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THE SUBCHONDRAL BONE OF THE PROXIMAL TIBIAL EPIPHYSIS IN OSTEOARTHRITIS OF THE KNEE

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The trabecular bone of the proximal end of the tibia was assessed as an endoprosthesis-bearing structure. The mass and mineral content as well as the activity of subchondral trabecular bone were determined in osteoarthritic knees with varus or valgus deformity.

Bone specimens were taken from the lateral condyle, the medial condyle, and centrally from the intercondylar area of seven varus and four valgus knees. The percentage volume of trabecular bone was determined by histomorphometry. On an additional nine knees, five with varus and four with valgus deformity, as well as ten knees from a normal autopsy material, photon absorptiometric determination of the mineral content of the same areas was performed. On average, the loaded condyle had twice the percentage volume of trabecular bone, and accordingly twice the mineral content, of the unloaded condyle. It was remarkable that the mineral content of the latter was of the same order as the condyles of the normal material.

Key words: bone in osteoarthritis; knee arthroplasty; knee osteoarthritis; osteoarthritis

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Even at a very early stage of osteoarthritis in the knee, scanning reveals an increased accumulation of radionuclide tracer in the subchondral trabecular bone (Anderson et al. 1967, Christensen et al. 1980). At a more advanced stage of the disease course this structure is morphologically characterized by sclerosis extending a few millimetres below the joint surface, but then changing to more normal-looking trabecular bone (Havdrup et al. 1976). The dynamic and structural changes manifest themselves in the mechanical properties of the bone. In experimental osteoarthritis of the knee a reduction in bony strength has been found at an early stage (Miyanaga 1979). and the immediate juxta-articular subchondral bone has proved to be less hard in osteoarthritic than in normal joints (Lereim et al. 1974).

In advanced osteoarthritis of the knee, weight-bearing in the proximal tibia is often characterized by progressing varus or valgus deformity. Even when moderate, such deformities cause a marked displacement of the weight-bearing axis (Maquet 1976, Johnson et al. 1980). The subchondral bone on the convex aspect is exposed to increased load-induced stimulus, while the contralateral bone is comparatively unloaded (Figure 1a). Consequently, the direction of the trabeculae alters, in accordance with Wolff's law (Wolff 1892), due to the altered loading. Moreover,

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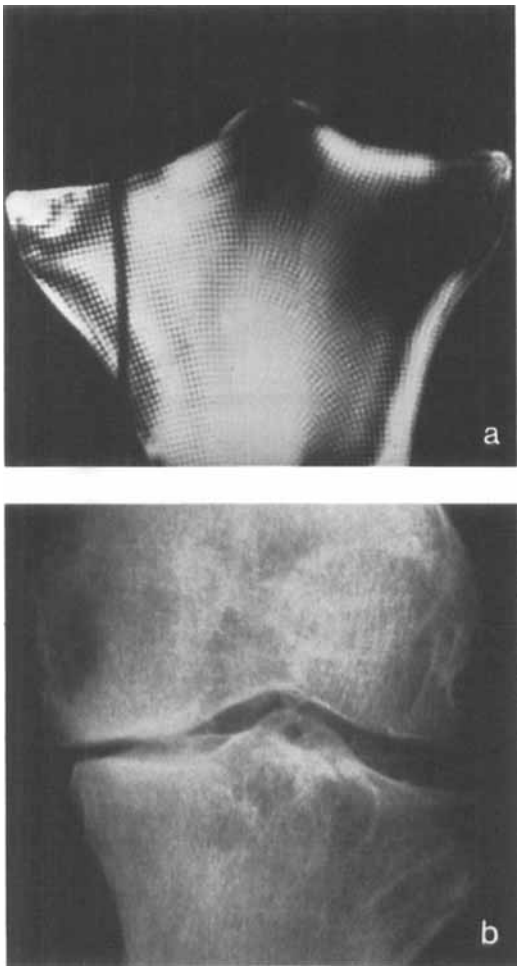

Figure 1. A photoelastic study of a tibia with asymmetric loading on the joint surface shows the stress trajectories centred in the loaded condyle, whereas a repulsive, singular point may be seen in the contralateral condyle (a). In conformity with this, X-rays show a condensed bony structure in the loaded tibial condyle and a relative thinning of the structure in the unloaded condyle (b).

some resorption of bone occurs in the unloaded condyle and bone formation is found in the loaded condyle (Figure 1b). In the intermediate stage of this re-structuring process the trabecular bone changes to mechanically rather inferior woven bone, characterized by a more disorganized lamellar and trabecular structure.

In modern knee replacement, using the non-constrained or semi-constrained prosthesis, the endoprosthesis is placed, after resection of the joint surface, on trabecular bone whose weight-bearing ability is then decisive to stability. Because of this, there is a risk that some of the changes in bone strength resulting from the stage of the disease, and in particular the varus or valgus deformity, may reduce the weight-bearing ability of the trabecular bone to below the critical level required for supporting an endoprosthesis.

From experimental *in vitro* studies and from clinical practice, it is known that the critical structure following knee replacement is the tibial resection surface, which has very little reserve strength. And it is, in fact, the tibial endoprosthesis which has a tendency to loosen (Bargren et al. 1978, Walker et al. 1980). The present study, therefore, was designed to determine, especially for the proximal tibia, the mineral content, bone mass and activity in the subchondral trabecular bone in osteoarthritis involving varus or valgus deformity. This was performed in an attempt to create a better basis for assessing the quality of this bone and its suitability as an endoprosthesis-carrying structure.

PATIENTS AND METHODS

Histomorphometry. This part of the study comprised nine women and one man in the age range 57–77 years ($\bar{x}$ = 71 years). All of them had osteoarthritis of the knee with varus or valgus deformity. In one patient biopsy specimens had been taken from both knees, so that the study comprises 11 knees, including seven with varus and four with valgus deformity. The duration of osteoarthritic complaints averaged 10 years, and the degree of deformity (varus or valgus) ranged from 5°–20° ($\bar{x}$ = 10°). All the patients underwent operation for the insertion of a total condylar knee prosthesis. During the course of the operation, and after horizontal resection of the tibial joint surface, tissue specimens were removed with a cylindrical drill from the resection surface in the proximal tibia. In each knee, three specimens were taken from the subchondral trabecular bone: one centrally in the medial condyle, one centrally in the lateral condyle, and one centrally in the intercondylar area. The cylindrical biopsies were 8 mm in diameter and about 20 mm in length. For histomorphometric evaluation, moreover, drill biopsies by the method of Bordier were taken preoperatively from the iliac crest, under the same anaesthesia. Out of the ten biopsies from the iliac crest seven were suitable for histomorphometry and nine for the determination of the osteoid and resorptive surfaces. To avoid shrinkage phenomena, all biopsies were fixed in methanol, em-

bedded undecalcified in methacrylate, and cut into approximately 7 μ sections on a hard-tissue microtome (Jung, model K). After staining, which permitted definite differentiation between mineralized and non-mineralized tissue, the percentage volume of trabecular bone (VTB percent), and the percentage extent of resorptive surfaces (RS percent) and of osteoid surfaces (OS percent) were determined under a light microscope with the use of the point-counting technique. In addition, a general evaluation of the structure of the trabecular bone was performed, particularly to assess the quantity of woven bone.

Bone mineral content (BMC) measured by photon absorptiometry

This part of the study comprised nine women in the age range 59–78 years ($\bar{x}$ = 67). All had osteoarthritis of the knee with varus or valgus deformity. In all of them a biopsy was taken from one knee, so that a total of nine knees are included in the study, five with varus and four with valgus deformities. The duration of their osteoarthritis averaged 15 years, and the degree of varus or valgus deformity ranged from 5°–20° ($\bar{x}$ = 15°). A control material was obtained by taking tissue samples from the knees of persons, without a known history of skeletal or articular disease, brought to the Medico-Legal Institute after sudden death. All the controls were over 30 years of age. Only knees found to be macroscopically normal on dissection were included. The control material comprised 11 knees. The tissue samples for BMC measurement were removed in connection with replacement operations in the same way as for the histomorphometric study. However, no biopsies were taken from the iliac crest. The biopsy specimens were immediately frozen to –18°C. After thawing they were scanned in the longitudinal direction by photon absorptiometry (Cameron et al. 1968) using a Gammatec® osteodensitometer (Nielsen et al. 1980). The bone mineral content (BMC) was expressed in arbitrary units per cm biopsy, then converted to ash weight in mg per cm biopsy, an arbitrary unit being 29.5 mg ash (Nielsen et al. 1980).

The values measured by histomorphometry and photon absorptiometry were statistically analysed by the Mann-Whitney rank sum test.

RESULTS

Table 1 gives the results of the histomorphometric study. The spongious bone iliac crest was in all cases normal for the age concerned. In knees with varus as well as with valgus deformity, the percentage VTB values of the loaded condyle were, on average, about twice those of the unloaded condyle ($P < 0.01$). The values in the intercondylar area were also lower than those of the loaded condyle ($P < 0.01$). As is apparent from Figure 2, all patients had higher percentage VTB values in the loaded condyle; in a few, the values were as much as four times higher than in the other areas. As regards the occurrence of resorptive and osteoid surfaces, there was no quantitative difference between the loaded condyle, the unloaded condyle, and the iliac crest. In all three bony structures the ration between the resorptive and osteoid surfaces was normal.

The general histological evaluation was as follows: the loaded areas, in contrast to the unloaded areas, contained large quantities of woven bone which represents a trabecular structure which is not finally remodelled, i.e. mechanically inferior bone.

Table 1. Variations in volume of trabecular bone, resorptive surfaces and osteoid surfaces in the proximal tibia of seven varus and four valgus knees. Range is given in brackets

Topographic area	Volume of trabecular bone %		Resorptive surfaces %		Osteoid surfaces %	
	Varus knees (7 cases)	Valgus knees (4 cases)	Varus knees (7 cases)	Valgus knees (4 cases)	Varus knees (7 cases)	Valgus knees (4 cases)
Lateral condyle	10.3(6.2–15.1)	20.4(14.1–27.2)	4.8(1.2–10.6)	3.6(1.4–6.4)	25.3(8.5–66.5)	24.6(16.9–42.3)
Intercondylar area	8.7(6.2–10.6)	7.8(6.2–10.8)	4.8(3.1–8.8)	3.4(1.2–4.7)	21.7(15.9–36.5)	24.5(8.0–41.6)
Medial condyle	19.2(12.4–31.4)	8.8(4.0–12.9)	5.1(2.4–8.4)	4.3(0.7–6.3)	19.8(14.3–29.6)	17.8(12.4–24.3)
Iliac crest	14.1(3.8–27.2)		7.1(3.5–12.4)		32.9(15.4–66.0)	

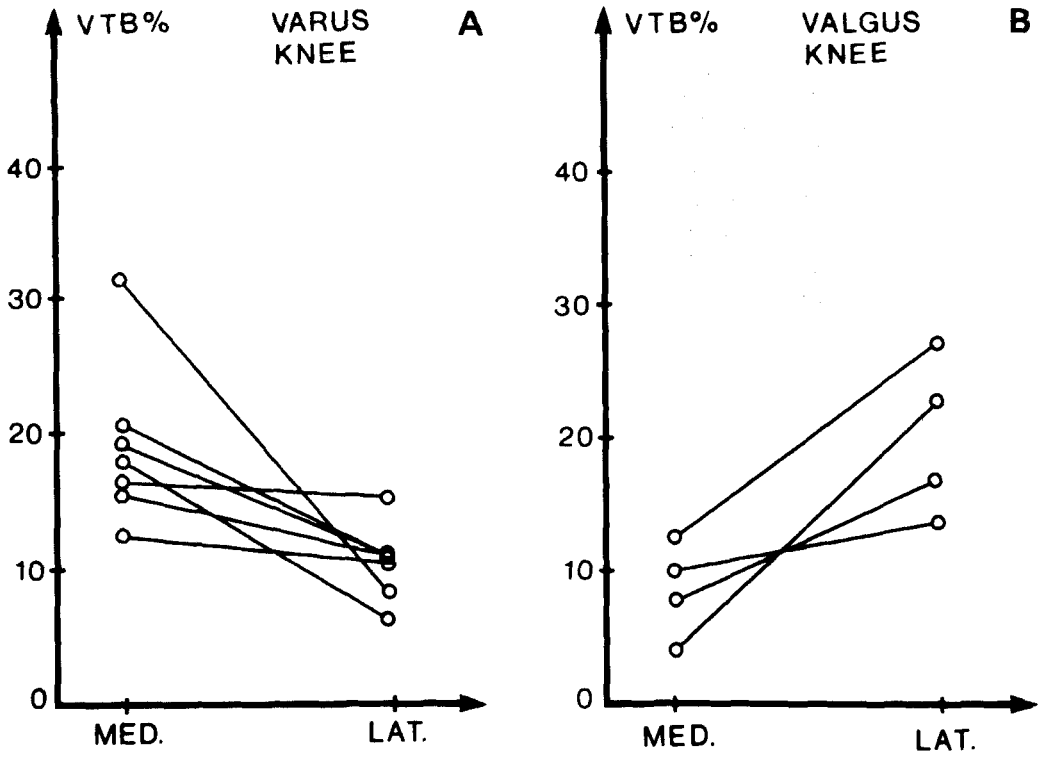

Figure 2. The variation in the percentage volume of trabecular bone (VTB percent) between the medial and lateral tibial condyle in each of the seven varus and four valgus knees.

Table 2 sets out the results of the BMC measurement by photon absorptiometry. Within the control material no difference in mineral content was found between the condyles. The intercondylar area, however, had a lower mineral content than either of the condyles. In the knees with varus or valgus deformities the mineral content of the less heavily loaded condyle was the same as that of the condyles in the control material. In the more heavily loaded condyle the values were higher than normal ($P < 0.01$). From Figure 3 it can be seen that all patients had a higher BMC value in the loaded condyle, in complete accordance with the histomorphometric findings (cf. Figure 2), whereas the non-deformed, normal knees showed individual variations, without any overall tendency. The intercondylar area in the osteoarthritic knees exhibited a higher mineral content than did the same structure in the normal knees ($P < 0.01$).

Table 2. Variation in mineral content, expressed as ash weight per cm trabecular bone biopsy in the proximal tibia of eleven normal, six varus, and three valgus knees. Range is given in brackets

Topographic area	Ash weight in mg/cm in trabecular bone		
	Normal knees (11 cases)	Varus knee (6 cases)	Valgus knees (3 cases)
Lateral condyle	71 (33–171)	96 (63–168)	157 (127–208)
Intercondylar area	34 (3–61)	132 (20–307)	78 (76–79)
Medial condyle	80 (33–131)	155 (100–295)	82 (55–116)

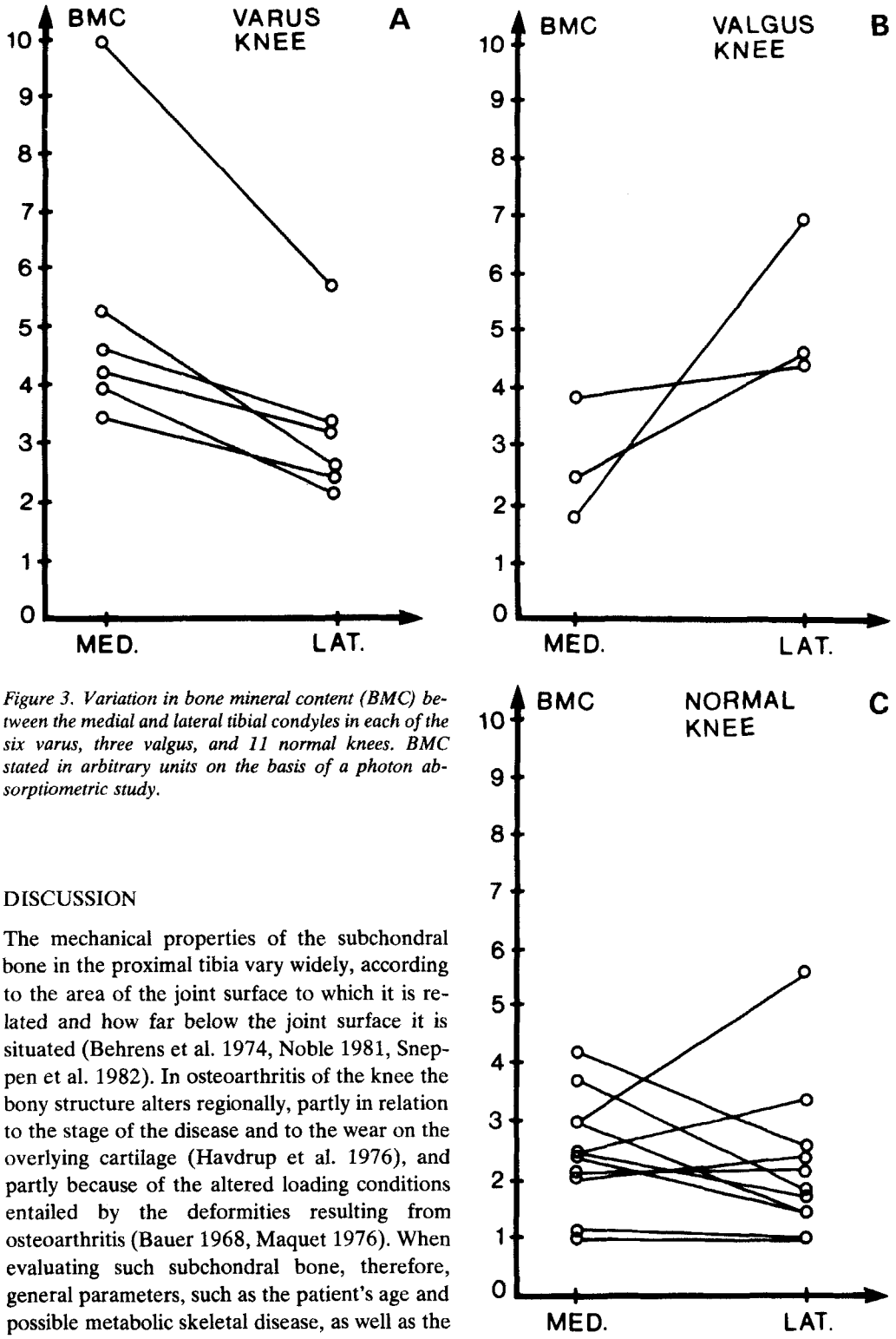

Figure 3. Variation in bone mineral content (BMC) between the medial and lateral tibial condyles in each of the six varus, three valgus, and 11 normal knees. BMC stated in arbitrary units on the basis of a photon absorptiometric study.

DISCUSSION

The mechanical properties of the subchondral bone in the proximal tibia vary widely, according to the area of the joint surface to which it is related and how far below the joint surface it is situated (Behrens et al. 1974, Noble 1981, Sneppen et al. 1982). In osteoarthritis of the knee the bony structure alters regionally, partly in relation to the stage of the disease and to the wear on the overlying cartilage (Havdrup et al. 1976), and partly because of the altered loading conditions entailed by the deformities resulting from osteoarthritis (Bauer 1968, Maquet 1976). When evaluating such subchondral bone, therefore, general parameters, such as the patient's age and possible metabolic skeletal disease, as well as the

exact site of the bony structure, the stage of the osteoarthritis and possible deformity of the joint must all be taken into consideration.

The present material comprised trabecular bony structures from patients with advanced osteoarthritis of the knee with long-standing deformity. It is also worth noting that the bone biopsies from the areas chosen were taken down to about 2.5 cm below the joint surface, as we wanted to investigate the bony structure which supports a tibial endoprosthesis after knee replacement.

The histomorphometric as well as photon absorptiometric findings indicated a greatly increased mass of bone in the condyle which bears more weight, owing to varus or valgus deformity. This shows that in this particular condyle the bony structure is particularly strong. This is in keeping with photoelastic and radiological findings (Figure 1) and, indeed, is a well-known phenomenon. On the other hand, it is remarkable that we found the quantity of bone in the less loaded condyle to be equal to that in the corresponding condyle in normal knees. Since the bony structure in a normal tibia is above the critical level required for supporting an endoprosthesis (Bargren et al. 1978), there is no particular risk that the tibial endoprosthesis will sink into the bony structure after replacement in moderately deformed osteoarthritic knees, such as those investigated in the present study. And indeed, the clinical results of such replacements have been good on the whole (Insall et al. 1979).

Concerning the extent of osteoid and resorptive surfaces, we found no difference between the loaded condyle, the unloaded condyle, and the bone from the iliac crest. When considering also the enormous mechanical stimulus exerted, in particular on the loaded condyle, as a result of the gradually progressing deformity, the trabecular bone appears to be in a steady state, as indicated by the constant proportions between resorption and osteoid covered surfaces. Although not significant, the resorptive and osteoid parameters suggest lower remodelling activity in the tibia than in the iliac crest. This observation agrees in part with the findings of Havdrup et al. (1976) who found very sparse osteoid tissue and no osteoclastic activity in juxta-articular sclerosed bone. On the other hand, experience with corrective tibial osteotomy in the proximal tibia in osteoarthritis has shown that this bone does possess sufficient activity for restructuring purposes (Bauer 1968, Maquet 1976).

Quite large quantities of woven bone were found in the trabecular bone of the loaded condyle. This is compatible with a low level of activity in this previously formed immature bone structure, in so far as a large mass of woven bone may be considered to be due to a retarded remodelling process. But in spite of marked mechanical stimulus, remodelling is not completed because of a lack of dynamic activity in the bone.

In contrast to what might have been expected from photoelastic and radiological evaluations (Figure 1), we did not find osteoporosis in the unloaded condyle. This too may be attributed to a lack of normal dynamic activity. Another explanation may have been that the knees in this study had fairly moderate deformities, so that in spite of everything, the relatively unloaded condyle received sufficient stimuli to maintain a normal mass of bone. A few investigations have suggested that osteoarthrotic patients may have a generally increased bone mass (Foss et al. 1972, Roh et al. 1974), but our histomorphometric evaluation of the trabecular bone in the illiac crest did not reveal any such tendency. Accordingly, this, incidentally doubtful, finding cannot explain the fairly large mass of bone in the unloaded condyle.

The variations in volume and mineral content of the subchondral trabecular bone observed in the present study do not indicate special problems in relation to knee replacement in osteoarthritis, insofar as the bony structure of the less loaded condyle seems to be of sufficient strength. On the other hand, relative inactivity in the trabecular bone could in some cases give rise to problems, as the endoprosthesis involves a new weight-bearing situation which, according to Wolff's law, requires further restructuring.

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