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Original Article

Long-Term Precision of Dual-Energy X-ray Absorptiometry Body Composition Measurements and Association With Their Covariates

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Abstract

Few studies have described the long-term repeatability of dual-energy X-ray absorptiometry scans. Even fewer studies have been performed with enough participants to identify possible precision covariates such as sex, age, and body mass index (BMI). Our objective was to investigate the long-term repeatability of both total and subregional body composition measurements and their associations with covariates in a large sample. Two valid whole-body dual-energy X-ray absorptiometry scans were available for 609 participants in the National Health and Nutrition Examination Survey 2000−2002. Participants with scan-quality issues were excluded. Participants varied in race and ethnicity, sex, age (mean 38.8 ± 17.5; range 16−69 yr), and BMI (mean, 26.9 ± 5.2; range 14.1−43.5 kg/m^2). The length of time between scans ranged from 3 to 51 days (mean, 18.7 ± 8.4). Precision error estimates for total body measures (bone mineral density, bone mineral content, lean mass, total mass, fat mass, and percent body fat) were calculated as root mean square percent coefficients of variation and standard deviations. The average root mean square percent coefficients of variation and root mean square standard deviations of the precision error for total body variables were 1.12 and 0.01 g/cm^2 for bone mineral density, 1.14 and 27.3 g for bone mineral content, 1.97 and 505 g for fat mass, 1.46 and 760 g for lean mass, 1.10 and 858 g for total mass, and 1.80 and 0.59 for percent body fat. In general, only fat and lean masses were impacted by participant and scan qualities (obesity category, sex, the magnitude of the body composition variables, and time between scans). We conclude that long-term precision error values are impacted by BMI, and sex. Our long-term precision error estimates may be more suitable than short-term precision for calculating least significant change and monitoring time intervals.

Key Words: Body composition; bone mineral density; Hologic; precision; whole body.

Introduction

Total body and subregional bone mineral density (BMD) and bone mineral content (BMC), as well as soft-tissue measurements such as fat mass and lean mass, can be measured with dual-energy X-ray absorptiometry (DXA) *(1)*. DXA is a safe, fast, and efficient method for bone and body composition assessment and thus its use has become increasingly popular in both clinical and research settings. DXA is most commonly used for measuring BMD, and most of the literature on the characteristics of DXA systems is related to bone measures. The precision of BMD and BMC measures is affected by body size *(2)*, bone density, and by system make and model *(3,4)*. However, much less is known about the accuracy and precision of total body soft-tissue measures.

To determine whether a change between 2 measurements is statistically significant, the precision error of the measurements must be known. The International Society for Clinical Densitometry states in its position paper on precision *(5)* that precision analysis is performed by calculating the root mean square standard deviation (RMS-SD) as an absolute measure

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in the units of the measure, and the root mean square percent coefficients of variation (RMS-%CV) as an expression of precision error in percent relative to the mean value of the population. The manufacturer's precision error values should not be used because of differences among study populations, technologist skill, and confidence intervals used.

Although there are many benefits to in the use of DXA to assess bone health and body composition, maintaining precision between repeated scans is a challenge. Repeatability is important in maintaining the consistency of DXA measurements in longitudinal studies. It is recommended that consecutive examinations be taken on the same system or a system from the same manufacturer to allow results to be comparable over time *(6)*. Previously, Lohman et al *(7)* reported excellent precision for total body and subregional measurements. However, this was a short-term study in which repeat scans were acquired on the same day on an all-male population. Long-term precision errors for bone variables measured in spine and hip scans *(8,9)*, based on scans that have been repeated after several days have passed, are larger than short-term estimates, which is due to differences in scan acquisition caused by patient repositioning problems and scanner calibration stability. Little is known about the relationship of sex, body mass index (BMI), age, and measurement magnitude to long-term body composition precision error values. The purpose of this study was to use repeated scan data collected in the National Health and Nutrition Examination Survey (NHANES) to estimate total body and subregional body composition precision measures and to determine their associations with potential covariates.

Materials and Methods

Participants

NHANES is a continuous program designed to assess the health and nutrition status of a representative sample of noninstitutionalized adults and children in the United States *(10)*. Interviews as well as physical examinations, including DXA examinations, are used to obtain demographic, socioeconomic, dietary, and health-related information for different population groups. During the survey years in which replicate DXA scans were collected (2000−2002), African Americans, Mexican Americans, low-income white patients, adolescents aged 12−19 years old, and those aged 60 years and older were oversampled to produce more reliable statistics for these groups. Race and Hispanic origin were self-reported.

Physical Examinations

When arriving at an NHANES mobile examination center (MEC), participants were asked to change into paper clothing. Participant body weight was measured using a Toledo digital scale; height was measured with a Seca electronic stadiometer (Seca, Chino, CA). BMI was calculated as weight (kg)/height (m^2). The BMI categories were defined via the World Health Organization weight categories: BMI <25.0 = normal weight, $25.0 \geq$ BMI ≥ 29.9 = overweight, $30.0 \geq$ BMI ≥ 34.9 = class I obesity, BMI ≥ 35.0 = class II obesity *(11)*.

In 2000−2002, whole-body DXA scans were administered to eligible participants aged 8 years and older. Pregnant subjects were not eligible for the DXA scans. Participants who weighed more than 300 pounds (136 kg, a limitation of the DXA table) or who recently had a medical test using contrast materials also were excluded from having a DXA scan. The DXA examinations were performed using 3 different Hologic QDR 4500 A systems (Hologic, Inc., Bedford, MA). For the DXA examination, participants were asked to remove jewelry, watches, and other objects from the body and keys and glasses from pockets of the paper clothing. (See the NHANES Body Composition Procedures Manual posted on the NHANES website, http://www.cdc.gov/nchs/data/nhanes/bc.pdf.) Participants were positioned according to the guidelines in the Hologic user's manual and were scanned using the whole-body fast mode.

A second physical examination, including DXA, was conducted on a nonrandom sample of self-selected volunteers for quality assurance and research purposes in the NHANES MECs in 2000 through 2002. No statistical sampling was applied for selection of second-day examination participants. For the second-day examination, the MEC staff recruited participants aged 16−69 yr, approximating percentages in demographic categories for the primary examination. Participants were given the option to decline the second examination. Approximately 11% of those who completed the first examination also completed the second examination.

Participants were asked to come for the second-day examination at least 8 d after their first examination. The second-day examinations were conducted in the same MEC as the primary examinations. The radiology technologist who conducted the second-day DXA scan was not always the same technologist who conducted the primary scan. The procedures for the second-day examination were the same as those for the primary examination. There were no additional exclusion criteria for the second-day examination.

Scan analysis was performed centrally at the NHANES DXA quality control center at the University of California, San Francisco with the use of APEX software version 3.0. Primary scans were analyzed using manual placement of regions of interest. Second-day scans were analyzed using the Hologic COMPARE feature to ensure consistent placement of the cut lines defining the regions of interest. Bone measures included BMD, BMC, and bone projected area. Body composition measures included lean mass, fat mass, total mass, as well as percent fat. All bone and body composition measures were reported for total body, trunk, and appendices. Appendicular values are defined as the sum of both arms and legs.

Scan quality issues were coded as part of the overall NHANES quality assurance program by the use of a table of codes developed by University of California, San Francisco. Codes were applied for such quality issues as implants, objects that had not been removed from the body or paper clothing, "obesity noise" due to a large amount of abdominal fat, positioning problems, and participant motion. On the basis of the application of these codes, 609 participants who completed both primary and second-day DXA examinations