PATELLO-FEMORAL JOINT MECHANICS AND PATHOLOGY

1. FUNCTIONAL ANATOMY OF THE PATELLO-FEMORAL JOINT


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Cadaver knee joints were mounted so that life-like forces of weight-bearing were simulated. The patello-femoral contact areas were defined under load throughout the range of movement by the dye method. During movement from extension to 90 degrees of flexion a band of contact sweeps across the patella from inferior to superior pole, but the odd facet makes no contact. At about 135 degrees of flexion separate medial and lateral contact areas form, the medial one limited to the odd facet. From extension to 90 degrees of flexion the patella holds the quadriceps tendon away from the femur, but in further degrees of flexion an extensive “tendo-femoral” contact area forms. Between 90 degrees and 135 degrees of flexion the patella rotates and the ridge between the medial and odd facets engages the femoral condyle. The odd facet is shown to be a habitual non-contact area and the ridge to be subject to high load, observations which correlate with cartilage lesions described in Part 2 of the paper.

In the course of investigating the degenerative changes which occur in the cartilage of the patella we found it necessary to review the normal anatomy of the patello-femoral joint, and to establish the precise areas of cartilage that sustain load in various positions of that joint.

Wiberg (1941) gave an excellent description of the varied forms of the patella, and by a variety of indirect methods of examination, including plain radiography, contrast arthrography and serial sectioning of frozen joints, he provided a general picture of the changing pattern of contact which occurs with movement of the knee. His method did not allow a sequence of observations in several positions in any one joint, and his conclusions were by inference from the contact areas observed in several joints, each in a different position. Furthermore, his studies on cadaveric joints were made in the unloaded state, and no serious attempt was made to reproduce the forces about the knee that stabilise it in life and to some extent determine the relative positions of its components.

The following description is based upon observations made on cadaveric joints in which the forces of normal weight-bearing were closely simulated.

EXPERIMENTAL PREPARATION

Normal knee joints from young subjects were removed at necropsy, and the femur and the tibia were sectioned well above and below the joint. After removal the whole joint was stored at −20 degrees Celsius and unfrozen immediately before use. Figure 1 explains the principle of the preparation. The wire (a) was woven through the quadriceps tendon immediately above the patella and fixed to the free end of the intramedullary rod (b). The length of this wire determined the degree of flexion which resulted when a weight was suspended from the end of the rod. The whole preparation was held with the tibia upright by a second intramedullary rod within the tibial shaft (c), fixed to the bench.

The preparation can therefore reproduce with some accuracy the physiological circumstances of static weight-bearing in all positions short of full extension, imposing no restriction upon the relative positions of the components of the joint, which are free to assume whatever relationship the balance of “muscle” and ligament tone imposes. By lengthening or shortening the wire (a) by means of a windlass the joint could be made to flex and extend at will throughout its whole range.

Of course, the line of pull of the wire (a) might not accurately represent that of the massive quadriceps muscle, but it was found in initial experiments that alterations in the line of pull within reasonable limits did not at all affect the position which the patella adopted. It was also shown by progressive excision under load that the medial and lateral quadriceps expansions were inessential, and that only the patellar tendon need be preserved to achieve a realistic position of the patella. In other words, under load the configuration of the joint surfaces and the length of the patellar tendon determine the posture and position of the patella.

It is remarked, in passing, that in all positions the tibio-femoral articulation enjoyed a freedom of rotation about a vertical axis of about 10 degrees in both directions from the position in which it settled. In the accomplishment of this movement the patella moved with the femur and no relative displacement occurred.

CONTACT PRINTS

With this preparation the patello-femoral contact areas were delineated by a dye technique similar to that described by Greenwald (1970) and modified by Deane (1970).

A sequence of four contact prints was made on each
Diagram of the experimental model. 

Diagrammatic representation of contact areas on the patella in varying degrees of flexion (see text).

Joint in 20, 45, 90 and 135 degrees of flexion. In this technique a series of dyes is injected into the joint. The dye stains all the non-contact areas of both joint surfaces and leaves the contact areas unstained. Whenever the resulting contrast was inadequate for photographic reproduction the contact area was outlined by pricking the cartilage with a needle dipped in Indian ink.

In Figure 2 the altering regime of contact is shown diagrammatically on the patellar outline at 20, 45 and 90 degrees of flexion. As the joint moves from extension to flexion a band of contact moves upwards over the patellar surface. As flexion increases, not only does the band move up, but it also becomes steadily broader. At about 90 degrees the contact area has reached the upper pole of the patella.

For the purposes of the argument which follows, it is important to note that whereas the band of contact reaches to the lateral margin of the patella in all these joint positions, it fails to reach the medial margin. Thus an odd medial facet is outlined which does not make contact in any position from full extension to 90 degrees flexion. The dotted line AB on the same diagram, which outlines the path of the medial margin of the contact zone, is found to coincide with a ridge upon the patella, which separates the odd facet from the medial facet proper.

Figure 3 shows the contact areas in the last position tested, 135 degrees of flexion. The contact band has now divided into separate medial and lateral zones, and the medial zone lies medial to the ridge (AB) and more or less exactly fits the "odd" facet.

Figures 4 to 7 exemplify the photographic evidence from which the diagrams in Figures 2 and 3 were constructed. The latter are approximations to the results in twenty-one knees tested.

INTERPRETATION

The loads employed (two to ten kilograms) were much less than those which occur in life. However, the joint surfaces are so distinctly incongruous that, while accepting that under some physiological conditions the contact areas will be marginally greater than those demonstrated, we believe that the pattern revealed is essentially position dependent rather than load dependent.

If the contact prints of the femur and patella are compared it is seen that up to 45 degrees of flexion the patella is the only component of the extensor mechanism which makes contact with the articular surfaces of the femur (Figs. 4 and 5). It holds the posterior surface of the quadriceps tendon away from the bone, and the very limited contact area of the patella must sustain the whole
Figures 4 to 7
Photographs of each stage of the experiment on one (right) knee. The extensor mechanism with the patella is turned down so that the femoral and patellar contact areas are revealed: Figure 4—20 degrees, Figure 5—45 degrees, Figure 6—90 degrees, Figure 7—135 degrees.
of that component of the force of the quadriceps muscle which acts at right angles to the articular surface of the femur. The magnitude of this component increases as flexion proceeds, and it is probably more than a coincidence that the area of the band of patello-femoral contact also increases.

Thereafter it might appear, from a consideration of the patellar contact areas only, that the surfaces available for the transmission of this component of the load actually diminished, with the development of the small medial and lateral contact areas. However, the patellar facets of the femur demonstrate an extensive (undyed) contact area in all positions of flexion beyond 90 degrees, an area which now makes contact with the broad posterior part of the patella which makes contact with the true tibial surface of the medial condyle of the femur; no such distinction of function exists on the lateral side of the joint.

It follows that in the performance of a range of movement from extension to 90 degrees of flexion all the articular surface of the patella, save only the odd facet, articulates with the femur. Only when flexion proceeds to about 135 degrees does the odd facet articulate.

It has been the authors' observation, both in the operation theatre and in the post-mortem room, that surface fibrillation of the cartilage of the odd facet is frequently found limited to this area (see Part 2). We attribute these surface degenerative changes on the odd facet, as we have done in other non-contact areas, to habitual disuse (Goodfellow and Bullough 1967). The cartilage of this facet is certainly out of contact when standing, sitting, walking and running, and probably out of contact during the hours of sleeping.

The possible significance of this facet of the patella in causing osteochondritis dissecans has already been discussed by Baumgartl (1964) and Aichroth (1971). The area of patellar contact on the lateral margin of the medial femoral condyle certainly matches the site at which this lesion is commonly found (see Fig. 7).

Lastly we would draw attention to the ridge which separates the medial from the odd facet. Beyond 90 degrees of flexion, as the patella slips off the true patellar facets of the femur, the ridge is engaged by the rounded lateral margin of the medial femoral condyle and there is a position between the two regimes of contact (between the positions shown in Figures 8 and 9) when the load is borne along its crest. In Part 2 of the paper it is suggested that this anatomical feature may account for the localisation at this site of some cartilage lesions typical of chondromalacia patellae.

**COMMENT**

These findings confirm the main features of Wiberg's description. His cross-section of frozen joints in several positions of flexion demonstrated, as do our contact prints, the unique circumstances of the cartilage on the odd facet. This part of the patella never makes contact with the true patellar facets of the femur; it is the only facet, as we have done in other non-contact areas, to habitual disuse (Goodfellow and Bullough 1967). The cartilage of this facet is certainly out of contact when standing, sitting, walking and running, and probably out of contact during the hours of sleeping.

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**REFERENCES**


