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Review

Influence of region size on bone mineral measurements along femoral stems in THA

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ABSTRACT: The influence of regional size on the precision error in the evaluation of bone mineral changes along femoral components in uncemented THA's was studied methodologically using Dual Energy X-ray Absorptiometry (DEXA) and with a review of the literature. A significant negative relation between region size and precision error was found in experimental studies and the precision error was shown to vary with type of DEXA scanner when reviewing the literature. When using Gruen's zones we found that the precision was best at the tip and poorest in the proximal regions. Guidelines based upon calculations of the approximate percentage changes necessary in a single individual to be statistically significant in a longitudinal study with 95% probability were made for three different types of DEXA scanners. (Hip International 2000; 10: 204-8)

KEY WORDS: Bone mineral, Region size, THA, Precision, DEXA, Uncemented

INTRODUCTION

Finite element analyses have shown that local bone remodelling in the femur is an expected consequence of total hip arthroplasty (THA) (1).

To identify changes in bone mineral density (BMD) on standard radiographs, changes in density must be of more than 30% to be observed with certainty (2). The application of Dual Energy X-ray Absorptiometry (DEXA) has increased rapidly during recent years making it possible to detect even small changes in bone mineral along femoral components in THA's. The numbers of prospective studies evaluating bone mineral changes in the proximity of the femoral component following uncemented THA are increasing rapidly (3-10). Also, several methodological studies evaluating accuracy, precision and the influence of femoral rotation on the precision error have been published (5,10-18). Cohen and Rushton (16) showed in a phantom study using three different femoral stems that the precision was unaffected by changes in material properties or the presence of metal in the scanned area. Gehrchen et al (11) have shown that the best precision was obtained using BMD compared to bone mineral content (BMC). However, no consensus on size and placement of regions of interest (ROI's), when measuring bone mineral in the proximity of femoral components after THA, exists. Some studies focus on specific parts of the proximal femur (10,12,13,15), while others measure the whole proximal femur, typically divided into ROI's as proposed by Gruen et al (19), or with modifications (5,11,14,16-18).

The objective of the present study was to evaluate the influence of regional size on the precision error expressed as the coefficient of variation (CV). This has not yet been examined and theoretically the precision error plays an important role in the evaluation of bone mineral changes in longitudinal studies. In

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addition, by reviewing the literature, the influence of scanner type on the precision error when Gruen zones are used was evaluated.

MATERIAL AND METHODS

Measurement of bone mineral in this study was performed by DEXA (20,21) using the XR-26 Mark II, dual energy, dual detector, X-ray absorptiometric system (Norland Corp., WI, USA). All the bone mineral measurements in this study were performed using the flexible research scan option, which includes the capability of prosthesis exclusion by disabling high density pixels (BMD values above 3.74 g/cm^2). The spatial resolution (pixel size) selected for all the measurements was 1.0 mm x 1.0 mm, and a scan speed of 45 mm/s was used. On the computerised image of the scan BMD (g/cm^2) was measured in various regions along the femoral stem.

Phantom study

In one human femur an uncemented titanium alloy femoral component (Bi-Metric primary stem, Biomet Inc.) was implanted. The phantom was scanned at different degrees of rotation along the longitudinal axis of the femoral shaft (11). A series of bone mineral measurements were performed with the phantom in 15, 20 and 25 degrees of anteversion. At every step (from 15-25 degrees) a new scan was performed with calculation of BMD in ROI's around the femoral stem. Reanalysis of each scan was repeated using ROI's with lengths of respectively 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 75, 100 and 120 mm along both sides from the tip to the top of the femoral stem.

In vivo *study*

The precision for BMD measurements *in vivo* was evaluated from measurements performed in ten patients (M/F = 5/5, mean age 58 years, range 49 - 65 years). The patients were operated on with insertion of a THA (uncemented Bi-Metric primary stem) because of osteoarthrosis 13 (range: 5 - 30) months earlier. The patients were scanned twice on the same day with complete repositioning between each scan using a device constructed to secure rotation. BMD was measured around the femoral stem using ROI's with lengths of 15, 30, 45 and 60 mm along the femoral stems.

Gruen zones literature study

The literature evaluating precision of BMD measurements in Gruen's zones was reviewed (5, 11, 14, 16, 18, 22, 23).

Statistics

The precision expressed as the CV was calculated using the equation:

$$CV = \frac{SD}{mean} \times 100$$

In both the phantom study and the study *in vivo*, the relation between region size and the CV were performed by linear regression analysis, with calculation of the regression line equation, 95% confidence limits, the coefficient of determination (R^2) and the p values for the t-test.

RESULTS

Phantom study

The CV ranged from 2.3% to 5.2% with the region size of 75mm giving the best precision and the region of 5mm giving the poorest (Tab. I).

Furthermore a tendency towards low CV at the tip and a high CV at the proximal end of the stem was seen. A significant negative relation between region size and CV was found indicating that 72% of the variability in CV could be explained by the variation in region size (Fig. 1).

In vivo *study*

The CV ranged from 1.7% to 3.1% with the region of 60 mm giving the best precision and the region of 15 mm giving the poorest. A negative relation between region size and CV was found ($p = 0.03$, $R^2 = 0.94$),

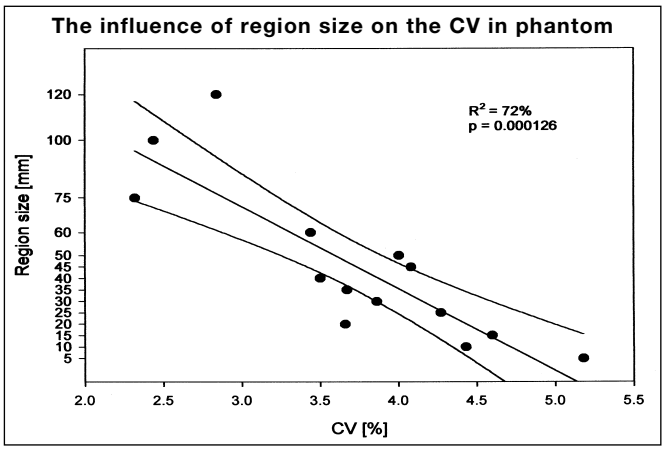

Fig. 1 - *Linear regression analysis of the relation between region size and the calculated CV's of the phantom study with calculation of 95% confidence limits, the coeffficient of determination (R^2) and the p value for the t-test.*

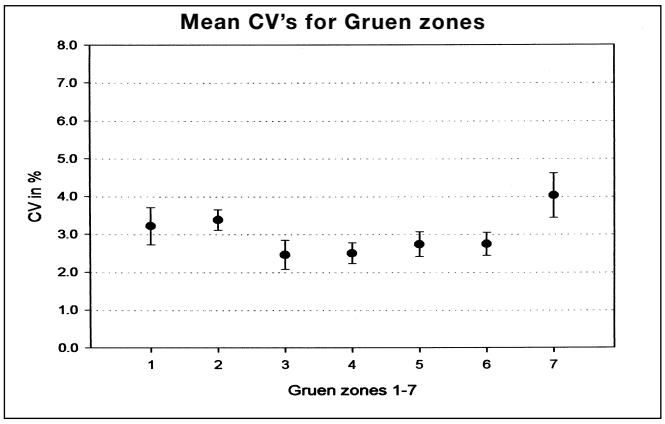

Fig. 2 - *Mean CV's for Gruen's seven zones (1 - 7). Error bars represent SD's. Data from seven previously published studies.*

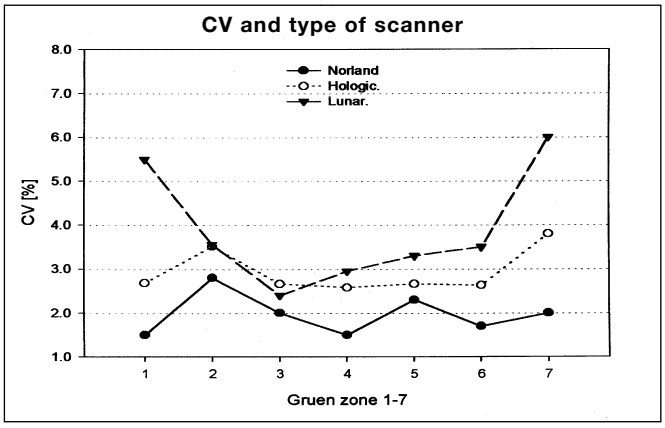

Fig. 3 - *Mean CV's for Gruen's seven zones (1 - 7) presented for three different DEXA scanners.*

TABLE I - THE PRECISION EXPRESSED AS THE COEFFICIENT OF VARIATION (CV) FOR EACH SIZE OF ROI IN THE PHANTOM STUDY

Region size (mm)	CV (%)
5	5.2
10	4.4
15	4.6
20	3.7
25	4.3
30	3.9
35	3.7
40	3.5
45	4.1
50	4.0
60	3.4
75	2.3
100	2.4
120	2.8

however, the number of data sets for doing this analysis were few.

Gruen zones-literature study

Analysing data from previous studies (5, 11, 14, 16, 18, 22, 23), the mean CV for all seven Gruen's regions ranged from 2.5% to 4.1%. In general the best precision was obtained at the tip of the stem (Fig. 2) and the poorest precision was seen in the proximal regions (Gruen zones 1, 2 and 7; Fig. 2).

DISCUSSION

In the present study the lesser the ROI the poorer the precision expressed as the coeffficient of variation. Thus, in prospective randomised clinical trials, the smaller the ROI studied the more patients would need to be included to statistically show a difference (e.g. the difference in bone remodelling due to different design of two femoral stems). It is very important that this fact be taken into consideration when planning a trial with sufficient statistical power, avoiding unnecessary and inconclusive studies.

The literature partly reflects these facts in the reported CV's using different DEXA scanners although methodological studies on this specific subject are

still very sparse. Analysing the results obtained with different DEXA scanners (Lunar, Hologic and Norland) it is graphically possible to demonstrate a difference of CV's. Thus Figure 3 shows pooled data for Lunar (means for 2 stem types) (5,18), Hologic (means for 5 stem types) (14,16,22,23) and Norland (1 stem type) (11). The CV differences are presumably caused by differences between the scanners although it must be remembered that the Gruen zones in the studies are not exact matches. Smart et al (18) account for the biggest deviation from original Gruen zones but precision values are lower than Nishii et al (5). Differences should be suspected even between different and upgraded versions of scanners and software. Other factors contributing to CV differences could be the technician and the calibration. If follow-up of changes in a single individual is performed, a change between two measurements on $2xCV\%x\sqrt{2}$ is required for the difference to be significant with a 95% probability (24).

Implementing the above mentioned results, guidelines based thereupon, gives the approximate percentage changes necessary in a single individual to be statistically significant in a longitudinal study with a 95% probability (Tab. II). As shown in Table II the values differ between scanners and a tendency to highest values are seen in the proximal zones caused by the more complex geometry in this region.

In conclusion we found a significant negative relation between region size and CV. Thus smaller regions require more patients to be included in prospective studies on bone mineral changes along the femoral component in THA to demonstrate a statistically significant difference. The type of scanner also has to be taken into account when planning a controlled clinical trial.

TABLE II - CALCULATED FOLLOW-UP CHANGE IN % BETWEEN TWO MEASUREMENTS OF BMD, IN A SINGLE PATIENT, REQUIRED FOR THE DIFFERENCE TO BE STATISTICALLY SIGNIFICANT WITH A 95 % PROBABILITY FOR DIFFERENT TYPES OF DEXA SCANNERS (LUNAR (5,18), HOLOGIC (14,16,22,23) AND NORLAND (11)).

Zone	Lunar	Hologic	Norland
Gruen 1	15.6	7.7	4.2
Gruen 2	10.0	9.4	7.9
Gruen 3	6.8	6.0	5.7
Gruen 4	8.3	7.6	4.2
Gruen 5	9.3	7.9	6.5
Gruen 6	9.9	7.1	4.8
Gruen 7	17.0	11.5	5.7

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