Decrease in bone mineral density and muscle mass after femoral neck fracture

A quantitative computed tomography study in 25 patients

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We performed a prospective, longitudinal, quantitative computed tomography (QCT) study of bone mineral density (BMD), cortical bone volume, bone mass and muscle volume in 25 patients who were operated on with osteosynthesis because of a displaced femoral neck fracture. Both legs were scanned within 3 days after the fracture, and 3 and 6 months after the operation. The measurements were performed by a computer tomograph equipped for bone mineral densitometry.

We found some side differences among the patients at the time of fracture, but none of the differences was statistically significant. After 6 months, we found reductions in BMD in the distal femur and proximal tibia on the fractured side of 11% and 19%, respectively, as well as a reduction in BMD of 7% in the proximal tibia on the uninjured side. We found no changes in cortical bone mass, either on the fractured femur or on the uninjured femur. The muscles of the thigh showed a loss of 9% on the fractured side, but a gain of 12% on the uninjured side.

The findings of a bone loss in the distal femur and proximal tibia of the fractured leg and in the proximal tibia of the healthy leg, but no cortical bone loss in the middle femur on any side 6 months after the fracture, indicate that the cancellous bone is more sensitive to osteopenia. Moreover, this bone loss is interpreted as mainly a posttraumatic effect, since we also found a decrease in bone mineral on the uninjured side, despite a gain in muscle volume on that side, an overuse which was not sufficient to counteract the posttraumatic effect on the bone of the uninjured side.

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Submitted 96-09-24. Accepted 97-04-29

Low radiographic bone density in patients with a femoral neck fracture was first described by Vose and Lockwood (1965), and later confirmed by others (Chevalley et al. 1991, Duboeuf et al. 1991, Karlsson et al. 1993). However, disuse or immobilization often accompanies the trauma, and it is difficult to distinguish between the osteopenia caused by the disuse and the posttraumatic effect on the bone caused by the fracture and the subsequent operation. Quantitative CT permits determination of linear attenuation coefficients in defined volumes, allowing separation of cortical and cancellous bone. Another advantage with the QCT method is the ability to measure soft tissue volumes; thus it is possible to follow the results of disuse and the impaired mobility after the fracture. We investigated whether the bone loss after a displaced femoral neck fracture is posttraumatic in origin or merely an effect of disuse.

Patients and methods

A consecutive series of 25 patients with a fresh displaced femoral neck fracture, Garden stage III–IV, was studied prospectively. There were 20 women and 5 men with a median age of 82 (66–91) years. The study started May 1992 and lasted until May 1996. The inclusion criteria were: age over 65 years, patients admitted from their own homes, and with no previous disabilities of the legs. They had had no previous hormonal therapy, other medications or illnesses known to affect bone metabolism. The patients were operated on within 2 days of the fracture with closed reduction and osteosynthesis using 2 parallel Olmed screws (Rehnberg and Olerud 1989). All patients were mobilized on the day after the operation, under the supervision of a physiotherapist, with full weight-bearing on the operated leg.

The cortical BMD, the cortical bone volume, and the transverse area of the thigh muscle were measured

Figure 1. Localization scan. "ScoutView™"

in the middle femur, and the average (cortical and cancellous) BMD in the distal femur and proximal tibia. The total bone mass of the cortical bone in the middle femur was calculated as the average BMD multiplied by the bone volume at that location. Both legs were scanned within 3 days after the fracture. The same regions were scanned 3 and 6 months after the operation.

Of the 25 patients, 1 died after the operation. Another patient developed a rapid onset of dementia postoperatively, and 2 patients refused to participate in the measurements after the operation. 1 patient's 6-month measurement was excluded due to a technical error. In addition to these drop-offs, 1 patient developed an early healing complication, this patient underwent a reoperation with a total hip arthroplasty between the 2 postoperative measurements. This left 16 patients for the measurement at 3 months and 19 patients for the measurement at 6 months.

Evaluation of bone and muscle

The BMD and the volumes were measured with a computer tomograph (General Electric Pace Plus™, Milwaukee, Wisconsin, USA) equipped for bone mineral densitometry. Thresholding was used to segment an image into regions of interest on the basis of gray level (Hounsfield units); this facilitates determination of the transverse muscle area.

Scanning procedures

The patient was scanned while lying on a reference phantom containing calibrated densities of calcium hydroxyapatite (150, 75 and 0 mg/cm^3) in a flexible water-equivalent plastic. A localization scan (ScoutView™) of the distal femur and the knee joint was performed (Figure 1). The femurs were scanned in the diaphyses 20 cm and 5 cm proximal to the distal limit of the lateral femoral condyle, and the tibiae 2 cm distal to this reference point. If there was a difference in leg length, due to compression of the femoral neck after the fracture, this localization scan facilitated the scanning at the proper locations.

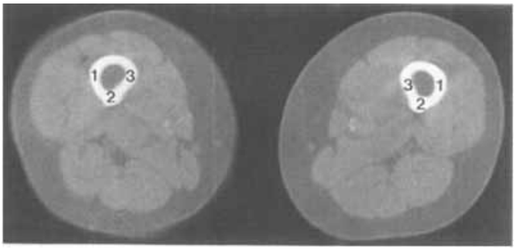

Figure 2. Scan through middle femur.

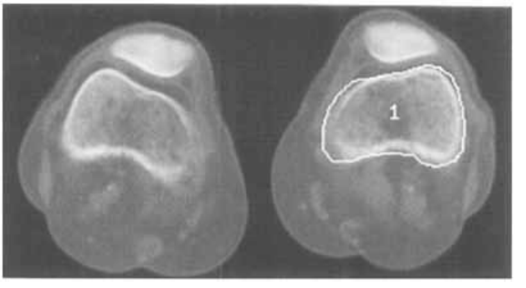

Figure 3. Scan through distal femur.

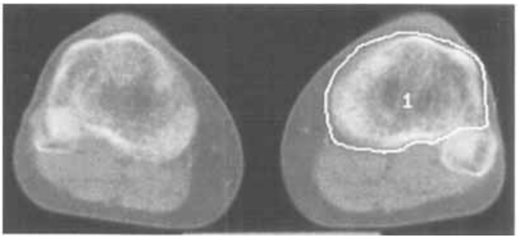

Figure 4. Scan through proximal tibia.

BMD measurements

3 circular regions (0.04 cm^2) of interest were chosen in the cortical bone (lateral, posterior, and medial) in the proximal femoral scan (Figure 2). The mean value of these 3 circular regions was estimated as the BMD at that location. From the distal femoral scan, we made an outline of the cortex of the femur with exclusion of the patella (Figure 3). From the proximal tibial scan, an outline of the complete tibia was made (Figure 4). Thus, the scans of the 2 distal regions included all the cortical and cancellous bone, except the patella. This integration of the cortical and cancellous BMD was done to overcome the large local variability in BMD of the cancellous bone in these locations.

Bone mass (g in a 1-cm thick slice), bone volume (cm^3), bone mineral density (BMD; mg x cm^{-3}) and muscle volume of the middle femur, and BMD of the distal femur and proximal tibia in 25 patients with a femoral neck fracture. Mean values (95% confidence intervals; 95%CI) are given. Bone mass is calculated as BMD x bone volume. Difference in mean % between legs at time of fracture and longitudinal differences in both legs. – sign indicates bone loss

	At time of fracture n 25			3 months n 16				6 months n 19			
	OP	CO	diff (%)	OP	diff (%)	CO	diff (%)	OP	diff (%)	CO	diff (%)
Middle femur											
Bone mass	6.53	6.78	–4	6.85	2	7.21	4	6.49	–1	6.85	0
95%CI	5.88–7.18	6.26–7.30		5.72–7.97		6.26–8.16		5.60–7.37		6.14–7.55	
Bone volume	6.08	6.13	–2	6.34	2	6.33	1	6.24	1	6.18	0
95%CI	5.29–6.87	5.71–6.55		5.24–7.44		5.63–7.02		5.26–7.22		5.61–6.75	
BMD	1087	1105	–2	1084	1	1134	3	1047	–2	1105	0
95%CI	1050–1124	1082–1127		1032–1136		1101–1166		993–1102		1075–1136	
Muscle volume	54	51	5	48	–16 [a]	59	6	49	–9 [a]	59	12 [a]
95%CI	48–60	46–57		42–55		51–66		43–55		52–67	
Distal femur											
BMD	149	155	–2	137	–6	151	–2	135	–11 [a]	154	–2
95%CI	132–166	136–173		117–157		135–168		116–153		135–173	
Proximal tibia											
BMD	72	77	–6	55	–22 [a]	67	–9 [a]	62	–19 [a]	76	–7 [a]
95%CI	62–83	66–88		42–68		53–80		48–76		61–91	

OP = operated leg. CO = control leg.
[a] $p < 0.05$.

Volume measurements

The volumes of the cortical bone in the middle femur and the thigh muscle were measured with thresholding from the proximal femoral scan. Hounsfield units (HU) for lean body tissue are well below 100; fat has a negative number and water is zero. HU for all normal musculature in the human body has been found to be between 32 and 89 (Termote et al. 1980). In an earlier study (Adolphson et al. 1993), we have found that dense bovine cortical bone has approximately 1300 HU, this HU number was verified when the cortical regions in the femur of the patients in this study were measured (822–1213 HU). Therefore, window intervals between 10-100 HU (muscle) and 101–2000 HU (cortical bone) were chosen to measure the volumes.

To check the accuracy of the method, we have earlier measured the cortical BMD in bovine femoral diaphyses, which were subsequently ashed (Adolphson et al. 1993). The mean accuracy (SD) was 0.3% (4.4).

To check the precision (reliability) of the method, we made 2 identical measurements in 5 patients, with complete reposition of the patient and the CT scanner in an earlier study (Neander et al. 1996). The reliability was found to be 98% for BMD and cortical bone volume of the middle femur, 97% for muscle volume of the middle femur, 96% and 95% for BMD of the distal femur and the proximal tibia, respectively.

Statistics

The Student's t-test for paired observations was used to analyze the difference between the legs at the fracture incident, and also the changes with time in each measuring site. The statistical analyses were performed on a Power Macintosh® 7500/100 computer with the statistical package StatView SE + Graphics™. Differences were considered significant at p-values < 0.05.

Results (Table)

We found some side differences among the patients at the time of fracture, but none of the differences in the bone mass was statistically significant. After the fracture, we found decreases in BMD of the distal femur and proximal tibia on the fractured side which, at 6 months, were 11% and 19%, respectively. The BMD in the proximal tibia on the uninjured side showed a smaller decrease of 7% after 6 months, the loss in BMD at that location was statistically significant after only 3 months. We found no changes in cortical bone mass in the middle femur on any side after the fracture. At 6 months, the thigh muscles showed a wasting of 9% on the fractured side and a gain of 12% on the uninjured side.

Discussion

Earlier investigators have reported development of bone loss after operative treatment of femoral fractures (Finsen et al. 1988, Bråten et al. 1992, Karlsson et al. 1993). Karlsson (1995) found that patients with hip fractures lose bone mass in most skeletal parts after the fracture, the bone loss being most distinct in the fractured hip. He also found that the patients lost muscle mass during the postoperative period, and concluded that the changes are caused by postoperative immobilization and postoperative osteopenia triggered by the fracture incident.

The method used in this study, QCT, implemented by Rüegsegger et al. (1973) and further developed by Genant et al. (1987), has several advantages compared to other bone assessment methods. It measures the true BMD (g/cm^3) and not as single-photon absorptiometry or dual-energy X-ray absorptiometry (DEXA), the areal BMD (g/cm^2). Moreover, the ScoutView™ facilitates repeated measurements of the same site, and the cortical and cancellous bone can be assessed separately. The precision of QCT has been found to be 1.5–4% (Genant et al. 1987, SBU 1995). In the equipment used in this study, we have found about the same precision (2–5%).

At fracture, we detected no side difference in bone volume or BMD at any location (Table). This is in agreement with Karlsson et al. (1993), who noted no side difference in BMD of the femoral head and trochanteric region directly after a femoral neck fracture.

After 6 months, we found a mean reduction in BMD in the distal femur of 11% and in the proximal tibia of 19% on the injured side. This corresponds well to an earlier cross-sectional study after osteosynthesis versus primary total hip arthroplasty for a displaced femoral neck fracture (Neander et al. 1996), where, after 18 months, we found, in the bone of the distal femur and proximal tibia, a 10% and 19% relative loss, respectively, in BMD on the fractured side, compared to the uninjured side. Karlsson et al. (1993), using DEXA, found a bone loss of 7% in the lower extremities after a hip fracture; they reported no separate side findings at that level, but noted a more marked osteopenia of the cancellous bone in the proximal femur on the fractured side compared to the uninjured side (9% versus 4%) during the first year. In addition, Bråten et al. (1992) reported, after locked intramedullary nailing of femoral shaft fractures, a relative reduction in bone mineral of 5% in the distal femur and 17% in the proximal tibia on the fractured side, compared to the uninjured side. This also agrees with a recent study by Bryan et al. (1996) who, after 10 years, found a bone loss of 16% in the proximal tibia distal to a unilateral well functioning total hip arthroplasty.

We observed no changes in cortical bone mass, either in the BMD or in the bone volume of the middle femur, on any side after 6 months. This finding indicates that the cortical bone is less sensitive to different forms of osteopenia. The cancellous bone, because of its high surface-to-volume ratio, has a presumed turnover rate about 8 times that of cortical bone and is highly responsive to various stimuli (Falch et al. 1985, Genant et al. 1987, Åkesson 1995).

After 6 months, the thigh muscles on the fractured side showed atrophy (–9%) and on the uninjured side, hypertrophy (+12%). In spite of this increase in muscle volume on the uninjured side, we found a decrease in BMD of the proximal tibia on that side after only 3 months. Wolff (1892) pointed out how mechanical stress acts on the size, shape and trabecular orientation of bone, i.e., form follows function. Thus, an increase in weight bearing could induce an increase in BMD on the uninjured leg. An overuse of the uninjured leg, causing an increase in BMD, has been described in an experimental unilateral study of arthritis in the dog (Søballe et al. 1991). However, in spite of the overuse, expressed as an increase in muscle volume on the uninjured leg, we found a bone loss on that side. An explanation could be that the osteopenic bone cannot adapt to the increased load on the uninjured side after the fracture.

The loss in BMD of the lower extremities after a femoral neck fracture is thought to be caused by the trauma. The bone loss in the uninjured leg, which was not subjected to disuse or immobilization, must be ascribed to a systemic posttraumatic effect. Systemic effects on the bone after trauma have been described by Westlin (1974) who, after a fracture of the wrist, found a bone loss of the uninjured forearm.

Acknowledgements

The study was kindly supported by grants from the Eva and Oscar Ahrén Foundation, the Lars Hierta Memorial Foundation, the O E and Edla Johansson Foundation, the Swedish Insurance Company EIR 50-year's Foundation, the Axel and Margaret Ax:son Johnson Foundation, the Anders Otto Swärd Foundation and the Åke Wiberg Foundation, Sweden.

References

Adolphson P, von Sivers K, Dalén N, Jonsson U, Dahlborn M. Bone and muscle mass after hip arthroplasty. A quantitative computed tomography study in 20 arthrosis cases. Acta Orthop Scand 1993; 64 (2): 181-4.

Åkesson K. Fracture and biochemical markers of bone metabolism. Thesis, University of Lund, Sweden 1995: 5.

Bryan J M, Sumner D R, Hurwitz D E, Tompkins G S, Andriacchi T P, Galante J O. Altered load history affects periprosthetic bone loss following cementless total hip arthroplasty. J Orthop Res 1996; 14 (5): 762-8.

Bråten M, Nordby A, Terjesen T, Rossvoll I. Bone loss after locked intramedullary nailing. Computed tomography of the femur and tibia in 10 cases. Acta Orthop Scand 1992; 63 (3): 310-4.

Chevalley T, Rizzoli R, Nydegger V, Slosman D, Tkatch L, Rapin C, Vasey H, Bonjour G P. Preferential low bone mineral density of the femoral neck in patients with a recent fracture of the proximal femur. Osteoporosis Int 1991; 1: 147-54.

Duboeuf F, Braillon P, Chapuy M C, Haond P, Hardouin C, Meary M F, Delmas P D, Meunier P J. Bone mineral density of the hip measured with dual energy X-ray absorptiometry in normal elderly women and in patients with hip fractures. Osteoporosis Int 1991; 1: 242-9.

Falch J A, Ilebekk A, Slungaard U. Epidemiology of hip fractures in Norway. Acta Orthop Scand 1985; 56 (1): 12-6.

Finsen V, Svenningsen S, Harnes O B, Nesse O, Benum P. Osteopenia after plated and nailed femoral shaft fractures. J Orthop Trauma 1988; 2 (1): 13-7.

Genant H K, Block J E, Steiger P, Glüer C-C. Quantitative computed tomography in the assessment of osteoporosis. In: Osteoporosis Update 1987 (Ed. Genant H K). Radiology Research and Education Foundation. San Francisco, USA 1987; 8: 49-71.

Karlsson M. Bone mass, fracture and physical activity. Thesis, University of Lund, Sweden 1995: 21-2.

Karlsson M K, Johnell O, Nilsson B E, Sernbo I, Obrant K J. Bone mineral mass in hip fracture patients. Bone 1993; 14: 161-5.

Neander G, Adolphson P, von Sivers K, Dahlborn M, Dalén N. Bone and muscle mass after femoral neck fracture. A controlled quantitative CT study of osteosynthesis versus primary total hip arthroplasty. Arch Orthop Trauma Surg 1997. In press.

Rehnberg L, Olerud C. Subchondral screw fixation for femoral neck fractures. J Bone Joint Surg 1989; 71B (2): 178-80.

Rüegsegger P, Niederer P, Anliker M. A method for the determination of the compact area and the mean absorption density of human bones. In: International Conference on Bone Mineral Measurements (Ed. Mazess R B). National Institute of Arthritis, Metabolism and Digestive Diseases. Bethesda, Maryland, USA 1973: 30.

SBU 1995. Measurements of bone density. The Swedish Council on Technology Assessment in Health Care. SBU, Stockholm, Sweden 1995.

Søballe K, Pedersen C M, Odgaard A, Juhl G I, Hansen E S, B-Rasmussen H, Hvid I, Bünger C. Physical bone changes in Carragheenin-induced arthritis evaluated by quantitative computed tomography. Skeletal Radiology 1991; 20: 345-52.

Termote J-L, Baert A, Crolla D, Palmers Y, Bulcke J A. Computed tomography of the normal and pathologic muscular systems. Radiology 1980; 137: 439-44.

Vose G P, Lockwood R M. Femoral neck fracturing - its relationship to radiographic bone density. J Gerontol 1965; 20: 300-5.

Westlin N E. Loss of bone mineral after Colles´ fracture. Clin Orthop 1974; 102: 194-9.

Wolff J. Das Gesetz der Transformationen der Knochen. Hirschwalk, Berlin 1892.