3

Mobility and Stability of the Intact and Replaced Knee

Having demonstrated in Chapter 2 that a fully conforming mobile bearing can minimise polyethylene wear, in this chapter we show that a mobile bearing prosthesis, unconstrained in the sagittal plane, can restore natural mobility and stability.

For surgeon readers who are less interested in the theoretical background, it might be advisable to go straight to Chapter 4, Indications, or to start by reading the final section of this chapter, The Loaded Prosthetic Knee. If that proves interesting, the surgeon might attempt The Unloaded Prosthetic Knee. For the more research minded surgeon or engineer, it seems more logical to start with the Unloaded Natural Knee (the longest section of the chapter) and to read from there. The chapter may also be of interest to those surgeons embarking on the use of a bi-cruciate retaining total knee replacement.

The numerous writings on knee movement and the many methods used for its measurement and analysis over the past two centuries have been reviewed in detail by Pinskerova, Maquet and Freeman [1] and by Freeman and Pinskerova [2]. We will not attempt to repeat such reviews. We present our own evidence as to how the passive soft tissues of the human knee interact to control the passive motion of the bones and how this motion is modified in activity in the presence of muscle force, external loads and consequent tissue deformation. This provides a base with which to compare the kinematics and mechanics of the Oxford Knee in cadaver specimens and in living patients. In designing these studies, we have used as our model the example of D'Arcy Thompson:

> …. *ligaments and membrane, muscle and tendon, run between bone and bone; and the beauty and strength of the mechanical construction lie not in one part or another, but in the harmonious concatenation which all the parts, soft and hard, rigid and flexible, tension-bearing and pressure-bearing, make up together.*
>
> D'Arcy Wentworth Thompson, *On Growth and Form*, 1945, Cambridge University Press, Macmillan Edition.

The shapes of the articular surfaces of the Oxford Knee components do not match those of either compartment of the natural joint and, even if they did, they could hardly be expected to match exactly the shapes of the surfaces of each individual patient. How is it possible for such an implant to restore normal mobility and stability, normal kinematics and mechanics?

The complex three-dimensional pattern of movement of the natural knee depends upon the following:

(1) the shapes of its articular surfaces which hold the bones apart;
(2) the design of the array of ligaments that hold the bones together;
(3) the deformation of the tissues dependent on the magnitude and direction of the forces applied by muscle contraction in response to gravity and ground reaction and other external loads.

In any particular joint, features (1) and (2) are constant and therefore the movements of the **unloaded** knee should be predictable and repeatable. However, the forces applied during activity are as infinitely variable as the uses to which the human limb is put, and the consequent patterns of movement of the **loaded** knee are also infinitely varied. Blankevoort *et al.* [3] noted that "*the basis for the understanding of the kinematics of the knee joint lies in the description of its passive motion characteristics*". Passive motion is what the surgeon observes on the operating table with the patient under anaesthetic.

The unloaded human knee

Relative movements of the bones

The pattern of movement of the unloaded knee is highly ordered. In a study in which the movements were controlled solely by the intact ligaments and articular surfaces, 12 unloaded cadaver knee specimens were examined with the muscle tendons removed, the proximal tibia fixed with its plateau approximately horizontal and an intramedullary rod in the distal femur lying on a horizontal rod which was gently lowered and raised to control flexion and extension (Fig. 3.1) [4-6]. The only load present was the weight of the distal femur (about 5 N, 1 lb), shared between the horizontal rod and the knee specimen. An electromagnetic digitiser (Isotrack II, Polhemus Inc, Vermont, USA) was used to track all six degrees of freedom of movement of the femur relative to the tibia. The entire rig was made of plastic so as not to distort the magnetic field of the digitiser.

Figure 3.2 shows axial rotation of the femur relative to the tibia plotted against flexion angle for one specimen. External rotation of about 20° accompanied 120° of flexion but it is notable that the path followed during flexing was almost exactly reproduced during extending, with very little hysterisis. Axial rotation was uniquely coupled to flexion angle.

The graph of axial rotation from Figure 3.2 is included again in Figure 3.3 together with plots against flexion angle of the angle of abduction/adduction and the three components of translation of a single point on the femur relative to the tibia (dotted lines). Movements are plotted relative to a coordinate system with flexion/extension calculated about a medio-lateral axis parallel to a line joining the centres of curvature of the posterior femoral condyles, axial rotation about an axis perpendicular to the medio-lateral axis and fixed in the tibia according to a method

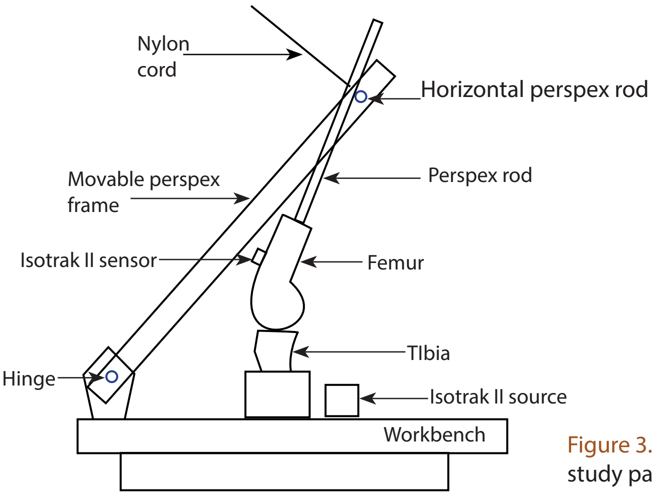

Figure 3.1 Fixed tibia rig used to study passive motion of the knee.

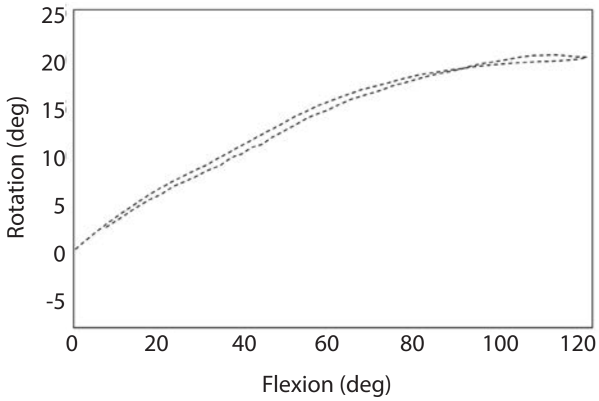

Figure 3.2 Axial rotation plotted against flexion angle for one specimen.

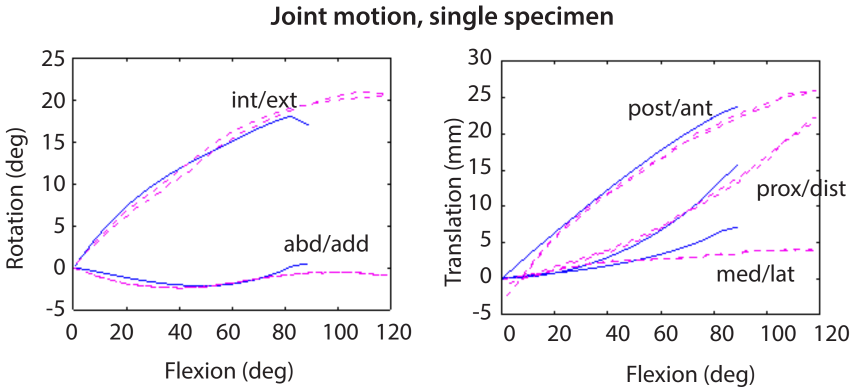

Figure 3.3 Axial rotation, abduction/adduction, and the three components of translation of a single point in the femur (the most proximal anterior point on the PCL attachment area) plotted against flexion angle for a single specimen (dotted curves). The solid lines on the graphs will be discussed later. (Adapted from Wilson DR, Feikes JD, Zavatsky AB, O'Connor JJ. The components of passive knee movement are coupled to flexion angle. *J Biomech* 2000; **33**:465-73, with permission.)

described by Yoshioka *et al.* [7], ab/adduction was calculated about a ‘floating’ anteroposterior axis perpendicular to both. The three components of translation were also calculated relative to these axes.

The figures show that axial rotation, abduction/adduction and the three components of translation of an arbitrarily chosen point on the femur (in this case, the most proximal point on the attachment of the PCL) were all uniquely coupled to flexion angle. In particular, for all five degrees of freedom, the path followed during flexion was almost exactly retraced during extension, with virtually no hysteresis. These curves are therefore characteristic of the unique path of passive motion followed by this specimen. Specifying the flexion angle completely determined the configuration of this knee joint, which therefore behaved like a single degree of freedom system. The solid lines in these figures will be discussed below.

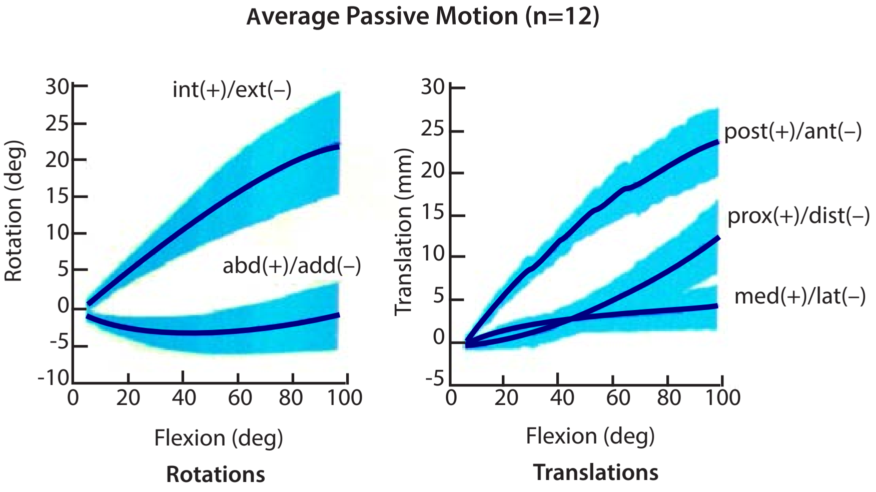

Figure 3.4 Axial rotation, abduction/adduction, and the three components of translation of a point in the femur (the most anterior point on the PCL attachment area) plotted against flexion angle for twelve specimens, the curves give mean values, the shaded areas defined by ± one standard deviation. (Reprinted from Wilson DR, Feikes JD, Zavatsky AB, O’Connor JJ. The components of passive knee movement are coupled to flexion angle. *J Biomech* 2000; 33: 465-73, Fig. 3, with permission.)

Figure 3.4 shows similar curves for 12 specimens tested in the same rig. All specimens exhibited minimal hysteresis. The results from specimen to specimen were quite repeatable and could be said to define the path of passive motion of the human knee. During passive flexion to 90°, the femur rotates externally on a fixed tibia (or the tibia rotates internally on a fixed femur) through about 22°. There is also a small amount of abduction/adduction. The components of translation vary from point to point on the femur but all are uniquely coupled to flexion angle. All specimens exhibited just one degree of freedom.