Precision of Regional Bone Mineral Measurements Obtained from Total-Body Scans

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Newer bone densitometers using dual-photon absorptiometry (DPA) or dual energy x-ray absorptiometry (DEXA) are capable of measuring the total-body bone mineral; regional analysis of these scans would have significant utility if adequate precision were possible. This study investigated short term precision by weekly scanning (three to five times) normal subjects (total 48 scans) and long term precision by scanning a whole-body phantom 30 times over 15 mo. For the 30 phantom scans, a coefficient of variation (CV) of bone mineral content (BMC) and bone mineral density (BMD) was calculated for each region. Nonrandom changes were analyzed by plotting the phantom data with time and testing the slope of the fitted line for significance. Similarly for the subjects, a CV for each region and the mean value for all subjects was obtained. From this study we conclude (a) BMD is more precise than BMC, (b) long-term precision was poorer than short term, (c) long-term regional BMD precision (%) was: head, 3.2; arms, 2.8; legs, 1.6; ribs, 2.6; pelvis, 3.8; thoracic spine, 3.8; lumbar spine, 7.1; total spine, 2.4; trunk, 2.2; total body, 1.2.

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Total and regional body calcium can be measured by neutron activation analysis while changes in total-body calcium can be estimated from calcium balance (*1–3*). Neutron activation analysis requires elaborate and expensive facilities and delivers a relatively high radiation exposure. Calcium balance studies are expensive and difficult to perform. Since skeletal calcium is a relatively constant fraction of the bone mineral and because of their relative simplicity, single and dual photon absorptiometry (DPA) of bone mineral has become the standard method for quantitating skeletal changes. Some newer dual photon devices are now capable of scanning the entire skeleton yielding measures of total-body bone mineral and total-body bone density, adding an important capability for the clinical assessment of bone disease (*4–6*). Total-body bone mineral which measures total mineral in grams has been shown to be highly correlated (s.e.e. = 36 g of calcium) with total-body calcium (*7*). The total-body bone density which is the total mineral divided by the bone area, is generally used because it provides size normalization. Short term precision of total body measurements have been reported to be ~2.5% using first generation equipment (*8,9*) while newer devices report precision ranging from 0.6 to 1.4% (*4,10–11*).

Because bone loss is not uniform throughout the skeleton, measuring regional changes during longitudinal studies is advantageous. Even for cross-sectional studies regional measurements may be necessary since, e.g., osteoporosis is usually associated with increased trabecular bone loss while the whole body is ~80% compact bone. Since these scans collect information from the entire skeleton, obtaining regional bone mineral content is possible. However, only limited data on regional precision from total body scans has been published (*8,11*). The purpose of this study was to determine the short and long term precision of regional estimates of bone mineral from whole body scans using the data acquisition and analysis techniques suggested by the manufacturer.

METHODS

Bone mineral measurements were performed using a dual photon (gadolinium-153) absorptiometer (Lunar Radiation Corp., DP4). A whole-body phantom (Alderson Research Laboratories, Inc.) containing a natural human skeleton was obtained and scanned periodically for 15 mo (30 scans). The total-body and regional bone mineral content (BMC) in grams and bone mineral density (BMD) in g/cm^2 were obtained. The mean and s.d. of all 30 scans for the total body and each region were calculated. From these data, coefficient of variations (CV) were obtained as the estimate of long-term precision. As an estimate of short-term precision, the phantom data were analyzed in sequential groups of three. A CV for each group was calculated and the overall mean for all groups for each region obtained. These short-term data were then used to compare with short-term in vivo data, described below,

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acquired in a similar manner in normal subjects. In order to determine the existence of nonrandom changes over time, the phantom and calibration standards were plotted as a function of time and fitted by linear regression. The resultant slopes were tested for significance. The slope was considered significant if it was more than twice the standard error of the slope.

We are conducting long-term bed rest studies in normal individuals to investigate the rate and extent of bone loss and recovery from disuse conditions. In order to improve our sensitivity to detect small changes in bone content with bed rest, we routinely scan each subject multiple times before and after bed rest. Seven normal individuals were scanned three to five times over a 5-wk period before bed rest. Six of these individuals were scanned an additional three times over a two week period after 4 mo of bed rest. These data (48 total scans) were then analyzed as 13 groups to calculate CV for each region. The mean and standard deviation of the individual CV were then calculated and used as the estimate of in vivo short-term precision. All scans were acquired and analyzed by the same individual. The data acquisition and regional analysis were performed according to the manufacturer's instructions. The regions analyzed were those defined in the instrument software: head, arms, ribs, legs, pelvis, thoracic spine, lumbar spine, total spine, trunk (ribs, spine, pelvis), and total body. In each case the automatic region of interest was adjusted to match the previous scan as closely as possible.

RESULTS

The short-term BMD in vivo (subject) and in vitro (phantom) CV were essentially identical. The BMC in vitro regional results however were consistently higher than the in vivo BMC data except for the total-body values which were not different. Table 1 compares the BMC and BMD CV results for the phantom (long-term precision) and subjects (short-term precision). With few exceptions both phantom and subject data showed that the BMD gave better precision than BMC. The CV for the phantom BMD and BMC values, of all regions but one, were larger than the subject values.

Plots of the phantom regional BMD values against time generally did not have slopes that were significant. Similar plots of BMC with time however demonstrated slopes that were significant. Figure 1 is a plot of the phantom total-body BMC and BMD data. The slope of the line fitted to the BMC data shows a decrease of ~5% per year. Similar plots of the instrument calibration standards demonstrated that the instrument drift (e.g., 0.6%/yr for the large standard) over this same time period, while significant, was an order of magnitude less than the BMC changes. There were no changes in collimation during this time with a single source change on 13 Dec. 1988.

DISCUSSION

Although not the purpose of this paper, it might be useful to examine possible sources for regional and total-body precision error; these include regional bone mass, cut selection, partial volume effects, anatomic positioning and composition, electronic drift, and software anomalies. The quantity of bone mass or sample size could affect precision from errors in edge detection or counting statistics. Obviously variation in positioning of the regional cuts on the bone image will affect precision, with less affect on BMD than BMC. Even with accurate cut positioning, partial volume affects will introduce variations because the step width is relatively coarse, i.e., 15 mm. Anatomic rotation from one scan to the next will cause variance in BMD but probably not in the BMC. This occurred in one subject scan when the forearms were placed in a semiprone position rather than the usual prone position. This caused an 8.5% increase in BMD with little change in BMC. Movement during a scan will increase precision error in both BMC and BMD. Varying amounts of colon contents could affect the soft-tissue R value (ratio of

TABLE 1
BMC (g) and BMD (g/cm^2) Coefficient of Variations (%) for Phantom (Long-Term Precision) and Subjects (Short-Term Precision)*

	Phantom (n = 30)		Subjects (n = 48)	
Regions	BMC	BMD	BMC	BMD
Head	3.0	3.2	1.6	2.4
Arms	7.8	2.8	2.0	1.8
Legs	3.9	1.6	1.0	1.1
Ribs	10.4	2.6	4.5	2.0
Pelvis	4.8	3.8	3.0	2.1
Thoracic spine	12.4	3.8	5.0	3.2
Lumbar spine	12.0	7.1	4.1	3.7
Total spine	11.6	2.4	3.3	2.4
Trunk	4.7	2.2	2.6	1.3
Total body	2.7	1.2	1.0	0.9

*The total number of scans used to calculate average is indicated by (n).

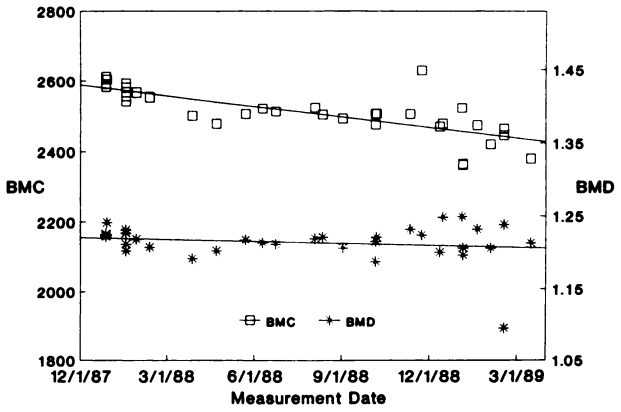

FIGURE 1
Plot of total-body phantom bone mineral (BMC) and density (BMD) with time. The slope of the BMC fitted line, 4.85%/yr, was significant (>2 s.e. of slope) while the BMD was not.

the 44 keV to 100 keV) used in the calculation of bone mineral although no direct evidence for this is available to these authors. Some electronic drift was evident from the plot of the standard values with time. The fact that the total-body BMD long-term (phantom) and short-term (subject and phantom) precision were similar, i.e., 1.2% versus 0.9%, respectively, suggests that electronic drift is adequately corrected by the calibration process. However, the significant decrease in BMC over time suggests that instrument drift or some other nonrandom change is occurring which is not adequately corrected. We do not have an explanation for this drift but it probably contributes to the poorer BMC precision relative to BMD. Probably related to the changes in BMC is a change in the soft-tissue R value of the phantom that we observed of ~1.5% per year. It is possible although unlikely that the phantom soft-tissue material might be changing over time which is reflected in the R value and that the system software is unable to correct properly. The Phantom R value is higher than in vivo values; Lean males have R values on our instrument of about 1.48 to 1.49 versus the phantom of 1.54 to 1.57.

The total-body BMD precision was found to be ~1% for both the short-term subject scans and the long-term phantom scans. This is similar to values for short-term precision reported previously (*4*). This is better precision than is achievable from long-term scanning of the spine, arm or heel which are reported to be ~2% (*12–14*). It appears from Table 1 that only the trunk and leg and possibly the total spine regions yield precision values close to that achievable from local area scanning. This is not surprising considering the relatively coarse step width used in total-body scanning compared with regional scanning. The values given in Table 1, however, probably represent the best that could be expected since these data were acquired and analyzed by the same individual in a laboratory oriented toward research. However, we have reported previously that if the observers are carefully trained, long-term precision (spine) is not significantly degraded by having multiple observers (*12*). Also, the subjects were all healthy males; female osteoporotics would probably give poorer results. The new generation dual-photon x-ray devices which employ improved image acquisition and display should have improved regional precision.

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