reference Values from NHANES. PLoS ONE 4(9):e7038. doi:10.1371/journal.pone.0007038
http://127.0.0.1:8081/plosone/article?id=info:doi/10.1371/journal.pone.0007038

PLOS | ONE

Table 1. Dual Energy x-Ray Absorptiometry Body Composition Reference values from NHANES. PLoS One 4(9):e7038.

The Hologic APEX software generates a range of reports and images utilizing the DXA data. It can display the DXA measurements along with a representative color image mapping of “fat” and “lean” tissue. These images are useful as a counseling tool to increase patient awareness and facilitate the process of shared decision making (Figure 1, Total Body DXA Report). The color image displays the relative amounts of fat and lean tissue in the DXA image, with yellow regions representing higher %Fat and orange and red regions indicating progressively lower %Fat. Bone containing regions are indicated in blue. Note that the color image does not contain diagnostic information. For diagnostic purposes the DXA measures must be compared to the NHANES database.

The APEX software also generates a gender and ethnicity-matched reference curve, in this case for Total Body %Fat versus Age, although any of the DXA measures in Table 1 can be plotted. The plot provides a graphical representation of the patient’s measurement relative to

Figure 1. Total Body DXA report. Color imaging mapping of body composition may be useful as a counseling tool.

age-matched peers. The midline of the graph represents the median reference value and the upper and lower shaded regions define the 95% confidence interval for the plot. Note that the upper and lower shaded regions may not be exactly equal in size; this is an indication the underlying reference data are not normally distributed. Many biological measures reveal some degree of skewness, and a special algorithm that adjusts for skewness must be employed to ensure that the resultant T-scores, Z-scores, and percentiles provide accurate diagnostic information.

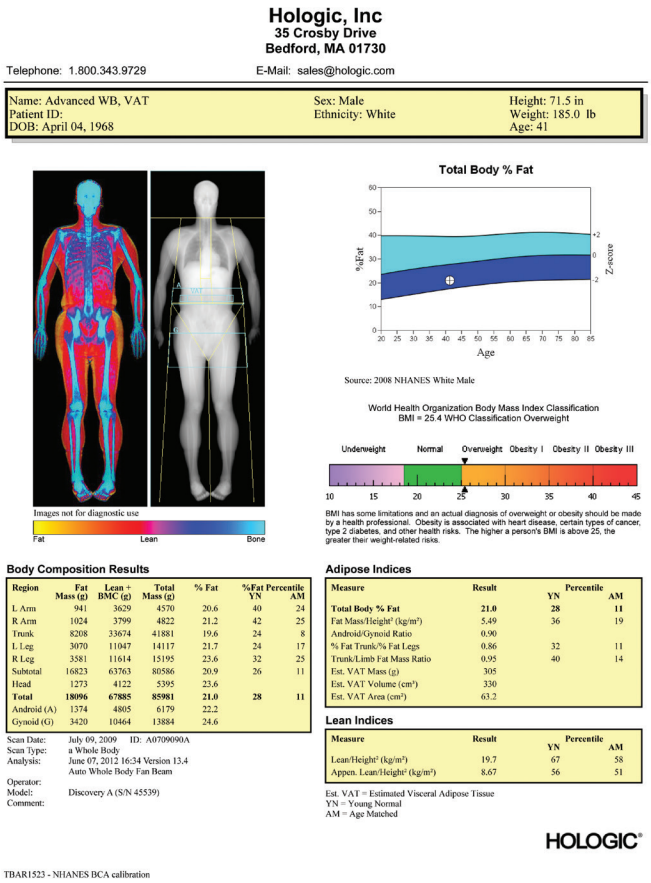
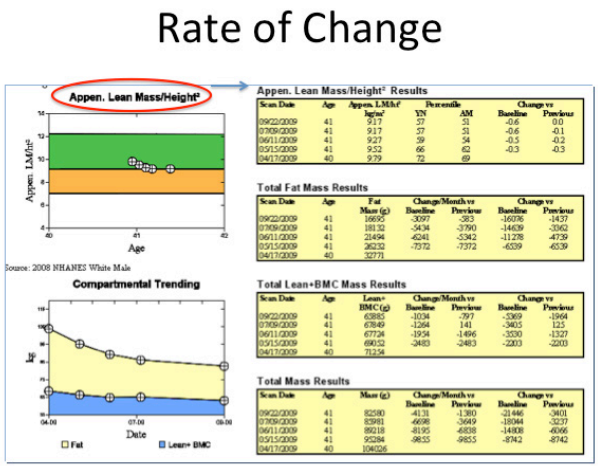


Figure 2. Body Composition Report.

A BMI scale appears on the report to display the patient's calculated BMI. Above the scale the WHO BMI classification appears along with an explanation of the health risks associated with a high BMI. Beneath the graph a paragraph appears that summarizes the U.S. Surgeon General's Health Consequences for being overweight and obese from their website (http://www.surgeongeneral.gov/topics/obesity/calltoaction/fact_advice.htm).

Patient results can be compared to reference values from NHANES both graphically and quantitatively (Figure 1, DXA Report). In adults, the quantitative comparison provides an Age-Matched (AM) Percentile value (or Z-score) and Young Normal (YN) Percentile value (or T-score) depending upon the software configuration. For subjects under the age of 20, only an AM Percentile or Z-score is generated. A mathematical transformation is used to convert Z-scores and T-scores to AM and YN Percentile values, respectively.

A Rate-of-Change report also can be generated to display the trend of serial bone or body composition measurements over time (Figure 2, Rate-of-Change Report). This example shows the effects of an exercise and diet intervention on body composition. The top left of the report displays the trend of Total Body %Fat results over time. These measurements are plotted on an age, gender, and ethnicity-matched reference curve from NHANES.



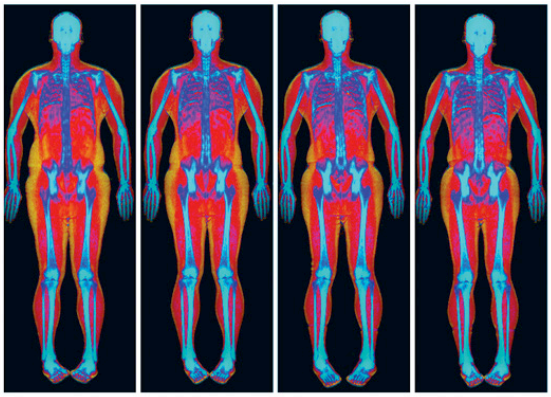


Figure 3. Rate-of-change report displays the subject's age at exam date, the results of the scan, and changes per month for fat mass, lean mass, and total mass.

Immediately below the Total Body %Fat curve is a plot labeled "Compartmental Trending". This plot provides a graphical display of the changes in Total Body Fat Mass

(yellow shaded region) and Total Body Lean Mass (blue shaded region). The uppermost line of the plot indicates total Mass or weight, i.e., the sum of the yellow Fat Mass region plus the blue Lean Mass region. In the example it is immediately apparent that Total Mass is decreasing (uppermost line) due to a reduction of the Fat Mass compartment (yellow region).

At the bottom left of the Rate-of-Change Report, serial images are displayed to show relative changes in fat and lean mass over time. Up to seven images can be displayed. The color image displays the relative amounts of fat and lean tissue in the DXA image, with yellow regions representing regions with higher %Fat and orange and red regions indicating progressively lower %Fat. Bone containing regions are indicated in blue. Beneath the image the phrase “Images not for diagnostic use” appears to inform the user that the image should not be used for diagnosis.

The right hand column of the Rate-of-Change Report displays the measured values for %Fat, Total Fat Mass, Total Lean Mass, and Total Mass, along with changes versus baseline and versus the previous exam. The %Fat table also contains YN and AM percentiles for the comparison of the patient’s Total Body %Fat versus the NHANES database.

Visceral Adipose Tissue: Clinical Significance

There is mounting evidence visceral adipose tissue (VAT) is a prognostic indicator for disease risk. Unlike subcutaneous fat whose main function is energy storage, visceral fat cells are metabolically active and impact a wide variety of clinical risk factors including fasting glucose levels, serum triglycerides, and cholesterol (1,2).

Visceral fat is found within the envelope formed by the abdominal muscles, principally within the greater and lesser omentum that connects the abdominal organs, and in mesenteric fat. A small amount is also found retroperitoneally (3). Visceral fat is more dangerous than subcutaneous fat because visceral fat cells release proteins that contribute to inflammation, atherosclerosis, dyslipidemia, and hypertension. Visceral fat is associated with metabolic risk factors and all-cause mortality in men (4), and is therefore considered a pathogenic fat depot (5).

Hologic scientists recently developed and patented methods for measuring VAT using a whole body DXA scanner. Several validation studies confirmed the high correlation and linear relation between DXA VAT measurements and those provided by computed tomography in children and adults (6,7). DXA VAT measurements have some significant practical and technical advantages over computed tomography including wider availability and automated analysis and calibration, and come at a small fraction of the cost and radiation dose. This breakthrough allows classification of patients with excess visceral fat, thereby identifying the population

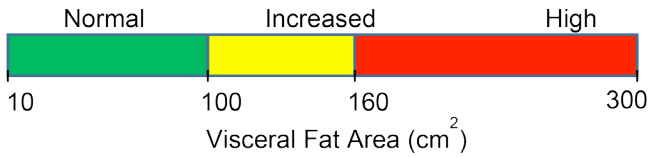


Figure 4. Visceral fat thresholds associated with metabolic risk factors for coronary heart disease.

with the greatest obesity related health risks and where interventions will confer the greatest health benefit.

Visceral fat diagnostic thresholds will become better established as further clinical and research experience is gained. Reference data from population-based studies, such as NHANES will supplement the knowledge base necessary to make clinical decisions. In the interim the currently available literature supports a visceral fat threshold for elevated disease risk at 100 cm^2 and with a high-risk threshold of 160 cm^2 (8-10).

DXA clinical thresholds for VAT were validated in a recent study in White and African-American adults. The thresholds, defined as the presence of two or more cardiometabolic risk factors, were higher in white men (154 cm^2) and women (143 cm^2) compared to African American men (101 cm^2) and women (114 cm^2). The authors concluded that DXA VAT is a useful clinical marker of cardiometabolic risk (11). A study in adolescents found that abdominal obesity is associated with a high metabolic syndrome

burden and that VAT had a stronger impact on insulin resistance than ratio-based DXA measurements (12).

International Society for Clinical Densitometry 2103 Official Positions on Body Composition

The International Society for Clinical Densitometry (ISCD) position paper on indications for body composition included patients with HIV to assess fat distribution, patients in bariatric surgery or other medical interventions to assess changes in fat and lean mass, and in sarcopenia to assess loss of muscle strength and functional ability (13). A consensus on the use of DXA for the management of clinical obesity could not be reached, but many clinicians felt it was a useful tool for patient management and counseling.

Sarcopenia is a rapidly evolving field with several major pharmaceutical companies developing interventions to prevent or reverse age-related muscle loss. The operational definition and diagnosis of sarcopenia is based on the presence of both low appendicular lean mass by DXA in combination with some sort of functional disability, e.g. low gait speed or grip strength. A prospective study looking into falls in sarcopenic versus non-sarcopenic individuals found the best predictor of falls was the Baumgartner definition based on low appendicular lean mass alone (14).

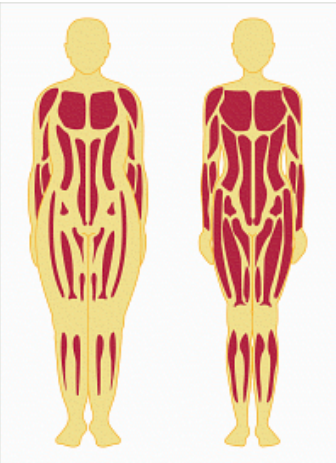


Figure 5. Sarcopenia is best measured by lean mass/height squared.

Clinical Utility of DXA Bone and Body Composition

The clinical utility of the various DXA measures in Table 1 are supported by reports from the medical literature. Selected studies are summarized in the following section. It is important to recognize that the DXA measures and reference database comparisons summarized below do not diagnose diseases or conditions, recommend treatment regimens, or quantify treatment efficacy; only the health care professional can make these judgments.

Total Body BMC and Total Body BMD versus Age

These DXA measures are useful for the evaluation of a wide variety of metabolic bone diseases and conditions, including the following:

- A study of glucocorticoid-treated patients with congenital adrenal hyperplasia found that Total Body BMD was significantly decreased, which may increase fracture risk later in life (Sciannamblo, Russo *et al.* 2006).

- In a comparison of type 1 diabetes patients with controls, Mastrandrea, Wactawski-Wende *et al.* 2008 found that diabetes subjects had a reduced Total Body BMD versus controls and that the reduced BMD persists over time, particularly in women over 20 years of age. They concluded "*Persistence of low BMD as well as failure to accrue bone density after age 20 years may contribute to the increased incidence of osteoporotic hip fractures seen in postmenopausal women with type 1 diabetes*".

- Total Body BMD in subjects with mild to moderate primary hyperparathyroidism was reduced compared to controls in untreated patients. Both Total Body BMC and Total Body BMD increased 4.4% and 3.0% in surgically treated patients during a 3-year follow up period (Christiansen, Steiniche *et al.* 1999). After surgical intervention and follow up, there were no differences in either Total Body BMC or Total Body BMD between treated patients and controls.

- Szulc, Munoz *et al.* 2005, found that Total Body Bone Mineral Density predicts osteoporotic fractures in elderly men better than Lumbar Spine, Hip, or Forearm BMD.

- It has been well established that women with anorexia nervosa develop osteoporosis (Seeman, Szmukler *et al.* 1992) (Stone, Briody *et al.* 2006) and that weight gain is associated with increases in fat mass, lean mass, and Total Body BMC (Orphanidou, McCargar *et al.* 1997). The evaluation of Total Body BMC values versus age-matched controls is an important clinical outcome in the management of anorexia nervosa.

- Osteogenesis imperfecta (OI) causes a wide range of skeletal deficiencies ranging from mild to profound depending upon disease classification and severity. Total Body BMC and Total Body BMD measurements and Z-scores are useful in the management of OI in adults (Reeder and Orwoll 2006) and children. In a two year clinical trial of oral versus intravenous bisphosphonates, an increase of Total Body BMD, the main outcome variable, was shown with both treatment groups along with increased linear growth and decreased fracture rates (DiMeglio and Peacock 2006).

Total Body %Fat vs. Age

During the last two decades there has been a dramatic and secular trend of increasing obesity in the United States in both children and adults. According to the CDC website, the health consequences of obesity include hypertension, osteoarthritis, elevated cholesterol and triglycerides, type 2 diabetes, stroke, coronary heart disease, and increased risk of endometrial, breast, and colon cancer http://www.cdc.gov/obesity/adult/causes.html. Numerous studies have shown the benefit of DXA to identify obesity.

- Although BMI is widely used to classify obesity, it is a measure of excess weight, not excess fat, and its association with clinical obesity may differ by gender, age, and ethnicity (Freedman, Wang *et al.* 2008), (He, Horlick *et al.* 2002).

- A study of British children measured by DXA, (Shaw, Crabtree *et al.* 2007) found clear gender and ethnic differences in percentage body fat (Total Body %Fat measured by DXA) that may be related to known ethnic differences in the risk of type 2 diabetes in adolescence and adulthood. BMI criteria for the definition of being overweight and obese could not accurately identify ethnic differences in body fat.

- Although BMI may identify obesity well at the group level, individual misclassification is generally higher with BMI than with DXA, leading to considerable misclassification of obesity. (Deurenberg, Deurenberg Yap *et al.* 1999).

- Researchers have found that body build (body frame size, e.g. slender) are at least partly responsible for differences between DXA classifications of obesity and BMI classifications among different ethnic groups (Deurenberg, Andreoli *et al.* 2001).

- A large study of elderly well-functioning men and women found that the best correlate with physical capacity (walking speed and one leg stand test) was Total Body %Fat measured by DXA (Bouchard, Beliaeff *et al.* 2007).

- In subjects with noninsulin-dependent diabetes mellitus (NIDDM) and insulin-dependent diabetes mellitus (IDDM), it was shown that patients with IDDM have significantly less total body fat and abdominal fat than patients with NIDDM, irrespective of age (Svendsen and Hassager 1998), and that greater total body and abdominal fat are associated with premature cardiovascular risks (Lapidus, Bengtsson *et al.* 1984).

Fat Mass/Height^2, Lean Mass/Height^2, and Appendicular Lean Mass/Height^2 vs. Age

There is convincing evidence demonstrating that fat mass, lean mass, appendicular lean mass, and weight (e.g. BMI) all scale to height raised to the power of 2, i.e. height^2 (Heymsfield, Gallagher *et al.* 2007), (Keys, Fidanza *et al.* 1972), (Heymsfield, Smith *et al.* 1990). These studies establish an analytical framework supporting the normalization of fat mass, lean mass, and appendicular lean

mass to height^2, providing relative measures of fat mass, lean mass, and appendicular lean mass that are stature independent.

- In study of nutritional status, researchers showed that fat mass and lean mass normalized to height^2 were valuable measures of nutritional assessment (Van Itallie, Yang *et al.* 1990).
- Skeletal, and in particular extremity muscle mass, is of intense interest (Heymsfield, Smith *et al.* 1990) in the evaluation of wasting diseases such as AIDS and muscular dystrophy and in the management of growth hormone deficient adults treated with growth hormone (Hansen, Vahl *et al.* 1995).
- Growth hormone is a potent anabolic agent that has been used to treat GH-deficient adults and children. It has been shown to have a pronounced affect on Fat Mass and Lean Mass in GH-deficient adults (Orme, Sebastian *et al.* 1992), with one study showing clinically significant increases in lean mass with no change in BMI (Ahmad, Hopkins *et al.* 2001).
- A longitudinal study of weight stable elderly adults demonstrated that Appendicular Lean Mass/Height^2 was significantly decreased during follow up (Zamboni, Zoico *et al.* 2003). Appendicular Lean Mass/Height^2 is seen as a surrogate for sarcopenia and there also is good evidence it may be clinically relevant in the elderly as a measure of frailty.

Appendicular Lean Mass over Height^2

Functional Impairment	Men		Women	
	Odds Ratio	95% CI	Odds Ratio	95% CI
3 or more Disabilities	3.66	1.42 – 10.0	4.08	1.52 – 11.3
More than 1 Balance Abnormality	3.23	1.13 – 9.74	1.77	0.48 – 5.75
More than 1 Gait Abnormality	1.87	0.94 – 3.74	1.12	0.43 – 2.73

1 Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB et al. (1998) Epidemiology of sarcopenia among the elderly in New Mexico. *AM J Epidemiol* 147: 755-763.

- In another study in elderly adults, strong associations were found between Appendicular Lean Mass/Height^2 and Lean Mass/Height^2 with functional impairment and disability (Baumgartner, Koehler *et al.* 1998).
- A longitudinal study of body composition by DXA revealed that patients with losses in appendicular lean mass were 2.15 times more likely to report physical disability than patients with no loss (Fantin, Di Francesco *et al.* 2007).
- Glucocorticoids are known to adversely affect bone mineralization, glucose metabolism, and lipids and therefore can affect body composition. In glucocorticoid-treated patients with giant cell arteritis, high doses of prednisolone resulted in an increase in total body fat that remained even after switching to a low dose schedule. DXA Fat Mass evaluation is valuable in assessing and monitoring the effects of high dose glucocorticoid therapy in glucocorticoid-treated subjects (Nordborg, Schaufelberger *et al.* 1998).
- In subjects with systemic lupus erythematosus, the severity of the disease and corticosteroid exposure were independently associated with a negative effect on Total Body BMD and Total Body Lean Mass (Kipen, Strauss *et al.* 1998).
- In children with Prader-Willi syndrome, GH-treatment improved Total Body %Fat and Lean Mass Z-scores improved compared to the control group (Festen, de Lind van Wijngaarden *et al.* 2008), indicating that GH-treatment may be an effective intervention in these children.
- Lean Mass measured by DXA in children with Duchenne muscular dystrophy was highly correlated with muscle strength and function (Palmieri, Bertorini *et al.* 1996).

%Fat Trunk/%Fat Legs and Trunk/Limb Fat Mass Ratio vs. Age

Antiretroviral agents may cause a redistribution of fat mass termed lipodystrophy. Lipodystrophy assessment is often made by physical assessment and is passively reported in trials of antiretroviral agents. DXA measurements of trunk to limb %Fat ratios or trunk to limb Fat Mass ratios are a reliable and useful tool for the assessment of lypodistrophy in special populations but are not particularly useful or informative in the general population.

- Using the %Fat Trunk/%Fat Legs ratio derived from whole body DXA scans, researchers demonstrated improved sensitivity with equal specificity in detecting lipodystrophy compared with criterion methods in antiretroviral treated adults (Law, Puls *et al.* 2006).
- A large study of HIV-infected men compared with controls demonstrated that the %Fat Trunk/%Fat Legs ratio measured by DXA were significantly higher for those with clinical lipodystrophy than for those without, and that treated HIV-infected men with lipodistrophy had the most elevated %Fat Trunk/%Fat Legs ratios. The authors concluded the use of the %Fat Trunk/%Fat Legs ratio should allow a more accurate diagnosis of lipodystrophy compared to clinical exam and could help diagnose lipodystrophy earlier (Bonnet, Delpierre *et al.* 2005).
- A study of growth hormone releasing hormone (GHRH) in HIV-infected men with lipodystrophy, (Nordborg, Schaufelberger *et al.* 1998) found that the GHRH treated group saw significant increases in lean mass and the ratio of trunk fat to lower limb fat improved significantly. Based on the data, the authors concluded that GHRH treatment was a potentially beneficial intervention for this population.

Sub-total Body BMD and Sub-total Body BMC vs. Age

Sub-total Body BMD and Sub-total Body BMC [Total Body Less Head results] were recommended in the International Society of Clinical Densitometry (ISCD) Official Positions for diagnosing bone disorders in children. The ISCD is a professional organization of physicians, scientists, and technologists who set forth guidelines on the appropriate use of DXA. (Crabtree *et al,* 2014: Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD Pediatric Official Positions).

The ISCD reasoning for excluding the "head results" in DXA whole body exams of children is that the head is large in young children relative to body size, and may therefore bias the results of the entire exam. The recommendation to exclude the head in whole body exams of children is further supported by the following position statement in the 2007 ISCD Pediatric Official Positions paper "*Skeletal sites recommended for assessment are the lumbar spine and total body less head, the latter being valuable as it provides information on soft tissue, as well as bone,*" (Gordon, Bachrach *et al.* 2008).

Total Body BMD, Total Body BMC, Sub-total Body BMD, and Sub-total Body BMC vs. Height

It would appear self-evident that body size, growth, and overall physical development should be taken into consideration when interpreting BMD studies in children because many children referred for DXA are small for their age due to chronic conditions, disease, or delayed maturation. Furthermore "*the interpretation of densitometric data in the young is difficult because the "normal" BMD values to be used for comparison are continuously changing with age, and in addition, depend on several variables, such as gender, body size, pubertal stage, skeletal maturation and ethnicity*" (Bianchi 2007).

It has been well established that examinations of skeletal status in children using dual-energy x-ray absorptiometry (DXA) are prone to size-related misinterpretation (Pludowski, Karczmarewicz *et al.* 2007). Because many chronically ill children are small in stature, the International Society of Clinical Densitometry Official Positions recommends normalizing DXA reference data in children to height or height Z-score to adjust for small stature. (Crabtree *et al,* 2014: Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD Pediatric Official Positions).

Normalizing total body BMC and BMC for height was demonstrated in a study that looked at skeletal deficits in two groups of children with chronic renal disease or hypoparathyroidism. After adjusting for height, the study found that total body BMC is not reduced in either group. As a result, the authors recommended adjusting BMC results for bone size (Ahmed, Russell *et al.* 2005).

Total Lean Mass vs. Height and Sub-total body BMC vs. Total Lean Mass

The 2007 ISCD Official Positions state that "*Soft tissue measures in conjunction with whole body scans may be helpful in evaluating patients with chronic conditions associated with malnutrition (such as anorexia nervosa, inflammatory bowel disease, cystic fibrosis), or with both muscle and skeletal deficits (such as idiopathic juvenile osteoporosis).*" (Gordon *et al.*, 2008: Dual Energy X-ray Absorptiometry Interpretation and Reporting in Children and Adolescents: The 2007 ISCD Pediatric Official Positions).

Guidelines for interpreting DXA total body exams have been published for children with growth hormone deficiency and anorexia nervosa (Hogler, Briody *et al.* 2003). These guidelines include normalizing BMC or BMD for age, height for age, and total lean tissue mass for height. This methodology allows differentiation of the origin of a skeletal deficit, "*for example, short stature and primary, secondary, and mixed bone defects*" (Hogler, Briody *et al.* 2003).

Investigators in the U.K. took a similar approach by using a two-stage algorithm that investigated the relationship between Total Lean Mass (abbreviated LBM "Lean Body Mass" in their study) and Total Body BMC in subjects with spinal muscular atrophy, osteogenesis imperfecta, and low trauma fractures. Stage 1 assessed Total Lean Mass vs. height Z-scores and stage 2 assessed BMC for Total Lean Mass Z-scores. *"Ten children with spinal muscular atrophy had a mean LBM for height Z-score of −1.8 but a mean BMC for LBM Z-score of 1.2 indicating their primary abnormality was reduced muscle mass (sarcopenia) with no evidence of osteopenia. In contrast, 21 children with osteogenesis imperfecta had a mean LBM for height Z-score of 0.4 but a mean BMC for LBM Z-score of −2.5 indicating normal LBM for size but significantly reduced BMC for LBM (i.e. osteopenia) confirming a primary bone abnormality. A third group consisting of 12 children with low trauma fractures demonstrated little evidence of sarcopenia [mean LBM for height Z-score −1.1] but significant osteopenia [mean BMC for LBM Z-score −1.9].*

Conclusion: The results from this study demonstrate how the relationship between height and lean body mass, and lean body mass and bone mineral content can be a useful method of diagnosing osteoporosis in children and how the relationships can be used to identify if the primary abnormality is in muscle or bone," (Crabtree, Kibirige *et al.* 2004).

In a study relating changes in body composition to longitudinal changes in total body bone mineral content, investigators found that changes in total body bone measures are strongly associated with changes in lean mass during linear growth, suggesting that any decoupling of lean mass and total body bone mineral content during the growth phase may indicate an underlying pathology of muscle or bone (Young, Hopper *et al.* 2001).

Paget's disease is characterized by high bone turnover, greater fracture risk, and focal lesions of abnormally dense bone. Treatment with bisphosphonates usually results in increases in whole body bone mineral content because of increases in pagetic and non-pagetic sites (Patel, Pearson *et al.* 1997).

Osteopetrosis is a disease usually diagnosed by standard radiographs. However, general radiography cannot determine the degree or severity of the disease. Total body BMC and Total Body BMD are markedly increased versus age-and gender-matched controls in both types of autosomal dominant osteopetrosis, and investigators suggest that DXA total body BMC and total body BMD measurements are useful for initial evaluation, making treatment recommendations, and for monitoring skeletal mass (Grodum, Gram *et al.* 1995).

Conclusion

The diagnosis and management of abnormalities in bone and body composition require accurate and precise DXA measurements coupled with nationally representative reference data. The NHANES database forms the foundation for the diagnostic measures provided by Hologic's whole body DXA system, and their integration forms an essential tool for both clinical medicine and research.

The present work has provided numerous examples of the clinical utility of whole body bone and body composition measurements in a wide variety of clinical populations. It has further demonstrated the expanding role of software analytics and reporting tools to support healthcare providers in the management of at risk patients while providing information that is both accessible and impactful to patient and practitioner.

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