

For more than 160 years, anatomists and surgeons have been fascinated by the anatomy and function of the knee. In Europe, besides the classical German publications referred to by Iwaki, Pinskerova and Freeman in their article in this issue (pp 1189-95), there are a few in French which are less well known including that of Edouard Bugnion (1845-1939), a Swiss from Lausanne, like myself, who wrote about *Le mécanisme du genou*.<sup>1</sup> He was an entomologist and anatomist, a man of an inquisitive mind and a great traveller. He was Professor of Anatomy, Physiology and Histology and Embryology, successively in Zürich, Bern and Lausanne, from where he published his article in 1892. In this article Bugnion gave a precise description of the anatomy with a kinematic analysis. He described all the classic concepts of tibial rotation in flexion, the gliding-sliding phenomenon and the role played by menisci and ligaments.

However, in spite of the considerable interest stimulated in the last 30 years by the development of surgery of the knee, and the progress made in understanding this complex joint, some aspects of the kinematics remain uncertain. The relationship in vivo between the kinematics, the three-dimensional shapes of the bones and the surrounding soft structures is not understood clearly. During flexion, the knee is required to resist loading resulting from the ground reaction force or the inertial dynamic force. Load-carrying influences movement of the knee and alters the kinematics, which may modify the contact distribution of joint pressure. Abnormal movement of the femoral condyle on the tibial plateau may lead to fibrillation and damage to the cartilage. Various approaches, such as studies in vitro or in vivo and theoretical modelling, have then been utilised to study the kinematics of the knee under different conditions of loading.

In vitro, cadaver knees have been used to assess bony movement under external loading, to evaluate the role of

muscles, ligaments and the joint surfaces in controlling and limiting the movements and to measure the load transfer across the joint. The location of the axis of rotation of the tibia and its change during passive knee flexion have been determined.<sup>2</sup> Rotation of the tibia of up to 32° has been demonstrated in a normal knee about an axis which remains approximately in the area between the insertions of the cruciate ligament throughout the range of flexion, but changes with the angle of flexion and the tension of the soft tissues. The Oxford rig has been used extensively for these studies but, despite its high sophistication, it fails to reproduce satisfactorily the conditions of loading in vivo. For instance, the forces simulated in the quadriceps muscle when measured at high angles of flexion on the rig are much larger than the physiological load under the normal stance in flexion. The physiological forces to which ligament and muscle are exposed remain difficult to reproduce experimentally in vitro.

Theoretical models of the knee have been developed, based on the rigid solid state and on finite-element methods,<sup>3</sup> which attempt to predict the interaction between movement and internal forces. In the sagittal plane, it is now understood that the femoral condyles roll and glide simultaneously on the tibial plateau during flexion. The kinematics of the knee and the shape of the condyles and of the tibial plateau are closely interrelated with the functions of the cruciate ligaments. However, the cross four-bar linkage model remains insufficient for further three-dimensional study. Three-dimensional rigid body dynamics have been used to model knee kinematics together with ligaments and contact forces.<sup>4</sup> The kinematics result from the combined actions of the surface geometry of the joint and of the soft tissues attached to it. In these models it is difficult to reconstruct accurately the shapes of the bones and to locate the insertions of the ligaments and muscles. Movement at the joint surfaces of the tibia, patella and femur has been studied in cadaver knees using stereophotogrammetry but remains difficult to determine in vivo. However, no rigorous comparison of the kinematics of the knee is available and few conclusions can be drawn from in vitro studies or from theoretical models which can then be applied to an individual.

Current research has moved more towards assessment of the kinematics in vivo. The method used most frequently

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0301-620X/00/811656 \$2.00  
*J Bone Joint Surg [Br]* 2000;82-B:1093-4.