Acta orthop. scand. 53, 451–462, 1982

HARDNESS OF THE SUBCHONDRAL BONE OF THE PATELLA IN THE NORMAL STATE, IN CHONDROMALACIA, AND IN OSTEOARTHROSIS

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The hardness of bone is its property of withstanding the impact of a penetrating agent. It has been found that articular degenerative changes in, for example, the tibia (knee) are combined with a decrease in the hardness of the subchondral bone.
In this investigation the hardness of subchondral bone in chondromalacia and osteoarthrosis of the patella has been analysed and compared with normal subchondral bone.
Using an indentation method originally described by Brinell the hardness of the subchondral bone was evaluated in 7 normal patellae, in 20 with chondromalacia and in 33 with osteoarthrosis. A microscopic and microradiographic study of the subchondral bone was carried out simultaneously.
Hardness was lowest in the normal material. The mean hardness value beneath the degenerated cartilage differed only slightly from that of the normal material, but the variation of values was increased. The hardness in bone in the chondromalacia area was lower than the hardness in bone covered by surrounding normal cartilage. The mean hardness value in bone beneath normal parts of cartilage in specimens with chondromalacia was higher than the mean hardness value of the normal material.
In the microscopic and microradiographic examination it became evident that there was a relationship between trabecular structure and subchondral bone hardness; high values: coarse and solid structure; low values: slender and less regular structure.

Key words: chondromalacia patellae; hardness of subchondral bone; osteoarthrosis

Accepted 17.vii.81

The capacity of bone – both cortical and cancellous – to resist the impact of a penetrating agent is dependent on the hardness of the bone (Weaver 1966). According to Currey (1970) the hardness of bone varies with the strength, the modulus of elasticity and the plastic flow that bone can undergo. Determinations have been made on individual trabeculae in cancellous bone and compared with those made on adjacent cortical bone; the hardness of the cancellous bone was somewhat less than that of the interstitial bone of the adjacent cortex (Weaver 1966).

Disease has an influence on bone hardness. In Paget's disease the hardness differs at various sites, with a good correlation with the histologic findings. In osteoporosis hardness is not significantly affected (Weaver 1966).

Hardness of subchondral bone can be determined by an identation method, described by Brinell (1900). Lereim et al. (1974) de-

This investigation has been supported by grants from Göteborgs Läkaresällskap and Medicinska Fakulteten Göteborgs Universitet.

0001-6470/82/030451-12 $02.50/0

monstrated that hardness of subchondral bone when measured in the medial tibial plateau was significantly lower in osteoarthrosis and rheumatoid arthritis than in normal bone.

Chondromalacia patellae is regarded as a probable precursor of osteoarthrosis and it has been suggested that the initiation and progression of cartilage lesions are related to the state of their underlying cancellous bone (Abernethy et al. 1978).

The purpose of this investigation has been to make systematic measurements of the hardness of the subchondral bone in the patella, in its normal state, in chondromalacia and in osteoarthrosis.

MATERIAL

Sixty patellae were removed at autopsy from patients without any obvious joint disease. The age range was from 15–75 years. Both sexes were equally represented, as well as sides of the body.

Abnormal changes observed by the naked eye and by palpation of the cartilage were classified as either chondromalacia patellae or osteoarthrosis, depending on the age of the individual from whom the specimen was taken. The material became divided into two age groups. One contained specimens from individuals between 15 and 34 years. This group was identified as chondromalacia patellae. The second group contained specimens from individuals between 36 and 75 years. This age group was identified as osteoarthrosis, one part of which was slight, and one severe (see below).

DEFINITIONS

Normal (n= 7)

The cartilage of the patella was regarded as normal when the colour was bluish-white and when no indentations or abnormalities were observed or palpated. The mean age of the individuals was 23 years, varying from 16–30 years.

Chondromalacia patellae (n = 20)

The grading followed that of Collins (1949).

Chondromalacia grade 1 (n = 10). Part of the cartilage was slightly swollen and soft. Occasionally the surface had lost its normal glossiness and the colour had turned slightly yellow. The mean age of the individuals was 22 years varying from 15–30 years.

Chondromalacia grade 2 (n = 6). In parts of the cartilage there were numerous superficial fissures and fragmentation. The surface was roughened. The colour was yellowish. The mean age of the individuals was 28 years varying from 19–34 years. The area of degeneration was partly surrounded by chondromalacia grade 1 and beside or beyond that by normal cartilage.

Chondromalacia grade 3 (n = 4). In parts of the cartilage there were areas with numerous fissures penetrating down to the bone and fragmentation. The area of degeneration was partly surrounded by chondromalacia grade 1 and beside or beyond that by normal cartilage. The mean age of the individuals was 25 years varying from 24–27 years.

Chondromalacia grade 4. Erosion of cartilage to bare bone. No specimen was classified in this category.

Osteoarthrosis (n = 33)

This term was used in individuals with any one or more of the changes described for chondromalacia patellae, provided the individuals had attained the age of 36 years or more.

Slight osteoarthrosis (n = 5). There was a lack of glossiness of the articular surface, as well as superficial fissures, unevenness of the cartilage surface and patchy indentations. The mean age of the individuals was 41 years varying from 36–47 years.

Severe osteoarthrosis (n = 28). There was a lack of the normal colour, which was yellowish in those areas where the cartilage was retained, as well as deep fissures, fragmentation and erosion to the bare bone. The mean age of the individuals was 47 years varying from 36–75 years.

Measurement areas of the patellar cartilage

The patellar cartilage was divided into 10 areas (Figure 1). They were equally demarcated proportional to the size of the medial and lateral facets. Thus systematic measurements could be made of the subchondral bone hardness of the whole patellar articular surface. Each area was marked with a letter and area A represented the odd medial facet (Goodfellow et al. 1976a, b). It is the most medial part of the medial facet and is separated from this by a more or less prominent longitudinal ridge (Figure 2).

The areas B, C, and D represented the proximal, central and distal parts of the medial facet. The areas E, F, and G represented the proximal, central and distal parts of the longitudinal crest between the medial and lateral facets. The areas H, I, and J represented the proximal, central and distal parts of the lateral facet.

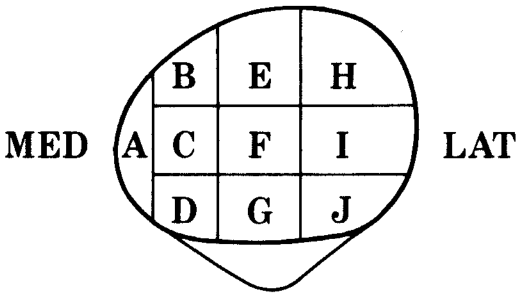

Figure 1. Division of the patellar articular surface into 10 areas for hardness tests.
A = odd medial;
B = proximal medial;
C = central medial;
D = distal medial;
E = proximal central;
F = central central;
G = distal central;
H = proximal lateral;
I = central lateral;
J = distal lateral.

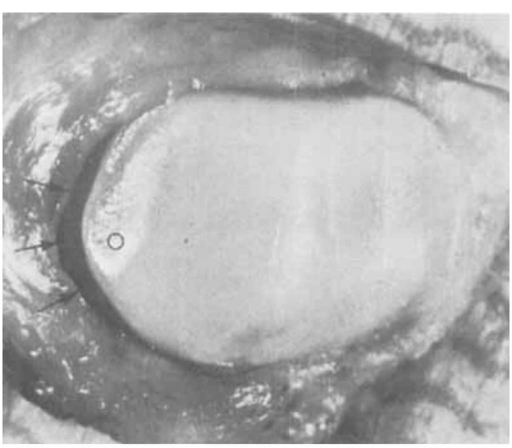

Figure 2. Photograph of the articular surface of the patella showing the surface contour, particularly the odd facet (0). The cuff of synovium surrounding the articular surface is also shown (arrows). From: Disorders of the Patello-Femoral Joints, R. Paul Ficat, M.D. and David S. Hungerford, M.D., Masson, 1977.

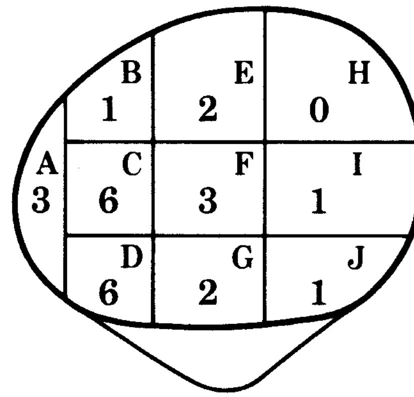

Figure 3. Frequency of chondromalacia grade 1 in the 10 areas subjected to hardness tests.

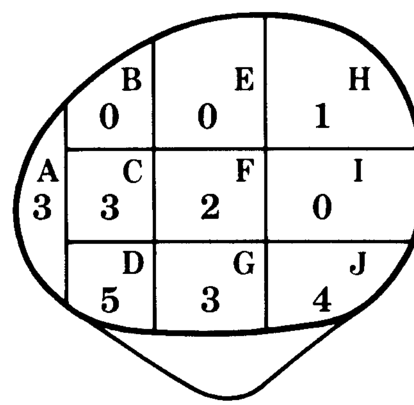

Figure 4. Frequency of chondromalacia grade 2–3 in the areas subjected to hardness tests.

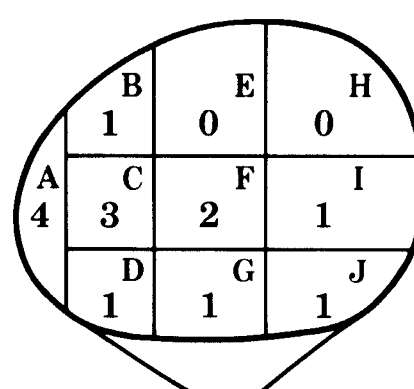

Figure 5. Frequency of slight osteoarthrosis in the 10 areas subjected to hardness tests.

Localization and frequency of degenerative changes

In Figures 3–6 the frequency is presented of chondromalacia and of osteoarthrosis in each of the 10 areas of each group in the material. As is seen from these figures chondromalacia patellae was mostly found in areas C, D, and F (Figures 3 and 4). Chondromalacia

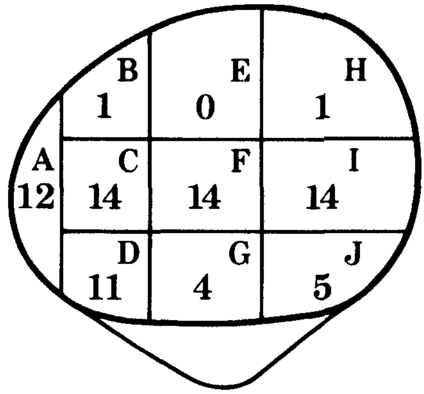

Figure 6. Frequency of severe osteoarthrosis in the 10 areas subjected to hardness tests.

grade 1 and 2–3 covered an average of 2.5 and 2.1 areas, respectively. Osteoarthrosis was mostly found in areas C, D, F, and I (Figures 5 and 6). Slight osteoarthrosis and severe osteoarthrosis covered an average of 2.8 and 2.7 areas, respectively.

Preparation of patellar subchondral bone

After removal, the patellae were wrapped in gauze soaked in Ringer's solution and kept in an air-tight bowl at a temperature of –20°C. According to Sedlin (1965) and Sedlin & Hirsch (1966) this procedure does not influence the physical properties of bone.

The apex and 1–2 mm of the base of each patella were cut off in order to obtain two even surfaces by which the specimens could be fastened in a vice. The superficial cartilage was cut with a knife. In the central part of each area the remaining cartilage was carefully ground down until the subchondral bone became visible. The grinding was checked under an operation microscope. A grinding rod with a plane surface (used for grinding hard metals) with a diameter of 8 mm was used. The rod rotated with 800 revolutions per minute. In order to minimize generation of heat by the grinding procedure the specimen and the rod were immersed in Ringer's solution. The grinding was done intermittently, with the rod in light contact with the specimen for 1 second at a time and with intervals of at least 2 seconds. The total time for preparation of a patella was at the most 3 hours.

Method for hardness test

Hardness of a material can be determined by applying a specified load for a certain time and calculating the ratio of load to indentation area. Brinell's method described by von Weingraber (1952) has been used.

A steel ball with the diameter D in mm is pressed for a specified time with a load P in N into the surface of the material. An indentation area A is formed and measured in mm^2. The Brinell value (HB) as measured in N/mm^2 is the ratio of the load P to the indentation area A (Figure 7).

For this investigation a steel ball with a diameter of 5 mm was used. The load was 49.0 N. The time for loading was 15 seconds. In all, some 600 hardness tests were carried out on the total material.

The elasticity of bone is such that after an impact restitution is so fast that the measurement of the indentation diameter can be difficult. The area to be tested was therefore covered with a polyester pressure sensitive tape which, together with its adhesive layer, measured 0.06 mm (Minnesota Mining Manufacturing Comp.). The indentation in the bone could thus be preserved on the tape and measurements were made in a measuring microscope in two directions at right angles. In some 20 out of 600 cases the indentation area was oval but the longer diameter never exceeded the shorter by more than 10 per cent. Mean calculations were made and in those cases where there was an oval indentation mean calculations were made of the maximal and minimal values.

Statistical method: Multiple regression analysis and analysis of variance. (Statistical analysis – Ulf Runze).

Objective examination of the subchondral bone surface

In order to check that measurements had been carried out on the subchondral bone, samples from the measuring areas were subjected to histologic and mi-

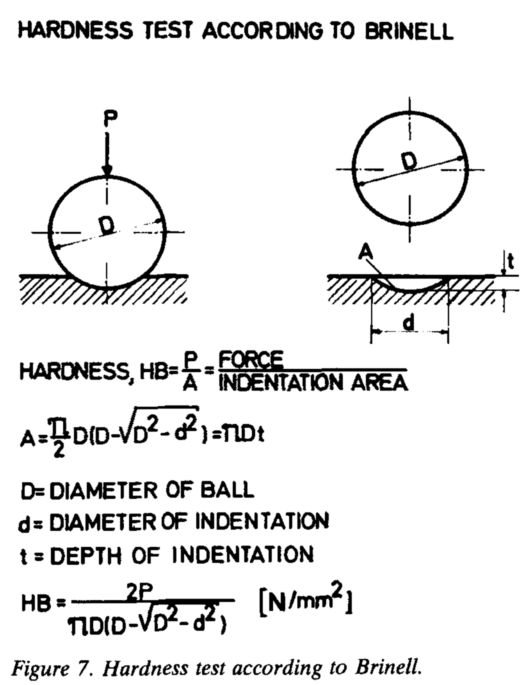

Figure 7. Hardness test according to Brinell.

croradiographic examination. This study made it possible not only to check the characteristics of the grinding surface but also to study the morphology of the subchondral bone in relation to the hardness measurements.

Method. The subchondral bone was sawed out from the 10 different patellar areas representative of the different cartilage changes. Thirty blocks were fixed in formalin and decalcified. They were cut in 7 μ sections and stained with haematoxylin and eosin.

After dehydration 110 blocks of subchondral bone were embedded in methylmethacrylate. Eighty of them were cut in 5 μ sections with a bone microtome, and stained with the Goldner stain (Schenk 1965).

Thirty blocks were cut out and sectioned with a diamond microtome in 100 μ sections for radiography. All sections were orientated in a plane at right angles to the longitudinal axis of the patella.

Morphologic examination (Figure 8). The grinding surface was straight and even. Cracks or splits of the bone trabeculae were observed frequently in the nondecalcified specimens and occasionally in the decalcified. These cracks which were thought to be caused by the microtome were evenly distributed in the bone beneath the prepared surface and in adjacent bone still covered by hyaline cartilage. There was no tissue reaction around the cracks.

The border line between the calcified cartilage and the subcondral bone was irregular. In specimens with chondromalacia or osteoarthrosis the border line was usually more irregular and extensions of the calcified cartilage were more numerous and reached further into the bone.

The subchondral bone plate was formed by the confluence of bone trabeculae. The morphology was varied. In the crest and medial half of the lateral facet the trabeculae usually had a columnar regular arrangement orientated perpendicular to the joint surface. Between those trabeculae the subchondral plate was in some

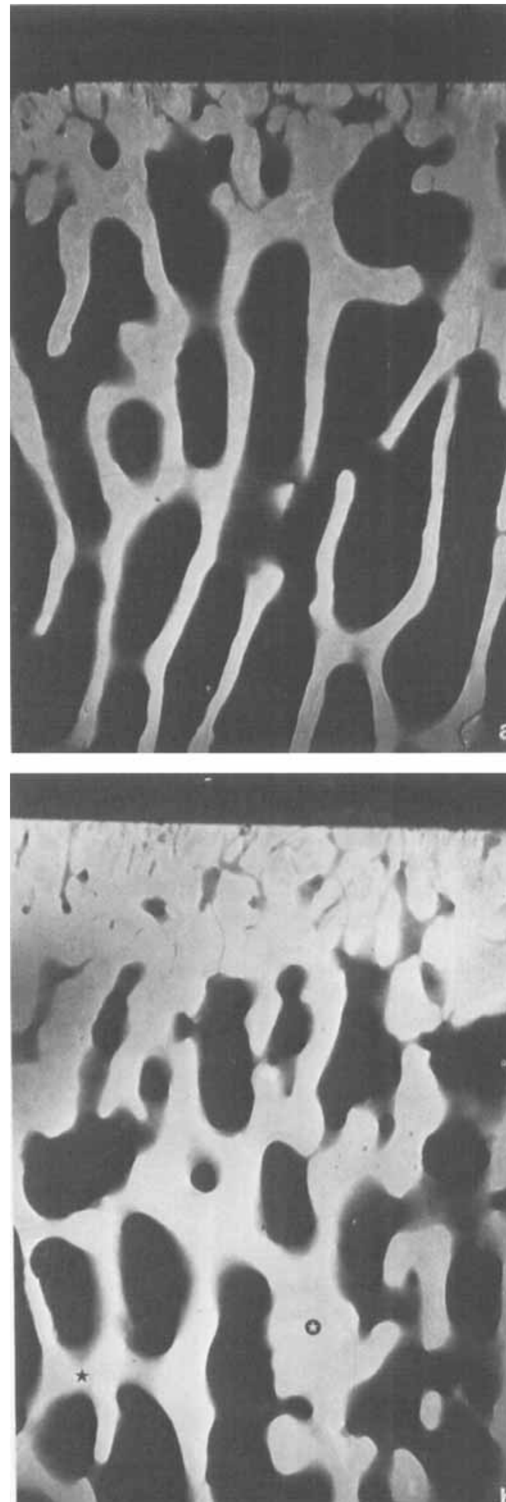

Figure 8. a) Microradiograph (×16) of the subchondral bone in the distal part of the longitudinal crest (area G cf. Figure 1) with chondromalacia grade 2 in a 27-year-old man. The upper part is the smooth grinding surface of the bone plate. The trabeculae of the subchondral zone have varied dimensions. The hardness value in this area was 36.6 N/mm².
b) Microradiograph (×16) of the subchondral bone in the central part of the lateral facet (area I cf. Figure 1) beneath normal cartilage in a patella with chondromalacia grade 2 located in the central part of the medial facet, in a 24-year-old man. A relatively dense bone plate is formed by confluence of broad trabeculae. Some of the irregular trabeculae are joined by broad transverse bars (★), and some form bone aggregates (✪). The hardness value in this area was 55.4 N/mm².

cases very thin in the crest region. In the bone beneath the medial facet and the lateral half of the lateral facet the trabeculae had an oblique orientation, irregular forms and more varied dimensions. In a zone beneath the superficial continuous bone plate the trabeculae usually were broader than those of the underlying calcellous bone. Aggregates of bone, varying in size were randomly spread in the subchondral zone. In the pathological material the trabeculae in the subchondral zone had a greater variation in dimension and orientation, and the aggregates of bone were more numerous.

Osteoid tissue was sparsely scattered in an irregular manner in most specimens but was rarely found in the subchondral bone plate.

In microradiographic examination occasional superficial cracks were found which were thought to be caused by the steel ball used for the indentation tests. No further observations were made which differed from the above described histologic investigation.

RESULTS OF HARDNESS MEASUREMENTS

Normal patellae (n = 7)

The mean hardness value of the 70 normal test areas was 38.4 (SD 3.5) N/mm^2 (Table 1).

The mean hardness values of the medial areas were somewhat higher than those of the lateral areas (Table 2).

In comparing the ten mean hardness values of each test area A–J (one in each of the seven specimens) it was found that the value was highest in area D and E, both 39.7 N/mm^2, next highest in area A, C, and F, all 39.2 N/mm^2, and lowest in area H, 36.9 N/mm^2.

The hardness value of each area was compared with those measured in the adjacent areas (e.g. area A was compared in the transverse direction with area C; in the diagonal directions with areas

Table 1. Mean hardness values (N/mm^2) in subchondral bone and standard deviation in 7 normal patellae and 10 patellae with chondromalacia patellae grade 1 and 10 with chondromalacia patellae grade 2–3

Specimen		Condition of cartilage covering measured areas: Normal cartilage	Chondromalacia Grade 1	Chondromalacia Grade 2–3
Normal specimens	n= 7	38.4±3.5	–	–
Chondromalacia grade 1	n=10	43.8±4.9	40.8±7.3	–
Chondromalacia grade 2–3	n=10	45.4±7.5	44.2±6.0	38.8±6.4

Table 2. Mean hardness values (N/mm^2) in the subchondral bone in groups of test areas underlying normal and pathologic cartilage in 60 patellae

Condition of cartilage in tested patellae	Medial odd facet A	Medial areas B, C, D	Crest areas E, F, G	Lateral areas H, I, J
Normal	39.3	39.0	38.7	37.2
Chondromalacia grade 1				
Normal	42.4	43.4	42.8	45.4
Chondromalacia grade 1	43.3	38.4	43.9	41.7
Chondromalacia grade 2–3				
Normal	46.0	44.5	44.3	47.2
Chondromalacia grade 1	51.2	43.5	42.7	44.9
Chondromalacia grade 2–3	37.6	38.0	42.2	37.3
Slight osteoarthrosis				
Normal	36.3	42.1	41.7	40.2
Slight osteoarthrosis	44.5	40.3	47.4	46.8
Severe osteoarthrosis				
Normal	39.4	38.8	41.0	40.3
Slight osteoarthrosis	41.0	38.0	41.3	43.1
Severe osteoarthrosis	36.0	38.5	37.3	40.5

Table 3. The hardness values in subchondral bone in each of the 10 test areas compared with the hardness values obtained in adjacent areas in normal patellae

Test area	Lower	Higher	Equal
A	10	7	4
B	14	9	5
C	16	19	7
D	9	14	5
E	8	20	7
F	17	27	12
G	18	16	1
H	12	5	4
I	20	9	6
J	9	7	5
Total	133	133	56
Mean difference (N/mm^2)	4.5	4.5	–

B and D. Area C was compared with areas A, B, D, E, F, and G. And so on). For area E higher hardness values outnumbered lower and for areas H and I lower values outnumbered higher. Otherwise the distribution between lower and higher values was comparatively equal (Table 3). The mean of the differences was 4.5 N/mm^2.

Patellae with chondromalacia grade 1 (n = 10)

The mean hardness value of all 25 areas with chondromalacia grade 1 was 40.8 (SD 7.3) N/mm^2. The mean hardness value of the 75 areas with normal cartilage of the same specimens was 43.8 (SD 4.9) N/mm^2. This value was significantly higher ($P < 0.05$) than the mean hardness value of the normal material (Table 1).

The mean hardness value of areas with chondromalacia grade 1 in the medial facet areas was lower than those in the crests and lateral facet areas (Table 2).

The hardness value of each chondromalacia grade 1 area was compared with those of the adjacent normal areas. The values of the chondromalacia grade 1 areas were lower in 61 measurements, higher in 9 and equal in 8. The mean of the differences was 5.8 N/mm^2.

The difference between the mean hardness value of the chondromalacia grade 1 areas and that of the normal areas in each specimen was calculated. In all specimens but one the mean hardness value of the chondromalacia grade 1 areas was lower than the mean hardness value of the normal areas. The mean of the differences was 6.0 N/mm^2.

Patellae with chondromalacia grade 2–3 (n = 10)

As the number of specimens with chondromalacia grade 3 was small ($n = 4$) these were combined with specimens with chondromalacia grade 2 ($n = 6$).

The mean hardness value of the 21 chondromalacia grade 2–3 areas, 38.8 N/mm^2, was significantly ($P < 0.05$) lower than that of the 50 normal areas of the same specimens, 45.4 N/mm^2. The mean hardness value and the standard deviation of the normal areas in the specimens with chondromalacia grade 2–3 were significantly ($P < 0.05$) higher than the values of the normal material (Table 1).

The mean hardness value of areas with a chondromalacia grade 2–3 in the crest areas was higher than those in the medial and lateral facet areas (Table 2).

The hardness value differences between each chondromalacia grade 2–3 area and the adjacent chondromalacia grade 1 and normal areas were calculated. In comparison with the adjacent chondromalacia grade 1 areas, the hardness val-

Table 4. Mean hardness value in subchondral bone beneath normal cartilage, chondromalacia grade 1 and chondromalacia grade 2–3 of each specimen, compared, in 10 specimens, with chondromalacia grade 2–3

Condition of cartilage in areas compared	Number of differences in mean hardness values: Lower	Higher	Mean difference (N/mm^2)
Chondromalacia grade 2–3 – Chondromalacia grade 1	9	1	6.1
Chondromalacia grade 2–3 – Normal cartilage	10	0	8.1
Chondromalacia grade 1 – Normal cartilage	8	2	2.3

ues of the chondromalacia grade 2–3 areas were lower in 22 measurements, higher in 6 and equal in 4 (mean difference 5.3 N/mm^2). In comparison with the adjacent normal areas, the hardness values of the chondromalacia grade 2–3 areas were lower in 29 measurements, higher in 4 and equal in one (mean difference 7.4 N/mm^2). In comparison with the adjacent normal areas, the hardness values of the chondromalacia grade 1 areas were lower in 35 measurements, higher in 20 and equal in 5 (mean difference 1.5 N/mm^2).

The mean hardness values of the areas with chondromalacia grade 2–3, chondromalacia grade 1, and areas with normal cartilage, in each specimen, were compared (Table 4). In all specimens but one the mean hardness value of the chondromalacia grade 2–3 areas was lower than that of the chondromalacia grade 1 areas (mean difference 6.1 N/mm^2). In all specimens the mean hardness value of the chondromalacia grade 2–3 areas was lower than that of the normal areas (mean difference 8.1 N/mm^2).

Patellae with slight osteoarthrosis (n = 5)

The mean hardness value of the 14 areas with slight osteoarthrosis was somewhat higher than that of the 36 normal areas in the same specimens (Table 5).

When compared with the adjacent normal areas the hardness values of the slight osteoarthrosis areas were lower in 11 measurements, higher in 26, and equal in none. The mean of the differences was 3.8 N/mm^2.

In four of the five specimens the mean hardness value of the slight osteoarthrosis areas was higher than the mean hardness values of normal areas in the same specimens. In one it was lower. The mean of the differences was 3.6 N/mm^2.

Patellae with severe osteoarthrosis (n = 28)

The mean hardness values of the 76 areas with severe osteoarthrosis was somewhat lower than those of the 79 areas with slight osteoarthrosis and the 125 areas with normal cartilage in the same specimens (Table 5). The variation of hardness value in severe osteoarthrosis areas, SD 10.4 N/mm^2, was significantly ($P < 0.05$) higher than that in the normal areas of the same specimens, SD 8.5 N/mm^2. Irrespective of appearance of the cartilage the mean hardness values of the medial areas were lower than those of the lateral areas (Table 2). The mean hardness value of areas with severe osteoarthrosis in the crests was lower than that in the lateral areas, and the lowest hardness value (36.0 N/mm^2) was found in the medial odd facet (Table 2).

When compared with the adjacent slight osteoarthrosis areas the hardness values of the severe osteoarthrosis areas were lower in 55 measurements, higher in 55, and equal in 19. When compared with the adjacent normal areas the hardness values of the severe osteoarthrosis areas were lower in 55 measurements, higher in 76, and equal in 17.

Irrespective of the appearance of the cartilage the mean hardness values in the age group 36–45 years were higher than the hardness values in the age group 46–75 years (Table 6). In the younger age group the mean hardness values of the areas with severe osteoarthrosis were lower than those with slight osteoarthrosis and the normal areas in the same specimens (Table 6).

According to the distribution of severe osteoarthrosis in the medial facet areas, the lateral facet areas or in transverse central and/or distal parts of the articular surface, the specimens were divided into three groups. The mean age of

Table 5. Mean hardness values (N/mm^2) in subchondral bone and standard deviation in 5 patellae with slight osteoarthrosis and 28 patellae with severe osteoarthrosis

Specimen		Condition of cartilage covering measured areas		
		Normal cartilage	Slight osteoarthrosis	Severe osteoarthrosis
Slight osteoarthrosis	$n = 5$	42.2±4.7	43.9±6.2	–
Severe osteoarthrosis	$n = 28$	40.1±8.5	40.8±8.5	38.3±10.4

Table 6. Mean hardness value (N/mm²) in subchondral bone in specimens with severe osteoarthrosis

Age group	Condition of cartilage covering measured areas		
	Normal cartilage	Slight osteo-arthrosis	Severe osteo-arthrosis
36–45 years $n=12$	43.7	45.0	40.9
46–55 years $n=8$	35.9	34.8	37.3
56–75 years $n=8$	37.4	37.7	38.6

the individuals from whom the specimens were obtained was 42 years, 49 years, and 55 years, respectively. The mean hardness values of the areas with normal cartilage, slight osteoarthrosis and severe osteoarthrosis of each group are presented in Table 7. The differences between the mean hardness values of osteoarthrosis areas and normal areas were small and in accordance with the differences found in the corresponding age groups (Table 6).

In five of the ten specimens with severe osteoarthrosis distributed in transverse parts the hardness values of the medial facet areas (mean 47.4 N/mm²) were higher than those of the lateral facet areas (mean 44.0 N/mm²). In four specimens the hardness values of the medial facet areas (mean 29.4 N/mm²) were lower than those of the lateral facet areas (mean 43.1 N/mm²).

The hardness values of subchondral bone were not correlated with sex or type of patella according to the classification of Wiberg (1941). There was no difference between specimens from either left or right sides.

Correlation of hardness values to morphology

High hardness values were found to be associated with some of the following morphologic features:

- confluence of trabeculae to a relatively dense bone plate
- increase of trabecular dimension
- relatively broad transverse bars joining trabeculae to a heavy mesh-work
- large amounts of irregular aggregates of bone in or near the subchondral plate.

Low hardness values were found to be associated with some of the following morphologic features:

- a thin subchondral plate
- decreased dimensions of subchondral bone trabeculae
- less regular trabecular arrangement
- orientation of the trabeculae more obliquely towards the joint surface.

DISCUSSION

In testing physical properties of cancellous bone some difficulties arise, among which is the inhomogenity of the trabecular structure. Furthermore, the preparation technique may enhance the difficulties by disrupting a surface which is being prepared, for example, for hardness tests. In this investigation the preparation of the subchondral bone was checked under an operation microscope. Verification of the relative intactness of the subchondral bone surface (bone plate) was

Table 7. Mean hardness values (N/mm²) in subchondral bone in varying areas in specimens with severe osteoarthrosis

Specimen	Condition of cartilage covering measured areas		
	Normal cartilage	Slight osteoarthrosis	Severe osteoarthrosis
Specimens with severe osteoarthrosis in medial facet $n=6$	44.2	46.3	41.4
Specimens with severe osteoarthrosis in lateral facet $n=7$	36.5	40.7	37.6
Specimens with severe osteoarthrosis in transverse parts $n=10$	39.7	38.6	39.5

obtained by objective methods, i.e. histologic and microradiographic examinations. By these latter methods it could be shown that the hardness tests were carried out on an even trabecular bone surface. The aim was thus achieved to prepare the specimens in a way which allowed the tests to be carried out directly on subchondral bone. The histologic examination also served in the further analysis of the trabecular structure and its relationship to the observations made in the hardness tests. The morphologic features observed in this investigation corresponded well to those earlier described by Green et al. (1970) and Stougård (1974).

The hardness values for the subchondral bone in the normal material in this investigation were comparatively uniform with a mean of 38.4 (SD 3.5) N/mm^2. The mean hardness value of the bone beneath changes corresponding to chondromalacia grade 1, 40.8 N/mm^2, was somewhat higher than that of the normal material. The mean hardness value in the bone beneath changes corresponding to chondromalacia grade 2–3 was on the whole the same as that of the normal material. The variation, however, in chondromalacia grade 1, SD 7.3 N/mm^2, and in chondromalacia grade 2–3, SD 6.4 N/mm^2, was significantly ($P < 0.05$) greater than the variation in the normal material.

The mean hardness value in the bone beneath normal cartilage in patellae with chondromalacia grade 1 and chondromalacia grade 2–3, 43.8 N/mm^2 and 45.4 N/mm^2, respectively, was significantly higher ($P < 0.05$) than the mean hardness value in the normal material. The variation in hardness values in the subchondral bone in normal parts of patellae with chondromalacia grade 2–3, SD 7.5 N/mm^2, was significantly ($P < 0.05$) greater than the variation in the normal material.

On perusing the hardness values obtained for the individual test areas (areas A–J; cf. Figure 1) no greater variation was noted in the normal patellae though a higher mean hardness value was found in area D and E, and a lower in area H.

In the material with chondromalacia grade 2–3 the hardness values in the bone under the focus of the degenerated cartilage were lower than the hardness both in the bone beneath slightly degenerated cartilage and in the bone beneath normal cartilage of the same specimens. In 22 out of 32 comparisons the hardness values of the chondromalacia grade 2–3 areas were lower than those of the adjacent chondromalacia grade 1 areas (mean difference 5.3 N/mm^2). In all specimens but one, the mean hardness value of chondromalacia grade 2–3 areas was lower than that of the chondromalacia grade 1 areas (mean difference 6.1 N/mm^2). In 29 out of 34 comparisons the hardness values of the chondromalacia grade 2–3 areas were lower than those of the adjacent normal areas (mean difference 7.4 N/mm^2). In all specimens the mean hardness value of the chondromalacia grade 2–3 areas was lower than that of the normal areas (mean difference 8.1 N/mm^2).

The normal material consisted of individuals whose ages did not correspond to those representing the osteoarthrosis group. In the course of this investigation it became evident that no patella appeared normal over the age of 36 years. This observation also coincides with those of others, e.g. Emery & Meachim (1973). For this reason no comparison of the hardness values of subchondral bone in the normal material has been made with those of the osteoarthrosis group.

In the comparatively small material ($n = 5$) with slight osteoarthrosis only, the mean hardness value of bone in the slight osteoarthrosis areas was slightly higher than the value of the normal areas of the same specimens.

In the material with severe osteoarthrosis the mean hardness value of the bone in areas with severe osteoarthrosis, 38.3 N/mm^2, was somewhat lower than the mean hardness value of the bone beneath normal cartilage, 40.1 N/mm^2. However, the variation of the hardness values for subchondral bone in areas with severe osteoarthrosis (SD 10.4 N/mm^2) was significantly ($P < 0.05$) higher than that in the normal areas of the same specimens (SD 8.5 N/mm^2).

The hardness values of the severe osteoarthrosis material in age group 36–45 years were somewhat higher than those in age group 46–75 years (Table 7).

In the severe osteoarthrosis material the mean hardness values of the medial facet areas were lower than those of the lateral facet areas irrespective of cartilage condition (Table 2). The distribution of severe osteoarthrosis was not found to be correlated with the measured hardness value in the subchondral bone.

In conclusion it may be said that the mean hardness values of the bone beneath chondromalacia grade 1 and chrondromalacia grade 2–3 changes differed only slightly from those of the normal material. The chondromalacia grade 2–3 values had a larger variation. The mean hardness value of the bone beneath chondromalacia grade 2–3 changes was significantly ($P < 0.05$) lower than that of the bone beneath normal parts of the same specimens. The mean hardness values of bone beneath normal parts of the cartilage in specimens with chondromalacia grade 1 and chondromalacia grade 2–3 changes were significantly ($P < 0.05$) higher than those of the normal material. In the specimens with osteoarthrosis the mean hardness values of bone beneath cartilage changes differed only slightly from those beneath normal parts of the same specimens. The variation in hardness values of bone beneath severe osteoarthrosis was significantly ($P < 0.05$) higher than that of bone beneath normal parts of the same specimens.

Hardness of the subchondral bone of the medial tibial condyle has been described by Lereim et al. (1974). It was found that the hardness increased significantly with increasing age irrespective of sex. In the present investigation it was found that in the chondromalacia material (age 15 to 34 years) the hardness did not correlate with age. In the osteoarthrosis material (age 36–75 years) there was a slight tendency for hardness of subchondral bone to decrease with increase in age. Moreover, no correlation could be found between hardness and sex, right or left side, and type of patella according to the classification of Wiberg (1941).

In the above-mentioned investigation by Lereim et al. (1974) it was also noted that difference of hardness in osteoarthrosis and rheumatoid arthritis in comparison with normal bone was associated with destructive phenomena of various types like invasion of granulation tissue, osteoporosis and signs of remodelling. In the present investigation there was a tendency for there to be a relationship between variation in hardness values and bone structure. Thus, high hardness values were found most often to be associated with confluence of the trabeculae to a relatively dense bone plate, increase of trabecular thickness, thick transverse bars joining trabeculae to a heavy mesh-work and large amounts of irregular aggregates of bone in or near the subchondral plate. Low hardness values were most often associated with either a thin subchondral plate, decreased density of the bone plate, less regular arrangements of the cancellous bone trabeculae, thin bone trabeculae and orientation of the trabeculae obliquely to the joint surface.

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