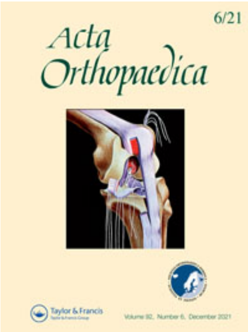

Acta Orthopaedica Scandinavica

ISSN: 0001-6470 (Print) (Online) Journal homepage: informahealthcare.com/journals/iort19

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To cite this article: Matthias Therbo, Michael Petersen, Henrik Schrøder, Palle Nielsen, Bo Zerahn & Bjarne Lund (2003) The precision and influence of rotation for measurements of bone mineral density of the distal femur following total knee arthroplastyA methodological study using DEXA , Acta Orthopaedica Scandinavica, 74:6, 677-682, DOI: 10.1080/00016470310018199

To link to this article: https://doi.org/10.1080/00016470310018199

Published online: 08 Jul 2009.

The precision and influence of rotation for measurements of bone mineral density of the distal femur following total knee arthroplasty

A methodological study using DEXA

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Submitted 02-11-20. Accepted 03-05-07

ABSTRACT We evaluated the feasibility of DEXA (Norland XR-26 mark II) for quantitative measurements of bone mineral density (BMD) in the lateral plane of the distal femur after total knee arthroplasty (TKA). BMD was measured in 5–6 regions of interest (ROI) in close relation to the femoral component. In an in vitro study using 3 different distal femur phantoms, we found that the precision was affected by rotation of the distal femur. When BMD measurements were repeated within a range of motion of 40°, 20°, and 0°, the coefficient of variation (CV) was approximately 15%, 10%, and 0.6%, respectively. We found that the use of bone cement for implant fixation had no effect on the level of BMD. Double measurements performed in 28 patients gave average CV values of 3.3%, 3.0%, and 2.6% for the uncemented Duracon, and Interax femoral components and the cemented AGC components, respectively. Our in vivo average CV measurements of BMD of the distal femur after TKA were on a level, suitable for repeated BMD measurements in prospective studies, wich evaluate adaptive bone remodeling of the distal femur after cemented and uncemented TKA.

■

Bone loss in the anterior distal femur after total knee arthroplasty (TKA) has been observed in radiographic studies (Cameron and Cameron 1987, Mintzer et al. 1990). Quantitative densitometric measurements of bone mineral density (BMD), using dual photon absorptiometry (DPA) (Petersen et al. 1995, 1996) or dual energy X-ray absorptiometry (DEXA) (Liu et al. 1995, Karbowski et al. 1999, Spittlehouse et al. 1999, Van Loon et al. 2001), have shown a decrease of about 15–40% in BMD of the distal femur during the first 6–12 months after TKA. Robertson et al. (1994) showed that the DEXA technique could be used for accurate measurements of bone mineral of the distal femur even in the presence of metal within the scanned area. The number of reports including methodological studies evaluating the precision of DEXA for measurements of BMD in the distal femur after TKA is increasing, but most of them have not evaluated the effect of rotation of the distal femur on the precision error (Robertson et al. 1994, Liu et al. 1995, Trevisan et al. 1998, Spittlehouse et al. 1999, Soininvaara et al. 2000, Van Loon et al. 2001).

We performed a methodological evaluation (both phantom and in vivo studies) of the DEXA technique for BMD measurements of the distal femur in patients operated on after a TKA. We tested cemented and uncemented implants and evaluated the effect of various degrees of rotation of the distal femur on the precision error.

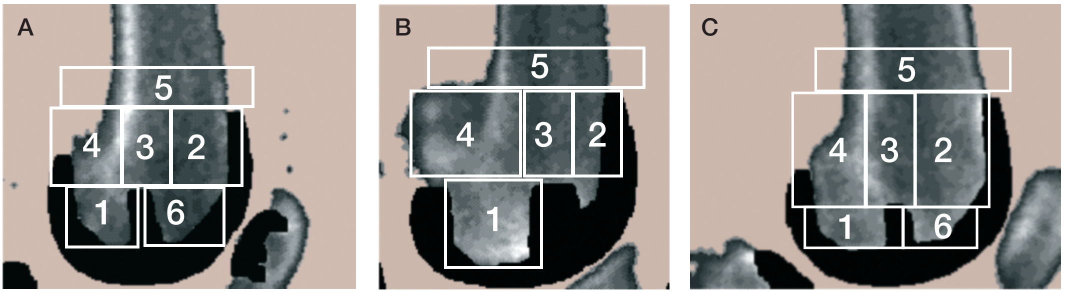

Figure 1. Scan plots showing the distal femur with the Duracon (A), Interax (B), and AGC (C) knee prostheses implanted. ROIs selected for measurements of BMD are shown.

Material and methods

Scanning technique

We measured BMD (g/cm^2) in the distal femur with DEXA, using a scanner (Norland XR-26 mark II, Norland Corp., WI, USA) that has been described in detail elsewhere (Gehrchen et al. 1995, Gehrchen 1999). The scans were done with a pixel size of 0.5 mm × 0.5 mm and a scan speed of 45 mm/second, using the flexible research scan option which permits exclusion of orthopedic implants by disabling high density pixels; the adjacent 4 pixels around a pixel with a BMD value above 3.75 g/cm^2 were considered metal and thus excluded from the calculation of BMD. Each scan was performed in the mediolateral plane of the distal femur with the scan lines perpendicular to the longitudinal axis of the bone thus moving step by step in a cranial-caudal direction.

Every day before the first measurements we calibrated the scanner with a 77-step calibration standard, according to the manufacturer's recommendations. The long-term precision, expressed as the coefficient of variation (CV) assessed from several measurements on a lumbar spine phantom performed after each calibration during 1 year, was below 0.5% for measurements of BMD.

Implants

We examined 3 chrome-cobalt alloy femoral components currently in use for routine TKA. 1) The Duracon femoral component (Stryker Howmedica) has a small pore size, porous-coated ingrowth surface designed for uncemented fixation. The implant has two small fixation pegs designed to penetrate centrally into the most distal part of the medial and lateral femoral condyles. 2) The Interax femoral component (Stryker Howmedica) has an uncoated large pore size, cast mesh ingrowth surface designed for uncemented fixation. It has only one relatively large fixation peg located anteriorly. 3) The AGC femoral component (Biomet Inc.), with a surface designed for cemented fixation has two small fixation pegs located in a way very similar to that of the Duracon prosthesis.

We selected on the computerized DEXA scan plots of the Duracon and AGC implants 6 regions of interest (ROI) in the distal femur for measurements of BMD. However, because of the design of the Interax prosthesis only 5 ROI were used for the measurements of BMD when we analyzed the scans of knees with this prosthesis (Figure 1).

In vitro study

We used 3 human dry femoral bones. In our operating room, employing the original instruments to make optimal bone cuts, the 3 femoral components were implanted in each femur, thereby creating 3 phantoms. Initially, all 3 components were fixed without bone cement. After the planned DEXA scans were completed, the AGC prosthesis was removed and fixed again to the same femoral bone with bone cement (Palacos R-40 cum Gentamicin, Schering Plough). Then the scans were repeated for the femur with the AGC prosthesis.

All in vitro measurements were done using a clamp set-up designed to keep the phantom in a correct position during scanning. To ensure correct rotation between each scan, a perspex device was used. The phantom was rotated around the center of the perspex device and, from this device, we measured the degree of rotation with a protractor (Figure 2). The phantoms were scanned once at every 5 degrees of rotation from 20 degrees

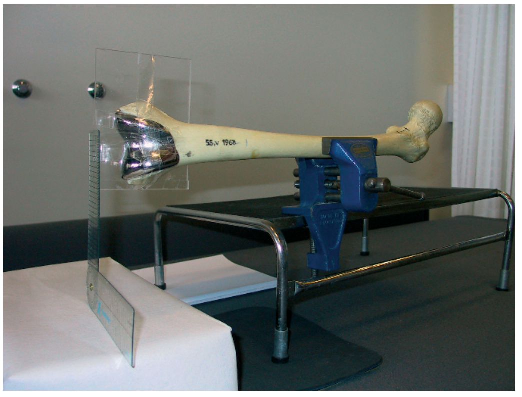

Figure 2. The clamp set-up designed to keep the phantom in an accurate position during scanning.

Figure 3. The scans were performed in the medio-lateral plane with the knee in 45 degrees flexion in lock-in position. All patients were scanned without slacks.

of inward to 20 degrees of outward rotation. At 0 degrees (medial-lateral plane), the phantoms were scanned three times. We made only 3 measurements of the femur with the AGC femoral component without bone cement at 0 degrees, and not at different degrees of rotation. BMD (g/cm^2), BMC (g) and the scanned area (cm^2) of bone were recorded at each scan sequence, using the ROI mentioned above, but only the results for BMD are given.

In vivo study

28 patients (23 women) having a mean age of 68 (25–83) years were included in the study. They had undergone insertion of a TKA because of osteoarthrosis 14 (2–35) months before and had received an uncemented TKA with the Duracon (n = 10) or Interax (n = 8) prosthesis or cemented (Palacos R-40 cum Gentamicin, Schering Plough) TKA with the AGC prosthesis (n = 10). All knees were scanned twice on the same day with complete repositioning between scans. No fixation devices were used, but the patients were placed in a "lock-in position" before the scan was performed (Figure 3). Initially a scout scan was done to ensure that the appropriate part of the distal femur was included in the scanned area and that the scan axis was parallel to the femoral shaft. If the first scan was not in an exact lateral projection of the prosthesis, it was restarted after adjusting the rotation of the limb. If it was very difficult to obtain a correct lateral projection of the prosthesis, adjustments were made during a scan and when the correct projection was achieved, the scan was restarted. The in vivo study was a part of 2 studies ((KF) 01-217/99 and (KF) 01-261/99) both approved by the local ethics committee of Copenhagen and Frederiksberg.

Statistics

The precision in vivo and in vitro estimated from double and triple measurements respectively, were evaluated by calculating the coefficient of variation (CV = SD/mean × 100%). The effect of rotation on BMD measurements was calculated as the CV for repeated measurements performed at various degrees of rotation. Mean values are presented together with range and when appropriate, the 95% confidence limits (95% CL) were calculated.

Results

In vitro study

The mean precision of all ROI was significantly affected by rotation of the distal femur, as shown by a mean CV of 12.3–14.9% and 7.3–10.1% when measurements were made within a range of rotation of 40° and 20°, respectively. With all types of implants, ROI 5 was only slightly influenced by rotation (CV of 3.2–5.4%). When triple measurements were made with the distal femur in neutral position the CV was only 0.5–0.6% (Table 1).

In the case of triple measurements performed on the same phantom at 0° of rotation, we found an average CV of 0.5% for both cemented and uncemented fixation of the prosthesis. The average CV

Table 1. In vitro study. Effect of rotation on CV (%)

Rotation	Duracon (uncemented) 20°/20° (n 9)	10°/10° (n 5)	0° (n 3)	Interax (uncemented) 20°/20° (n 9)	10°/10° (n 5)	0° (n 3)	AGC (cemented) 20°/20° (n 9)	10°/10° (n 5)	0° (n 3)
$CV_{ROI\ 1}$	22.0	10.8	0.4	4.8	3.7	0.9	15.6	7.2	0.5
$CV_{ROI\ 2}$	9.0	6.4	0.1	6.7	2.8	0.5	14.6	13.8	0.3
$CV_{ROI\ 3}$	15.8	14.7	1.5	12.0	14.2	0.4	4.0	4.0	0.2
$CV_{ROI\ 4}$	20.7	13.7	0.4	33.0	25.0	0.7	6.3	5.1	0.5
$CV_{ROI\ 5}$	5.4	3.2	0.4	5.4	4.8	0.6	4.1	3.2	0.3
$CV_{ROI\ 6}$	16.9	7.9	0.9	–	–	–	45.1	10.5	1.5
Mean CV (All ROIs)	14.9	9.4	0.6	12.3	10.1	0.6	13.2	7.3	0.5

The CV (%) was calculated for measurements of BMD in different ROIs of the distal femur. The phantoms were scanned once at every 5° of rotation from 20° of inward to 20° (20°/20°) of outward rotation (n 9) or from 10° of inward to 10° (10°/10°) of outward rotation (n 5) and, in the exact lateral plane (0°) measurements were repeated three times (n 3).

Table 2. In vitro study. Effect of bone cement on CV (%)

AGC [a] Rotation Measurements	Cem 0° triple	Unc 0° triple	Cem/Unc 0° 3 double
$CV_{ROI\ 1}$	0.5	0.6	1.5
$CV_{ROI\ 2}$	0.3	0.2	0.1
$CV_{ROI\ 3}$	0.2	0.5	0.5
$CV_{ROI\ 4}$	0.5	0.3	0.1
$CV_{ROI\ 5}$	0.3	0.4	0.5
$CV_{ROI\ 6}$	1.5	1.0	1.4
Mean CV (All ROIs)	0.5	0.5	0.7

[a] Cem – cemented; Unc – uncemented.
The CV (%) for measurements of BMD in different ROIs of the distal femur was calculated from DEXA scans repeated three times (n 3) in the exact lateral plane (0°) for cemented and uncemented fixation of the femoral component. Problems with accuracy when scanning cemented femoral components were evaluated by calculating the average CV from 3 double measurements (one BMD value for cemented and one value for uncemented fixation).

of 3 double measurements (pairs of uncemented and cemented implant fixation) showed that the bone cement did not contribute significantly to the level of BMD measured in cemented TKA (Table 2).

In vivo study

The precision was estimated from double measurements in 28 patients and gave average CV values of 3.3%, 3.0%, and 2.6% for the Duracon, Interax, and AGC femoral components, respectively. The best precision was obtained in ROI 5 with CV 1.0–2.2% and, in general, the poorest precision was seen in ROI 3 with CV of 4.1–6.0% (Table 3).

Discussion

Our findings confirm that rotation of the limb can affect the precision error greatly when using

Table 3. Clinical reproducibility CV (%). The mean (range) [95%-CL] CV (%) for double measurements of BMD in different ROIs of the distal femur was calculated from lateral DEXA scans performed in n patients. Various femoral components and fixation modes were tested.

Double measurements	Duracon (uncemented) n 10			Interax (uncemented) n 8			AGC (cemented) n 10		
$CV_{ROI\ 1}$	2.8	(0.4–5.4)	[1.5;4.2]	1.9	(0.4–6.5)	[0.2;3.6]	3.2	(0.8–7.4)	[1.6;4.8]
$CV_{ROI\ 2}$	1.5	(0.1–4.0)	[0.6;2.4]	2.8	(0.5–8.2)	[0.7;4.9]	2.3	(0.1–7.7)	[0.7;3.9]
$CV_{ROI\ 3}$	4.8	(0.8–9.5)	[2.5;7.1]	6.0	(0.7–18.0)	[0.9;9.3]	4.1	(0.3–13.0)	[1.2;7.1]
$CV_{ROI\ 4}$	5.2	(1.1–13.6)	[2.0;8.3]	2.5	(0.1–5.4)	[0.7;4.2]	3.5	(0.1–13.9)	[0.1;7.2]
$CV_{ROI\ 5}$	1.4	(0.4–2.4)	[0.8;2.2]	2.2	(0.3–10.0)	[–0.2;4.5]	1.0	(0.2–3.5)	[0.3;1.8]
$CV_{ROI\ 6}$	4.2	(0.1–16.0)	[0.9;7.6]	–			1.8	(0.3–4.2)	[0.8;2.8]
$CV_{all\ ROIs}$	3.3	(1.4–4.8)	[1.6;5.1]	3.0	(1.9–6.0)	[1.0;5.2]	2.6	(1.0–1.8)	[1.3;4.3]

DEXA to measure BMD of the distal femur after TKA. Several authors have shown that the same problem exists for DEXA measurements of the hip with (Kiratli et al. 1992, Gehrchen et al. 1995, Mortimer et al. 1996) and without (Girard et al. 1994, Goh et al. 1995) a hip stem implanted in the bone. To our knowledge no previous studies have evaluated the effect of rotation on the precision error when making DEXA measurements of the distal femur in patients with TKA. However, Spittlehouse et al. (1999) performed double DEXA measurements in the lateral projection of the distal femur in patients with an uncemented titanium Miller-Galante TKA and found an unacceptably high precision error with a CV above 20%. Using a specially-designed brace, the CV was significantly reduced to 3.9–5.7% and it was concluded that the poor precision obtained without the brace was due to considerable variation in positioning of the knee.

In our study, the method of fixation had no effect on the precision. In our phantom studies with no rotation allowed, the CV of 0.5–0.6% was about the same as obtained with repeated measurements on a spine phantom designed for checking the calibration of the scanner, thus the variability must therefore be due to the technique itself. Our in vivo average CV of 2.6–3.3% for measurements of BMD of the distal femur after TKA was about the same as in a DPA (Petersen et al. 1996) and most DEXA studies (Liu et al. 1995, Trevisan et al. 1998, Soininvaara et al. 2000).

We obtained the best precision for BMD measurements in ROI 5, which was also the region least affected by rotation. Soininvaara et al. (2000) found that the most accurate measurements were made in a ROI very similar to our ROI 5 located above the prosthesis in the diaphyseal bone of the distal femoral shaft. Methodological evaluations of BMD measurements of the proximal femur after total hip arthroplasty by Gehrchen et al. (1995) also showed that the ROI least influenced by rotation was the ROI including the diaphyseal bone just below the femoral stem.

In prospective studies with repeated measurements performed in the same individuals a low precision error is important. When follow-ups of changes in an individual are performed, a change between two measurements of $2 \times CV\% \times \sqrt{2}$ is necessary before the difference can be regarded as statistically significant. When changes in a group of patients are studied the CV is important for the number of participants needed to detect a significant change with an appropriate statistical power (Nilas et al. 1988). Our in vivo average CV of 2.6–3.3% for measurements of BMD of the distal femur after TKA is suitable for repeated measurements of BMD in prospective studies evaluating adaptive bone remodeling of the distal femur after cemented and uncemented TKA.

No competing interests declared.

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