Repair of trabecular fatigue fractures

Cadaver studies of the upper femur

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The healing process and the distribution of trabecular fatigue fractures were studied on upper femora obtained at autopsy. Macroscopically, two main types of trabecular fatigue fractures were found on the basis of callus formation that in histologic sections were composed of woven and lamellar bone. A third type characterized by its vestigial callus was found only in histologic sections. Fatigue fractures were more numerous in regions of the femoral head submitted mainly to compressive rather than tensile stress. Trabeculae submitted to compressive stress had a majority of the type of fatigue fractures with an exuberant thorny callus composed of woven bone (most of them located subjacent to the subchondral bone plate), whereas trabeculae submitted mainly to tension or to minimal stress, as in Ward's triangle, had a majority of fatigue fractures with a small, smooth-surfaced callus composed of lamellar bone.

McFarland and Frost (9) described microcracks in the trabeculae of femoral heads from osteoporotic patients, suggesting their relationship with the collapse of the femoral head seen in Cushing's syndrome. Trabecular fatigue fractures were successively described in idiopathic osteonecrosis (8), in chondromalacia patellae (2), and in subcapital fractures of the femoral neck (15, 4). In 1972, Radin et al. (12, 14) proposed that trabecular fatigue fractures initiated the changes of degenerative arthrosis, and the thickening and the increase in resistance to deformation of the subchondral bone resulted from the repair process.

Vernon-Roberts et al. (17, 3), as well as Kitahara et al. (6), classified trabecular fatigue fractures in rounded nodular and fusiform types that were supposed to represent respectively an early and a late stage of the repair process; but this morphologic classification had some deficiencies, for a nodular trabecular fatigue fracture with a smooth callus could represent a late stage of the repair process as well. Also, no description of the thorny type of trabecular fatigue fracture was made by these authors. Pugh and Radin (11) have also described early and late stages of the healing process on acrylic-embedded histologic sections with respect to the abundance of callus present, but no emphasis was placed on the type of repair process associated with these stages,

The present study was undertaken to investigate and classify the healing process of trabecular fatigue fractures. The distribution and the incidence of the different types of trabecular fatigue fractures in the proximal femur were also studied.

Material and methods

Eighteen upper femora (7 males and 11 females) were obtained at routine autopsies from 10 subjects at the pathology department of Ottawa General Hospital. The median age of the subjects was 66 (44–83) years. Cases with metastatic bone disease, bone tumor, and known metabolic disorders were excluded.

Femora were cut in half in the frontal plane using a computerized milling machine. The posterior part was then macerated using the method of Todd et al. (15).

A map (Figure 1) was constructed after the anatomic description of Koch (7); 18 regions were delineated with respect to compressive and tensile trabeculae and

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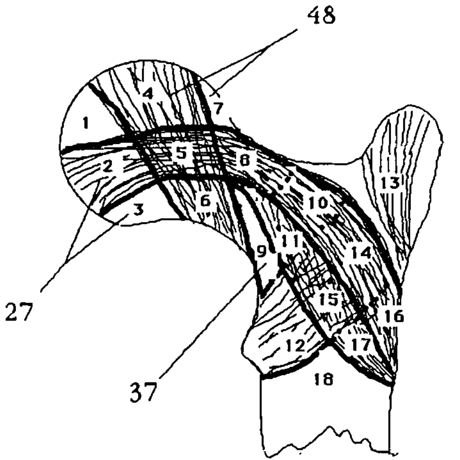


Figure 1. Mapping of the proximal femur for trabecular fatigue fracture studies. Areas 4 and 7 were taken as compression areas; areas 2 and 3 as tension areas. Ward's triangle is area 9. The arrows indicate the total number of trabecular fatigue fractures in these three different areas in the 18 specimens studied. In compression areas, 36/48 of trabecular fatigue fractures were of the A type. In tension and Ward's triangle areas, the proportions of type B trabecular fatigue fractures were 17/27 and 28/37, respectively.

Table 1. Type and number of trabecular fatigue fractures in different areas of 18 upper femora

Type	Compression areas	Tension areas	Ward's triangle
A	36	10	28
B	12	17	9

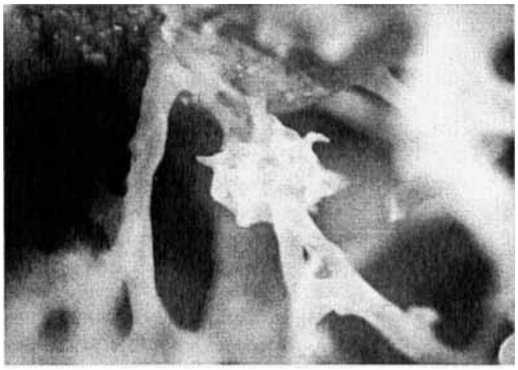


Figure 2. Type A trabecular fatigue fracture located subjacent to subchondral bone plate in compression areas of the femoral head. Thorny and relatively thick callus. x40.

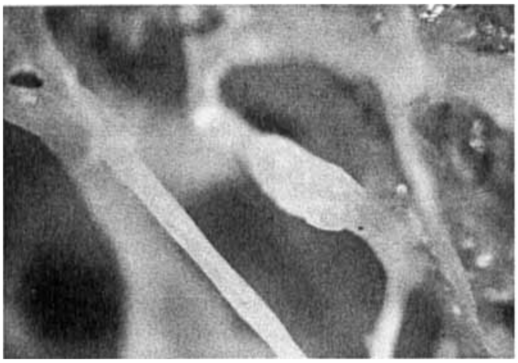


Figure 3. Type B trabecular fatigue fracture. Smooth and relatively thin callus. x40.

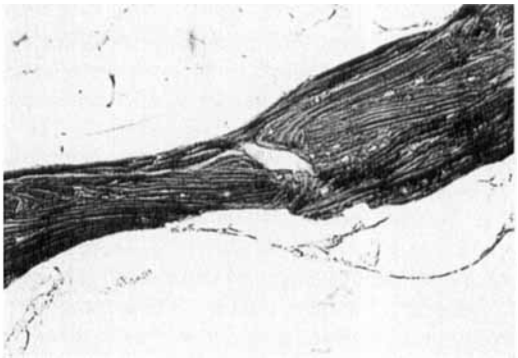
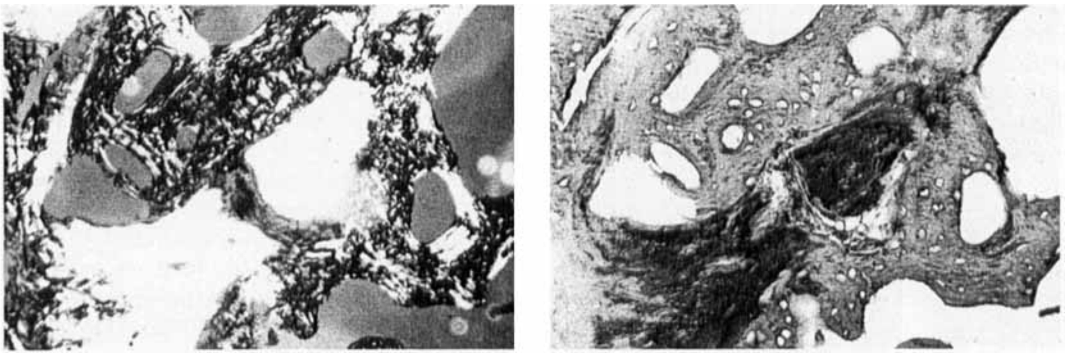


Figure 4. Type C trabecular fatigue fracture. Persistent fracture line with vestigial callus. Goldner's stain, x100.



A. Woven bone has formed around the fractured trabecula. Goldner's stain, x100.

B. Same lesion in polarized light demonstrating callus made mostly of woven bone. x100.

Figure 5. Typical Type A trabecular fatigue fracture.

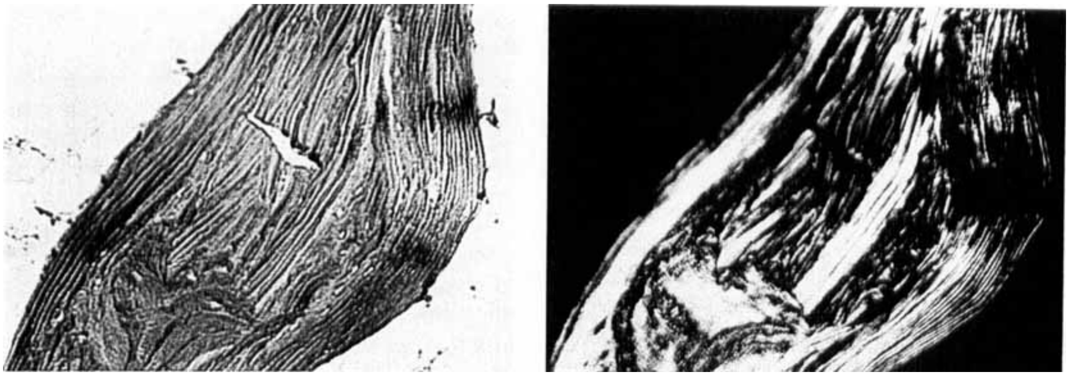


Figure 6. A. Typical Type B trabecular fatigue fracture. The callus is composed of lamellar bone. Goldner's stain, x100.

B. Same lesion in polarized light demonstrating callus made mostly of lamellar bone. x100.

their intersections, as well as with respect to the base of the femoral neck. Given the principal direction of trabeculae, areas 4 and 7 are mainly sites of compressive stresses, whereas areas 2 and 3 are mainly sites of tensile stresses. The surfaces of areas 4 and 7, and areas 2 and 3, were in all the cases approximately comparable in size.

Within areas 4 and 7, and areas 2 and 3, as well as in Ward's triangle (area 9), trabecular fatigue fractures were counted with a dissecting microscope and their morphologies recorded. Type A trabecular fatigue fractures (Figure 2) were defined as having a thorny and relatively large callus, while Type B fractures (Figure 3) were defined as having a smooth surface and relatively small callus. Type C trabecular fatigue fractures (Figure 4) consisted of a healing trabecula with minimal callus formation. The trabecular fatigue fractures of the C Type were recognized fortuitously only in histologic sections because of a persistent fracture line surrounded by a very small callus made of lamellar bone, and thus its frequency was not included in the study.

Sections for transmitted and polarized light microscopy were prepared only from selected decalcified specimens and were stained with Goldner's trichrome.

Results

Trabecular fatigue fractures were much more numerous in compression than in tension areas (Table 1, Figure 1). Further, compression areas had the highest proportion of Type A fractures (75 percent) while Ward's triangle had the highest proportion of Type B fractures (75 percent). Values for tension areas were in between. Areas surrounding Ward's triangle had a total number of trabecular fatigue fractures ranging from 0 to 2.

Compression areas had more Type A trabecular fatigue fractures than in tension areas ($P < 0.025$) or in Ward's triangle ($P < 0.025$). The incidence of Type A trabecular fatigue fractures in tension areas did not differ from that of Ward's triangle. There was no difference in the incidence of Type B trabecular fatigue fractures in tension areas when compared with compression areas or with Ward's triangle, but Type B trabecular fatigue fractures were more frequent in Ward's triangle when compared with compression areas ($P < 0.05$).

The incidence of the two types of trabecular fatigue fractures in the different subjects was not homogeneous. The individual total number of trabecular fatigue fractures in compression areas ranged from 0 to 11. In tension areas the individual total number of Type B trabecular fatigue fractures ranged from 0 to 7. Only in four out of 18 cases was the number of type B trabecular fatigue fractures greater than that of Type A in compression areas. In these four cases, the numerical difference was between 1 and 3. In tension areas a greater number of Type A trabecular fatigue fractures were only seen twice, and the numerical difference was only 1 in both cases. These individual variations did not correlate with age; and, because femora were obtained from autopsies, we were unable to correlate such differences with the activity of the patient during the few last months of life.

Most trabecular fatigue fractures in compression areas were just subjacent to the subchondral bone plate.

In histologic sections, using polarized light, Type A trabecular fatigue fractures (Figure 5) had a callus composed mostly of woven bone, whereas Type B (Figure 6) had a callus consisting mostly of lamellar bone. In some sections of Type A fractures, lamellar bone appeared on both deep and superficial aspects of the callus

Discussion

We have assumed that a classification of trabecular fatigue fractures based primarily on the surface morphology and secondarily on the size of the callus would be the most appropriate. Although examination with polarized light of histologic sections permits distinguishing between woven and lamellar bone, respectively, it is difficult to know whether thorny and smooth surfaces of the callus represent early or late stages of the repair process, since the study was conducted on specimens obtained at autopsy. A trabecular fatigue fracture could start with a Type A callus, which could become Type B through bone remodeling. Although this succession seems logical, we could as well have the direct formation of a Type B callus. Because the proportions of Types A and B trabecular fatigue fractures in compression are different from those of the two other regions studied, we can conclude that the repair process is different according to the type of stress the trabecula was submitted to, and we suggest the following explanation. In compression areas the cyclic impaction of the two trabeculae ends might trigger a greater interfragmentary motion and thus more important bone apposition, whereas in tension areas the fractures undergo less displacement, which might result in limited bone apposition and formation of more mature, but less, bone. Vernon-Roberts et al. (17, 3) and Kitahara et al. (6) have classified trabecular fatigue fractures into several types, the principal ones being rounded nodular and fusiform. The other types were the angulated excrescence and the arched bridges. Although nodular and fusiform trabecular fatigue fractures were considered to be early and late stages of the repair process, respectively, the staging of possible smooth nodular trabecular fatigue fractures, often seen in our specimens, was still unclear, because the smooth surface could indicate an ongoing remodeling process. Pugh and Radin (11) also described an early and a late stage of the repair process; but for the earliest stages, the type of bone involved was unclear. The late stage described in acrylic-embedded sections by these two authors was very similar to the Type C we described. Again, it is difficult to determine when the Type C trabecular fatigue fracture occurs during the repair process or to relate it to Type B fractures. It could represent an early stage of the repair process because of the fracture line and the limited callus formation, but it could also represent a late stage of the repair process because of the lamellar quality of the callus.

The fact that trabecular fatigue fractures are the most numerous in compression areas seems to indicate that these are mainly caused by load-induced compressive stresses (11). On the other hand, tensile stresses seem to induce fewer fractures.

Our finding that trabecular fatigue fractures were located subchondrally in the femoral head is similar to the observation made by Ohtani et al. (10) on the weight-bearing surface of the acetabulum, where 78 percent of all the trabecular fatigue fractures were located within 10 mm of the articular cartilage. It is understandable that in the case of an accumulation of trabecular fatigue fractures these areas might be the first to give way. According to Trueta et al. (16), multiple trabecular fatigue fractures known to occur in advanced arthrosis could cause a flattening of the femoral head. This flattening might well originate in these regions.

Our study suggests that the main cause of trabecular fatigue fractures in the femoral head is compressive stress, leading to a different repair process than that seen in areas of tensile stress or in areas of poor stress, such as Ward's triangle. Carter et al. (1) showed that in the human femoral head, trabecular strength was equal in compression and in tension. But because of impaction of trabeculum ends, energy absorption was found to be greater in trabeculae fracturing in compression. If we agree that trabecular fatigue fractures help to absorb energy resulting from loading (13, 3), then, we have to admit that bone gives preference to the most energy-absorbing way of fracturing (1). However, fractures of trabeculae in compression areas, areas where most of degenerative changes are seen, exhibit a peculiar repair process that seems to produce an increase in bone mass, and thus, probably less energy absorption by the bone. This represents a positive element for Radin's theory, which was recently questioned by Fazzalari and Venron-Roberts (3), who felt that a decrease rather than an increase in this energy-absorbing mechanism was responsible for degenerative processes; hence, trabecular fatigue fractures could represent a protective rather than a destructive mechanism. Whatever their exact role, however, the cause of the difference in number and in shape of trabecular fatigue fractures still awaits clarification.

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