J. Anat. (1992) **180**, pp. 425–433, with 8 figures. Printed in Great Britain

Distribution of subchondral bone density and cartilage thickness in the human patella

F. ECKSTEIN, M. MÜLLER-GERBL AND R. PUTZ

Anatomische Anstalt, Ludwig-Maximilians-Universität München, Germany

(*Accepted 21 February 1992*)

ABSTRACT

Subchondral bone density (by means of CT osteoabsorptiometry), and cartilage thickness (directly measured on photocopies of frozen sections), were examined in 30 human patellae, with an age range from 47 to 90 y. A surface demonstration of the distribution was prepared, and representative pictures produced by summation with a computer. Subchondral bone-density maxima were found in the proximal part of the lateral facet, and the density pattern interpreted as the expression of the long-term distribution of stress in the joint. It is reasonable to assume that cartilage thickness, of which two-thirds of the maximum values occupy a lateral position, is also dependent on the local stress. The 2 distributions show correlation coefficients > 0.5 in approximately a third of the cases we examined. Displacement of the higher values of cartilage thickness relative to the subchondral density maxima is attributed to incongruence in the medial part of the joint.

INTRODUCTION

Although there are many publications dealing with chondromalacia of the patella and arthrosis of the femoropatellar joint, there has been very little written on the functional architecture of the bone and cartilage in the patella itself. Such work as there is involved a small number of specimens, and goes no further than an assessment of subchondral bone density and total articular cartilage thickness in single sections (Marar et al. 1975; Tillmann & Brade, 1980; Hehne, 1983; Putz et al. 1987). Even so, Radin et al. (1970, 1975, 1978) drew attention to the importance of subchondral bone for shock absorption in joints. They established that subchondral changes occur in the early stages of arthrosis—i.e. with an increase of stiffness—so that the importance of the subchondral region for the development of the very commonly occurring damage found in the articular cartilage of the patella can be accepted.

According to Pauwels (1965) and Oberländer & Kurrat (1982), the distribution of both the subchondral bone density and the thickness of the articular cartilage is due to the process of functional adaptation to the long-term loading history of a joint; and from either of these parameters the distribution of the stresses in the joint can be derived. A positive correlation between the subchondral density and the distribution of cartilage thickness has accordingly been demonstrated in the hip joint (Oberländer, 1973, 1977), although this does not seem to have been confirmed with certainty in the femoropatellar joint (Putz et al. 1987).

The object of this investigation is, therefore, to arrive at a precise demonstration of the relevant parameters in a large sample, and their relationship to existing concepts of the mechanics of the femoropatellar joint. The assessment of the bone density is supported by the use of CT osteoabsorptiometry (CT-OAM), introduced by Müller-Gerbl et al. (1989, 1990).

MATERIALS AND METHODS

We examined 30 specimens of the knee joint (13 pairs, 4 single), fixed in an iron-free buffered solution of 4% formalin and 0.5% phenol. This sample was chosen from 120 specimens available in the dissecting-room during a normal course in topographical anatomy, our object being to obtain an age distribution which

Correspondence to Dr F. Eckstein, Anatomische Anstalt, Ludwig-Maximilians-Universität München, Pettenkoferstrasse 11, D-8000 München 2, Germany.

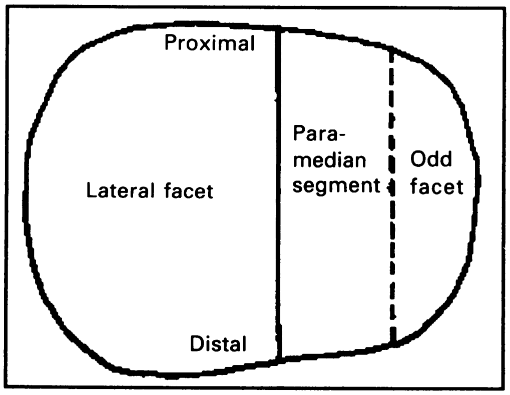

Fig. 1. Outline template of the articular surface of the patella, built up from measurements of 30 joints.

included as many younger individuals as possible. Care was also taken to ensure that the specimens presented a normal appearance to the naked eye, and that the CT findings obtained at the beginning of the investigation revealed no indications of osteoarthritic change in the femoropatellar joint. The cause of death was known for all individuals examined, but not the length of any possible hospitalisation or immobilisation immediately preceding death. The height and weight of the subjects were also unknown. There was no indication of any disease of the passive locomotor apparatus.

The age at death of the subjects ranged from 47 to 90 y, with 15 of these aged less than 60 y making up a younger group Y (mean age 53 y) set against 15 specimens from older subjects (group O; mean age 73 y). Since only 7 specimens came from women (group W), these latter were compared with 7 specimens from men of the same age (group M).

Measurement of subchondral bone density

The knee joints were placed in extension in a CT scanner (Siemens Delta Scan 50 FS 2). Transverse sections 4 mm apart with an overlapping section thickness of 8 mm were taken between the tibial plateau and the upper pole of the patella. CT osteoabsorptiometry (Müller-Gerbl et al. 1989, 1990) was used to obtain 'isodensities' (contour lines joining

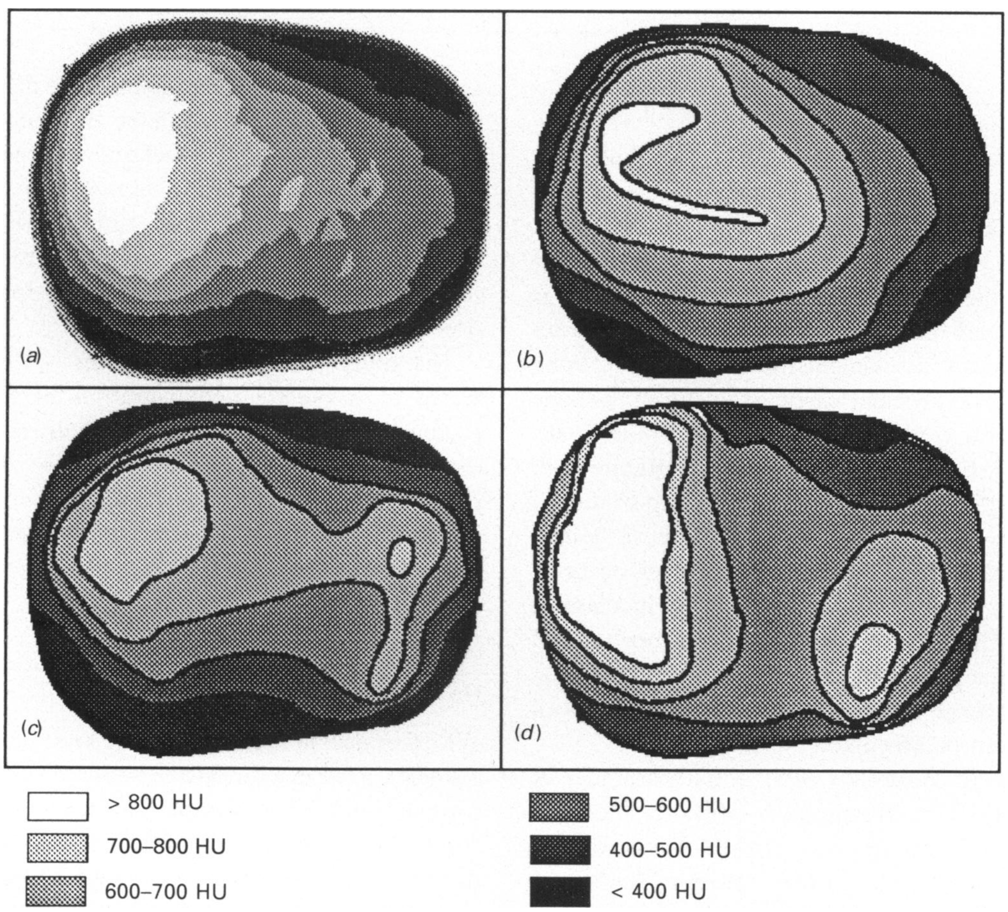

Fig. 2. Surface distribution of the subchondral bone density in the patella. (*a*) Summation picture of all patellae examined (n = 30). (*b*) Single example of concentric decay of the density values (specimen 17). (*c*) Single example of extension of the region of moderate density (600–700 HU) medially (specimen 18). (*d*) Single example of isolated increases of density medially in the region of the secondary ridge (specimen 2).

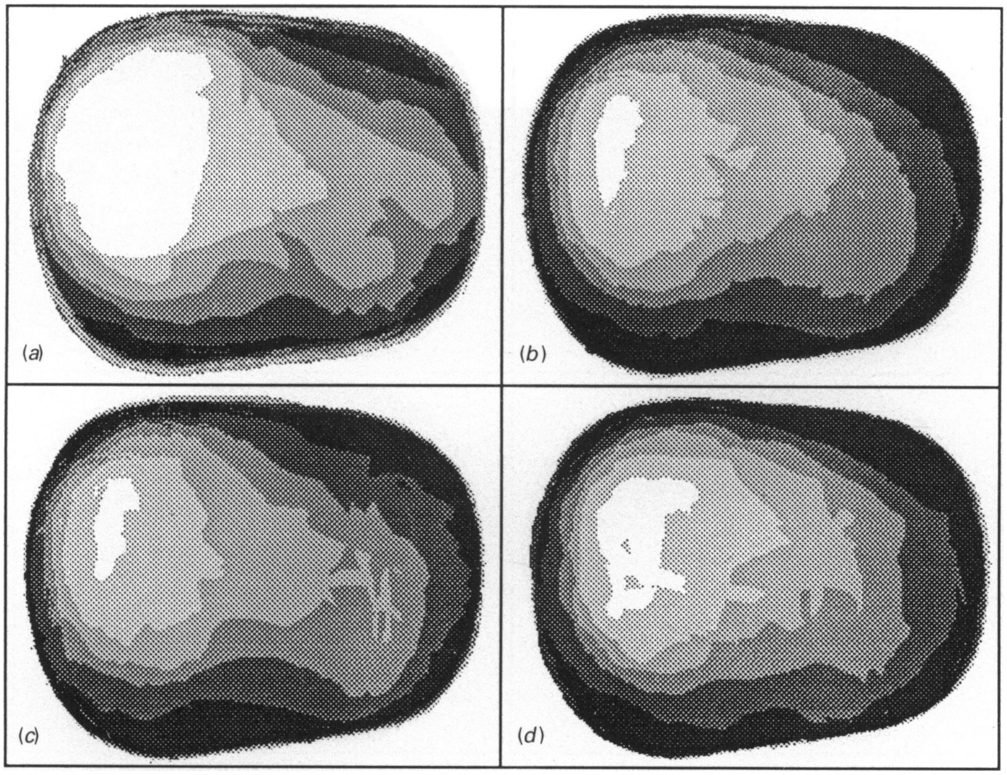

Fig. 3. Summation picture of the surface distribution of the subchondral bone density in the patella. (*a*) Group Y (age < 60 y, n = 15); (*b*) Group O (age > 60 y, n = 15); (*c*) Group M (men, n = 7); (*d*) Group W (women, n = 7).

points of equal density) of 400, 500, 600, 700 and 800 Hounsfield units (HU) on each section, high Hounsfield values representing areas of dense bone. The density at a depth of 1.5 mm below the border between cartilage and subchondral bone was projected onto the articular surface and the distribution transferred from the CT sections to a 2-dimensional template (Fig. 1) reconstructed from measurements of all the patellae. The resulting 6 regions from < 400 HU to > 800 HU were provided with standardised 'grey' values in an Apple Macintosh computer, and the patterns fused in a black and white mixing program which calculates the average grey value for each pixel in the picture. The newly obtained intermediate 'grey' stages were then redefined as the closest neighbouring original grey shade, so that the isodensities could be restored to a summation picture.

Measurement of cartilage thickness

Frozen sections, 4 mm thick, were taken from each specimen, care being taken to ensure that each individual transverse section was cut at right angles to the surface of the cartilage. Each section was then photocopied (Xerox 1025), and the total cartilage thickness from the dividing line between black and white (an idealised macroscopic representation of the jagged border between calcified cartilage and subchondral bone) was measured perpendicular to the articular surface. Measurements of each section were taken at 7 predetermined points: in the centre of the 'odd facet', at the secondary ridge, in the centre of the paramedian segment, at the principal ridge, and at 3 equidistant points distributed over the lateral facet. The means of 6 sets of measurements made on the copies lay in all cases within 1 S.D. of the corresponding sets of measurements made on the original, and the S.D. for the single measurements on the copy was ±1.7%. By representing the integral intermediate values (in millimetres) graphically and joining them to form contour lines, the distribution of the cartilage could be represented in 2 dimensions. For establishing summation pictures, the same technique was used as for subchondral bone density.

Correlating subchondral bone density with cartilage thickness

In order to compare the 2 distributions, the Hounsfield region corresponding locally to each measurement of cartilage thickness was determined, and the 2 values transferred to a Cartesian coordinate system. Paired values from regions of severely damaged cartilage (grades 2 and 3) were eliminated after documentation

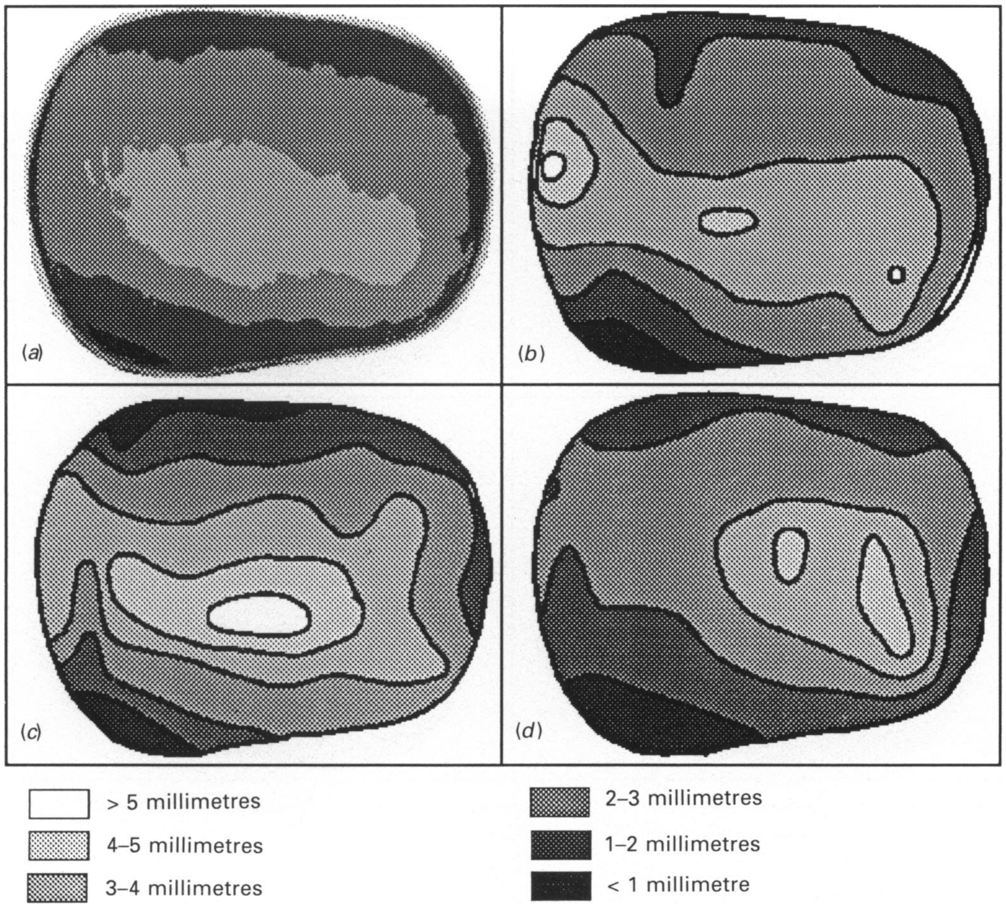

Fig. 4. Surface distribution of the cartilage thickness in the patella. (*a*) Summation picture of all patellae examined (n = 30). (*b*) Single example of a maximum at the lateral border of the joint surface (specimen 3). (*c*) Single example of a maximum in the medial region of the lateral facet (specimen 10). (*d*) Single example of maxima lying medially over the ridges (specimen 6).

of the lesion. A correlation coefficient was finally calculated for each individual patella, although this was for technical reasons only possible for 26 of the 30 bones examined.

RESULTS

Subchondral bone density

The region of maximum bone density was constantly found in the proximal part of the lateral facet and amounted to between 600 and 1100 HU, the density values falling off towards the periphery (Fig. 2*a*). In about a third of the cases a practically concentric pattern appeared (Fig. 2*b*), in a further third the regions of intermediate density extended medially (Fig. 2*c*) and in the remaining third island peaks were seen medially in the region of the secondary ridge (Fig. 2*d*).

In the younger subjects (group Y, Fig. 3*a*) there was a greater extension of the highest density level than in group O (Fig. 3*b*). A significant overlap of the more highly mineralised density regions towards the medial was particularly striking in the younger group. Comparison of group M (Fig. 3*c*) with group W (Fig. 3*d*) revealed a slightly greater extension of the highest density level in women.

Cartilage thickness

The thickness maxima for the cartilage lay between 3.0 and 5.5 mm, and they were distributed horizontally over the facets and ridges half-way between the upper and lower borders of the patella. The articular cartilage was found to be most thickly developed within a strip which ran from lateral to medial (Fig. 4*a*), although there was a greater degree of variation in the distribution pattern than for the subchondral density. The maxima lay laterally in two-thirds of the cases, over the principal ridge in one-sixth, and medially in the remaining sixth. They were frequently localised at the lateral border of the patella (Fig. 4*b*), in the medial part of the lateral facet (Fig. 4*c*) and over the principal and secondary ridges (Fig. 4*d*).

The cartilage was thicker in group Y than in group O (Fig. 5*b*), and thicker in group M (Fig. 5*c*) than in group W (Fig. 5*d*).

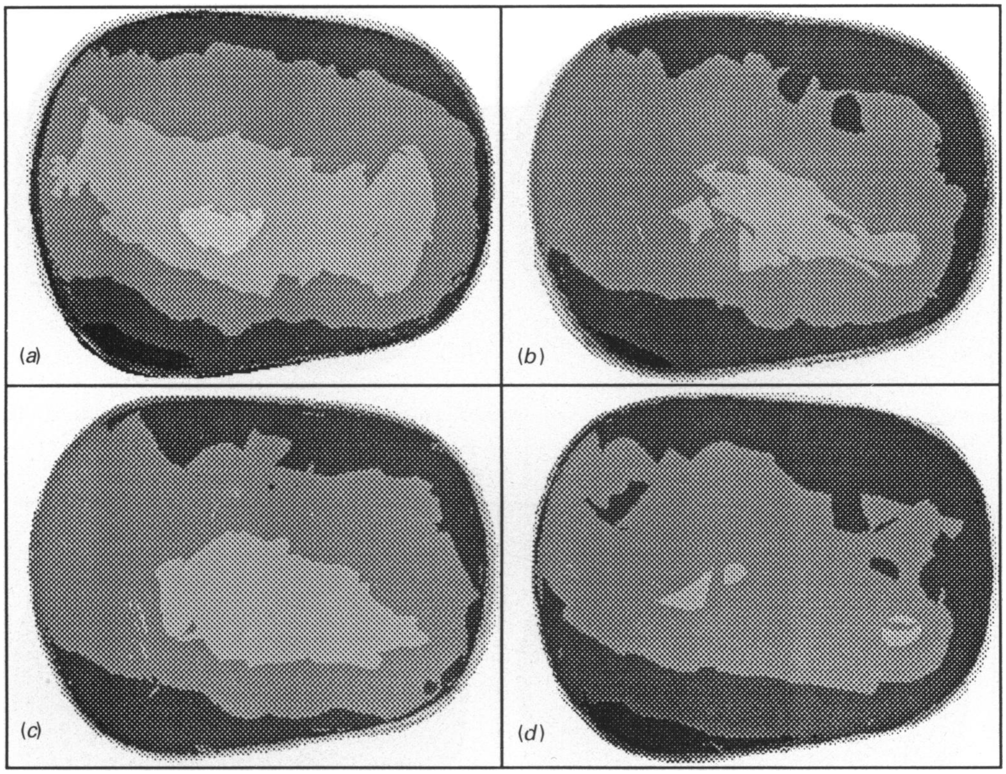

Fig. 5. Summation picture of the surface distribution of the cartilage thickness in the patella. (*a*) Group Y (age < 60 y, n = 15); (*b*) Group O (age > 60 y, n = 15); (*c*) Group M (men, n = 7); (*d*) Group W (women, n = 7).

Table 1. *Correlation coefficients* (r) *for the 26 patellae examined (coefficients* >*0.5 in italics)*

Specimen	(*r*)	Specimen	(*r*)
13	−0.149	22	0.439
6	0.026	5	0.451
19	0.031	17	0.468
2	0.173	27	*0.574*
18	0.179	20	*0.575*
	0.205	26	*0.596*
16	0.208	29	*0.605*
28	0.218	21	*0.649*
9	0.289	14	*0.663*
12	0.342	3	*0.689*
30	0.407	4	*0.725*
24	0.415	25	*0.791*
15	0.423	23	*0.862*

Correlation of subchondral density with cartilage thickness

The correlation coefficients between total thickness of the cartilage and the subchondral density for each of the patellae lay between $r = -0.149$ and $r = 0.862$. Correlation of the distributions in 10 of the 26 cases is represented by a coefficient greater than 0.5 (Table 1).

Figure 6 displays an example of high correlation ($r = 0.725$), and Figure 7 a typical displacement of higher values for the cartilage thickness in relation to the maxima for subchondral density towards the medial side over the ridges ($r = 0.026$). This is also striking when the summation pictures for the 2 parameters are compared.

DISCUSSION

Subchondral bone density

Our determination of the pattern of subchondral density extends the X-ray densitometry findings on individual sections reported by Tillmann & Brade (1980), Tillmann et al. (1981) and Hehne (1983), and the agreement is good insofar as it applies to the position of the maxima in the lateral region of the patella. This also agrees with the findings obtained with the photoelastic model and split-line analysis by the above-mentioned authors, who have reported stress maxima in the lateral facet. Furthermore, observation of the proximal–distal extension of the density distribution shows the maxima lying always in the proximal part of the lateral facet, as also observed by Hehne (1983). In the medial region of the joint, the surface demonstration reveals a whole variety of distribution patterns. This is again in accordance with the different conditions of stress reported medially by Tillmann & Brade (1980) following the interpretation of split-line patterns. To this extent the subchondral

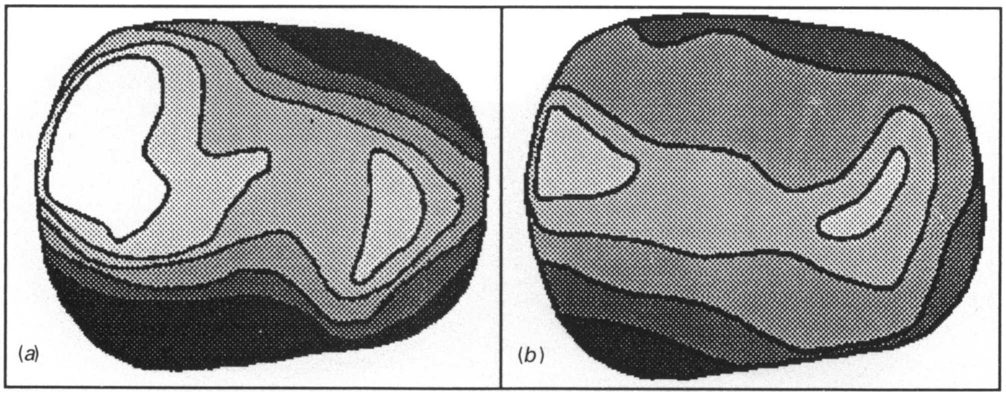

Fig. 6. Single example of high agreement of the distribution of the subchondral bone density (*a*) with that of the cartilage thickness (*b*) (specimen 4, $r = 0.725$).

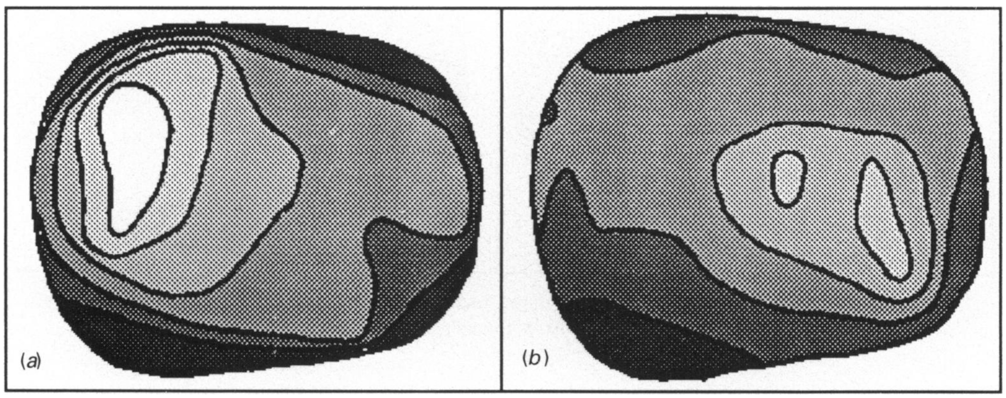

Fig. 7. Single example of a typical displacement of the higher cartilage thickness values (*b*) relative to the maximum subchondral density (*a*) medially on to the ridges (specimen 6, $r = 0.026$).

density distribution in the patella can be regarded—as in other joints (Pauwels, 1965; Tillmann, 1978)—as a materialised diagram of stress (verkörpertes Spannungsdiagramm).

When comparing our results with other reports on the transmission of pressure in the femoropatellar joint, it is important to remember that the distribution of subchondral bone density is determined (Pauwels, 1965) by the average long-term stress ('loading history', Carter, 1984). This means it is dependent on the areas of contact, on the size of the resultant and on the 'period of time during which the resultant force is effective in the various areas of the articular surface' (Tillmann, 1978). The proximal part of the lateral facet—which plays an active role at all angles of flexion greater than 60° (Hehne, 1983) and in which we found all the density maxima—is subject to great pressure, since the tension exerted by the quadriceps increases considerably when the knee joint is flexed (Maquet, 1976). Whereas there is a changeover medially from the paramedian segment across the secondary ridge to the 'odd facet' between 60° and 140° of flexion of the knee joint, the proximal facet on the lateral side is retained for all angles of flexion between 60° and 140° as a supporting prop (Hehne, 1983). Stress of greater duration on the lateral side of the joint can plausibly account for the greater degree of bone mineralisation in this region. It is, however, possible, that the functional dominance of the vastus lateralis and the lateral retinacula (Ficat & Hungerford, 1977) here play a certain role, which might lead to greater stress on the lateral facet.

Medial islands of increased density, which we found in a third of the subjects investigated, probably reflect the point-like contribution of the secondary ridge during the apposition of the articular surfaces on the medial side at 120° of flexion of the knee joint (Hehne, 1983), and it is possible that this may be traced back to a more extensive flexion of the knee joint in this group. This is also supported by the encroachment of the more highly mineralised region medially in the younger sample (group Y), in whom we must assume more active flexion of the joint than in the older subjects.

The distribution pattern of subchondral bone density found by us is therefore in agreement with the known theories of stress distribution in the femoropatellar joint and can provide information about the individual mechanical conditions of the joint. In this connection, CT osteoabsorptiometry makes possible a noninvasive and repeatable examination of patients to answer specific questions about deformities of the joint, for instance, or to monitor the postoperative course of a corrective osteotomy.

The absence of distinguishing sexual differences in the distribution of the subchondral density is surprising, insofar as one would expect it to be reduced in older women because of the high prevalence of osteoporosis. Whether this is simply a chance finding, or whether postmenopausal demineralisation of the bone does not extend to the subchondral region, must remain an open question. The lack of detailed information available also makes it impossible to throw any light on the influence of physique and weight on the degree of subchondral mineralisation.

The striking similarity of the density pattern with the distribution of stiffness of the subchondral patellar bone determined by Townsend et al. (1976) by means of compression tests is remarkable. A dependent relationship between the Hounsfield density and the mechanical parameters of the subchondral bone has already been demonstrated at the upper end of the tibia by Bentzen et al. (1987). Taking into account the statement by Radin et al. (1970, 1975, 1978) that an increase in stiffness of the subchondral bone may be the initial step in the development of osteoarthritis, one is forced to ask what significance the density pattern of the patella obtained by CT osteoabsorptiometry may have for our understanding of cartilaginous degeneration in the femoropatellar joint.

Whether stiffness gradients of the subchondral bone are really responsible for the initiation of damage to the cartilage (Abernethy et al. 1978) and an increased subchondral mineralisation for its progression (Radin et al. 1978; Pedley & Meachim, 1979) are questions which only further research can answer.

Cartilage thickness

Our findings concerning the distribution of the cartilage thickness—and particularly the predominantly lateral position of the maxima—are in agreement with those of Schlentzka et al. (1978) and Putz et al. (1987), but not with those of Marar et al. (1975) or Hehne (1983), who described the thickness maxima as usually medial. We attribute these differences to the superiority of the assessment from a 2-dimensional reconstruction of the distribution pattern over the examination of single axial sections used by Marar et al. (1975). In our opinion, measurements made with contrast arthrography, as used by Hehne (1983), are falsified by the density of the contrast medium and superimpositions in the region of the 2 ridges.

With regard to possible distortions due to fixation, Kurrat (1977) claims that this has no effect on cartilage thickness. Should any shrinkage nevertheless have occurred in our specimens, we assume that the percentage factor will be the same at all points, and this means that the primarily important 'relative' distribution of the thickness will remain unaffected.

Comparison of the average distribution of the thickness and the contact areas found by Hehne (1983) leads to similar positions for the area of thick cartilage and that of the most commonly occurring joint contact, which also coincides to a large extent with the contact surface at 60° of knee-flexion. It can be imagined that this region is frequently subjected to high pressure during everyday life; mounting a staircase, for instance, or during sports. We conclude that the thickness of the patellar cartilage also presents a distribution dependent upon stress, which confirms the findings of Oberländer & Kurrat (1982) in the elbow joint, and is in agreement with the results reported by Kiviranta et al. (1987), which demonstrated the adaptation of cartilage thickness to the current pressure conditions in experimental animals.

We are bound to ask why the cartilage thickness maxima are so variously distributed, and why a third of them lie over the principal ridge and in the medial part of the joint. It should not be forgotten that our measurements were sometimes distorted by damage to the cartilage, which naturally makes interpretation more difficult. Such damage was found invariably in the older subjects, and was by no means uncommon in the younger group. However, the younger group Y reflects the relationships in a healthy joint better; and in these subjects the thickness maxima in the summation pictures lay—in contrast to the older group O—within the lateral facet. The reduced cartilage thickness in the older subjects—particularly the women—can be attributed to the reduction of the matrix brought about by cartilaginous lesions, which are generally found in greater numbers in the women and on the lateral facet (Meachim et al. 1977). We are able to confirm this distribution in our own material.

Correlation of subchondral density with cartilage thickness

The extensive agreement between the distribution patterns of both parameters in one patella reported by Putz et al. (1987) applied to approximately one-third of our material. In the other cases the differences between them was sometimes considerable. This naturally makes one ask why, in contrast to the conditions in other joints of the lower limb (Oberländer, 1973, 1977), the femoropatellar joint presents a positive correlation between the subchondral density and the cartilage thickness in only a limited number of cases. Since paired values from regions of severe damage to the cartilage were eliminated from this comparison, the answer cannot lie in loss of thickness due to pathological change. This is supported by the fact that examples of positive correlation were not found in our material predominantly in the younger subjects, in whom damage to the cartilage was less marked.

The very variable degree of incongruence in the medial region of the joint (Wiberg, 1941; Hepp, 1983) might, however, account for the great differences in the correlation between bone density and cartilage thickness. The suggestion of Pauwels (1965) that the distribution of the subchondral bone density is principally a reflection of the main static stress on the joint, may be of some importance in this connection, and this—according to the comments made above—is supposed to lie most often in the proximal part of the lateral facet.

As against this, Pauwels (1965) ascribed the cartilage-preserving function to an intensive 'kneading'—i.e. to an intermittent stress with short loading peaks. Medial incongruence of the patella results in 'point-like' contact areas at the secondary ridge and odd facet, owing to the alteration of the contact surfaces in extreme flexion of the knee joint (Hehne, 1983), which is responsible for the recognised mechanical conditions. This interpretation is in agreement with the finding of Müller-Gerbl et al. (1988) on the shoulder, showing different distribution patterns of the subchondral bone density and the cartilage thickness in this joint.

We conclude that the distribution of both variables can be interpreted as the expression of a biomechanical function, thus providing a reasonable explanation of the structure–function interdependence as a functional adaptation. Whether or not we have here a key to the pathogenesis of damage to the cartilage of the patella, and how the distribution of cartilaginous degeneration is related to the patterns of thickness and density distribution which have appeared, must remain open questions.

ACKNOWLEDGEMENTS

Our grateful thanks are due to Professor W. Platzer, Director of the Department of Anatomy, University of Innsbruck, for generously putting this material at our disposal and for making the computer tomographic exposures possible on the scanner of the institute. We also thank Dr F. Steel for the translation of the manuscript.

REFERENCES

Abernethy, PJ, Townsend PR, Rose RM, Radin EL (1978) Is chondromalacia patellae a separate clinical entity? *Journal of Bone and Joint Surgery* **60B**, 205–210.

Bentzen SM, Hvid I, Jorgensen J (1987) Mechanical strength of tibial trabecular bone evaluated by X-ray computed tomography. *Journal of Biomechanics* **20**, 743–752.

Carter DR (1984) Mechanical loading histories and cortical bone remodeling. *Calcified Tissue International* **36**, 519–524.

Ficat P, Hungerford DS (1977) *Disorders of the Patellofemoral Joint*. Paris: Masson.

Hehne HJ (1983) *Das Patellofemoralgelenk*. Stuttgart: Enke.

Hepp HP (1983) *Radiologie des Patellofemoralgelenkes*. Stuttgart: Enke.

Kiviranta I, Jurvelin J, Marrku T, Säämänen AM, Helminen HJ (1987) Weight bearing controls glycosaminoglycan concentration and articular cartilage thickness in knee joints of young beagle dogs. *Arthritis and Rheumatism* **30**, 801–809.

Kurrat HJ (1977) Die Beanspruchung des menschlichen Hüftgelenks. 6. Eine funktionelle Analyse der Knorpeldickenverteilung am menschlichen Femurkopf. *Anatomie und Embryologie* **150**, 129–140.

Maquet PGJ (1976) *Biomechanics of the Knee*. Berlin, Heidelberg, New York: Springer.

Marar BC, Orth MC, Pillay VK (1975) Chondromalacia of the patella in Chinese. *Journal of Bone and Joint Surgery* **57A**, 342–345.

Meachim G, Bentley G, Baker R (1977) Effect of age on thickness of adult patellar articular cartilage. *Annals of the Rheumatic Diseases* **36**, 563–568.

Müller-Gerbl M, Putz R, Hodapp N, Schulte E, Wimmer B (1989) Computed tomography-osteoabsorptiometry for assessing the density distribution of subchondral bone as a measure of long-term mechanical adaptation in individual joints. *Skeletal Radiology* **18**, 507–512.

Müller-Gerbl M, Putz R, Hodapp N, Schulte E, Wimmer B (1990) Die Darstellung der subchondralen Dichtemuster mittels der CT-Osteoabsorptiometrie (CT-OAM) zur Beurteilung der individuellen Gelenkbeanspruchung am Lebenden. *Zeitschrift für Orthopädie und ihre Grenzgebiete* **128**, 128–133.

Müller-Gerbl M, Putz R, Schulte E (1988) Zur Verteilung der Knorpeldicke und der subchondralen Knochendichte in der Cavitas glenoidalis. *Verhandlungen der Anatomischen Gesellschaft* **82**, 393–394.

Oberländer W (1973) Die Beanspruchung des menschlichen Hüftgelenks. 5. Die Verteilung der Knochendichte in Acetabulum. *Zeitschrift für Anatomie und Entwicklungsgeschichte* **140**, 367–384.

Oberländer W (1977) Die Beanspruchung des menschlichen Hüftgelenks. 8. Die Verteilung der Knorpeldicke im Acetabulum und ihre funktionelle Deutung. *Anatomie und Embryologie* **150**, 141–153.

Oberländer W, Kurrat HJ (1982) Die Knorpeldickenverteilung im distalen Teil des Ellenbogengelenks und ihre funktionelle Deutung. *Morphologia Medica* **2**, 45–52.

Pauwels F (1965) *Gesammelte Abhandlungen zur Biomechanik des Bewegungsapparates*. Berlin, Heidelberg, New York: Springer.

Pedley RB, Meachim G (1979) Topographical variation in patellar subarticular calcified tissue density. *Journal of Anatomy* **128**, 737–745.

Putz R, Müller-Gerbl M, Schulte E, Wimmer B (1987)

Verteilung der Knorpeldicke und der Mineralisierung im Kniegelenk. In: *Der alloplastische Ersatz des Kniegelenkes* (ed. H. J. Refior, M. H. Hackenbroch & C. J. Wirth). Stuttgart, New York: Thieme.

Radin EL, Abernethy PJ, Townsend PM, Rose RM (1978) The role of bone changes in the degeneration of articular cartilage in osteoarthritis. *Acta Orthopaedica Belgica* **44**, 55–63.

Radin EL, Paul IL, Lowy M (1970) A comparison of the dynamic force transmitting properties of subchondral bone and articular cartilage. *Journal of Bone and Joint Surgery* **52A**, 444–456.

Radin EL, Paul IL, Rose RM (1975) Mechanical factors in the aetiology of osteoarthritis. *Annals of the Rheumatic Diseases (Supplement)* **34**, 132–133.

Schlentzka D, Schwesinger G, Plewka F (1978) Zur Chondropathia patellae. *Beiträge zu Orthopädie und Traumatologie* **25**, 559–563.

Tillmann B (1978) A contribution to the functional morphology of articular surfaces. In: *Normale und pathologische Anatomie, Band 34* (ed. W. Burgmann & W. Doerr). Stuttgart, New York: Thieme.

Tillmann B, Blauth M, Schleicher A (1981) Zugverspannungen der Patella. In: *Kapselbandläsionen des Kniegelenkes* (ed. Jäger, M. H. Hackenbroch & H. J. Refior. Stuttgart: Thieme.

Tillmann B, Brade H (1980) Die Beanspruchung des Femoropatellargelenkes. *Anatomischer Anzeiger* **147**, 477–478.

Townsend PR, Miegel RE, Rose RM, Raux P, Radin EL (1976). Structure and function of the human patella: the role of cancellous bone. *Journal of Biomedical Material Research Symposium* **7**, 605–611.

Wiberg G (1941) Roentgenographic and anatomic studies on the femoropatellar joint. *Acta Orthopaedica Scandinavica* **12**, 319–410.