LOCKING AT THE KNEE JOINT

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INTRODUCTION

Many theories have been advanced in the past to account for the medial rotation of the femur upon the tibia that takes place during the last phase of extension at the knee joint. For example, this 'locking' movement has been ascribed to tautening of the anterior cruciate ligament (Young, 1889), unwinding of the twisted cruciate ligaments (Haines, 1941), an inclined axis of rotation (Meyer, 1853), unequal curvatures of the femoral condyles (Bugnion, 1892), altered weight distribution (Walmsley, 1933), and the inequality of antero-posterior length of the femoral condyles. The last is the most popular view as judged by the accounts in current text-books; the lateral femoral condyle, shorter than the medial, is said to be 'used up' first as the knee extends, and the remainder of the medial condyle comes into apposition with the tibia by sliding backwards. In considering these theories it must be borne in mind that the alleged cause of the medial femoral rotation may be in fact merely its result. If rotation is to occur—whatever the cause—the femoral condyles must inevitably be unequal in length to accommodate the movement, and the attachments of the cruciate ligaments must be so situated as to allow it.

It is questionable whether axial rotation at the knee joint should be dismissed as 'a small movement of no particular functional significance' (Haines, 1941). Many other hinge joints exhibit such rotation, which has been shown to be mechanically advantageous in reducing the frictional wear of articular surfaces (MacConaill, 1946). It is probable that axial rotation of the femur serves to improve the mechanical efficiency of the knee joint, particularly during the phase of extension when, during walking, there is the greatest pressure across the articular surfaces. Moreover, this rotation is of definite clinical importance, for if it is forcibly prevented internal derangement of the knee is likely to result (Smillie, 1951).

The nature of the movements that can occur at any joint depends on the form of the articular surfaces, the restraining influence of ligaments and the control exerted by the muscles acting on the joint, and the locking movement at the knee is no exception (Goodsir, 1855). While the ligaments and the muscles acting at the knee joint have often been discussed, the part played by the articular surfaces in producing axial rotation has received less attention. The present investigation is therefore concerned mainly with this aspect of the problem.

MATERIAL AND METHODS

Three ciné-radiographic films have been made of normal subjects showing axial rotation of the femur as the knee is extended. In one the subject was rising to his feet from a stooping posture; in the other two, the thigh was supported in a horizontal position and the knee was slowly extended, care being taken to keep the long axis of the foot in a vertical plane so that any rotation at the knee would be of the femur upon the tibia and not vice versa.

Twenty knees from dissecting-room subjects have been examined; twelve which showed no pathological changes were selected for detailed measurement. In addition eleven freshly amputated normal knees were used to study the movements of the menisci during flexion and extension.

The curvatures of the articular surfaces were measured either by means of a planimeter or by sawing them through and tracing around the cut edges. It was found that a length of wire moulded to fit the profile of each femoral condyle was useful in assessing the congruity between the femoral condyles and the underlying articular surfaces.

OBSERVATIONS AND DISCUSSION

Cine-radiography clearly shows that while medial rotation of the femur can be detected at least 30° short of full extension, it is maximal during the last 10°. It is clear that the factors bringing about axial rotation must begin to take effect before extension is complete.

Extension of the knee takes place between the femur above and the menisci and tibial condyles below. Rotation, on the other hand, involves movement of the femur and the menisci upon the fixed tibia. It is convenient to consider these movements separately even though, during locking at the knee, they are occurring simultaneously.

The profiles of the medial and lateral femoral condyles are spiral in form, and extension of either condyle must cease as soon as the upper and lower articular surfaces become congruous, in the 'close-packed' position (Walmsley, 1928; MacConaill, 1932). In the normal knee, however, close-packing of the lateral condylar surfaces always precedes that of the medial surfaces. There are two reasons for this: firstly, the profile of the lateral femoral condyle flattens, from back to front, more rapidly than that of the medial condyle (Bugnion, 1892); secondly, the lateral receiving surface, i.e. the lateral tibial condyle with the meniscus *in situ*, is more concave than the medial. These differences are clearly seen if sections of the normal knee are cut in the sagittal plane with the menisci in place (Fig. 1).

As the knee is straightened the lateral femoral condyle thus becomes prematurely close-packed and its further extension is necessarily brought to a halt. Medial rotation around a vertical axis is, however, still possible (Walmsley, 1933). The exact location of this vertical axis is disputed and probably varies with the degree of flexion at the knee (Brantigan & Voshell, 1941; Abbott, Saunders, Bost & Anderson, 1944). In the phase at which locking occurs, it appears to pass through the head of the femur above and a point between the tibial attachments of the two horns of the lateral meniscus below. The medial rotation of the femur is brought about by the contracting quadriceps muscle which pulls the upper end of the femoral shaft forward relative to the fixed lateral femoral condyle, thus rotating the bone medially about the vertical axis (Fig. 2).

While the medial femoral condyle glides backwards, the lateral femoral condyle rotates medially about this vertical axis. The lateral meniscus rotates likewise (Weber & Weber, 1843), pivoting about the closely set attachments on the tibia of its anterior and posterior horns. This rotation causes the anterior horn to glide down a cambered surface on the front of the lateral tibial condyle (Fig. 3) and thus the concavity of this part of the receiving surface is reduced. As a result the lateral condylar surfaces are no longer close-packed and further extension is again possible.

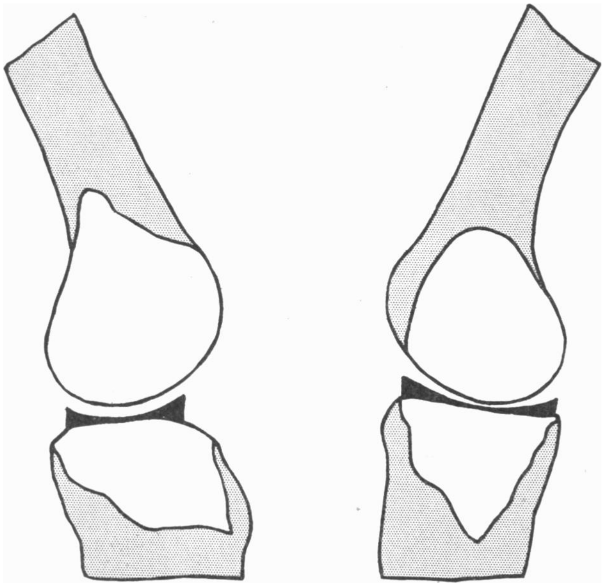

Fig. 1.

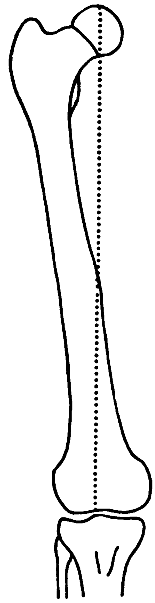

Fig. 2.

Fig. 1. Sagittal sections through the lateral and medial condyles of a normal knee. The stippled portions are excluded from the section. (Drawn from photographs.)

Fig. 2. The vertical axis around which medial rotation of the femur occurs during locking at the knee.

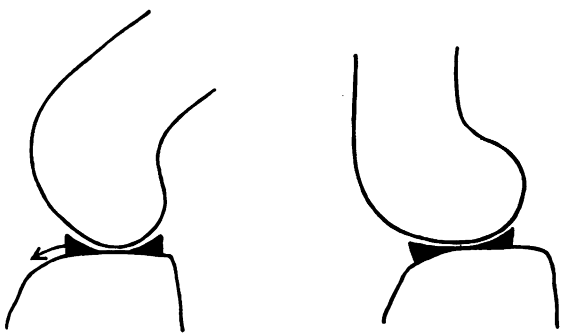

Fig. 3. Diagram illustrating the movement of the lateral meniscus as the knee is extended.

It is obvious that in the normal knee there is no alternation of extension and rotation. The femur is extended steadily and the lateral condylar surfaces are prevented from becoming congruous by the simultaneous recession of the anterior horn of the lateral meniscus. The sequence of events can be visualized more clearly, however, if they are considered as a cycle of alternating extension and rotation as in Table 1.

Table 1

Movement of femur	Effect: Lateral condyles	Effect: Medial condyles	Result
(1) Extension	Close-packed	Not congruous	Further extension checked
(2) Medial rotation	No longer congruous	Not congruous	Extension again allowed
(3) Further extension	Again close-packed	Not congruous	Extension again checked
(4) Movements (2) and (3) repeated	Close-packed	Eventually close-packed	Full extension with locking

It can be seen that eventually both the lateral and medial condylar surfaces are close-packed in full extension, producing maximal stability. MacConaill (1932) has demonstrated this fact experimentally by observing the interior of normal knee-joints through holes bored in the bones.

Minor incongruities found between the femoral and tibial articular surfaces can be explained in terms of compression of articular cartilage (Hirsch, 1944), peripheral distraction of the menisci (Fairbank, 1948) and release of tension in the ligaments of Humphrey and Wrisberg during extension of the knee (Holtby, 1915).

UNLOCKING OF THE KNEE JOINT

Cine-radiography indicates that lateral rotation of the femur commences as soon as flexion is attempted, and is completed when the knee has undergone only a few degrees of flexion. This rapid movement is presumably brought about by contraction of the popliteus muscle. Preliminary observations, based upon electromyographic recordings from needle electrodes inserted directly into the muscle during weight-bearing, show that activity can be recorded only at the commencement of flexion. The attachment of part of the popliteus tendon to the back of the lateral meniscus (Last, 1948) presumably causes the marked recession of the posterior horn of the lateral meniscus that occurs as flexion of the knee commences (Brantigan & Voshell, 1941).

SUMMARY

Locking at the knee joint—the medial rotation of the femur that occurs as the normal knee is extended—is shown by means of ciné-radiography to commence at least 30° short of full extension, although maximal during the last 10°. In contrast, lateral rotation of the femur as the knee is unlocked is confined to the first few degrees of flexion. This axial rotation probably improves the mechanical efficiency of the joint by reducing the frictional wear of the articular surfaces, especially during walking.

The conformation of the articular surfaces helps to produce this rotation; early close-packing of the lateral condyle as the knee is straightened restricts further extension of the femur until medial rotation, brought about by the contraction of the quadriceps muscle, has occurred.

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REFERENCES

ABBOTT, L. C., SAUNDERS, J. B. DE C. M., BOST, F. C. & ANDERSON, C. E. (1944). Injuries to the ligaments of the knee joint. *J. Bone Jt Surg.* **26**, 503–521.

BRANTIGAN, O. C. & VOSHELL, A. F. (1941). The mechanics of the ligaments and menisci of the knee joint. *J. Bone Jt Surg.* **23**, 44–66.

BUGNION, E. (1892). Le mécanisme du genou. Recueil Inaug. de l'Université de Lausanne. Quoted by Poirier, P. & Charpy, A. (1911). *Traité d'Anatomie Humaine*, **1**, 3rd ed. Paris: Masson et Cie.

FAIRBANK, T. J. (1948). Knee joint changes after meniscectomy. *J. Bone Jt Surg.* **30B**, 664–670.

GOODSIR, J. (1855). On the horizontal curvature of the internal femoral condyle; on the movements and relations of the patella, semilunar cartilages, and synovial pads of the human knee joint. Contained in *Anatomical Memoirs of the late John Goodsir*, 1868. Edinburgh: Adam and Charles Black.

HAINES, R. W. (1941). A note on the actions of the cruciate ligaments of the knee joint. *J. Anat., Lond.*, **75**, 373–375.

HIRSCH, C. (1944). A contribution to the pathogenesis of chondromalacia of the patella. *Acta chir. scand.* **90** (Suppl. 83), 1–106.

HOLTBY, J. R. D. (1915). A note on the posterior cruciate ligament of the knee-joint. *J. Anat., Lond.*, **49**, 386–388.

LAST, R. J. (1948). Some anatomical details of the knee joint. *J. Bone Jt Surg.* **30B**, 683–688.

MACCONAILL, M. A. (1932). The function of intra-articular fibrocartilages, with special reference to the knee and inferior radio-ulnar joints. *J. Anat., Lond.*, **66**, 210–227.

MACCONAILL, M. A. (1946). Studies in the mechanics of synovial joints. III. Hinge-joints and the nature of intra-articular displacements. *Irish J. Med. Sci.* (Sept.), pp. 620–626.

MEYER, H. (1853). Die Mechanik der Kniegelenks. *Arch. Anat. Physiol.* pp. 497–547. Ed. J. Müller. Berlin: Verlag von Veit et Comp.

SMILLIE, I. S. (1951). *Injuries of the Knee Joint*, 2nd ed. Edinburgh: E. and S. Livingstone Ltd.

WALMSLEY, T. (1928). The articular mechanism of the diarthroses. *J. Bone Jt Surg.* **10**, 40–45.

WALMSLEY, T. (1933). The vertical axes of the femur. *J. Anat., Lond.*, **67**, 284–300.

WEBER, G. & WEBER, E. (1843). Mécanique des organes de la locomotion. In *Encyclopédie Anatomique*, **2**, 2nd ed. Ed. by Bischoff, G. T. *et al.* Paris: J. B. Baillière.

YOUNG, R. B. (1889). On the grooves separating the patellar from the menisco-tibial surfaces of the femur, and on locking of the knee-joint in full extension. *Memoirs and Memoranda in Anatomy*, **1**, 147–158. By Cleland, J., Mackay, J. Y. & Young, R. B. London: Williams and Norgate.