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The Functional Flexion-Extension Axis of the Knee Corresponds to the Surgical Epicondylar Axis

In Vivo Analysis Using a Biplanar Image-Matching Technique

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Abstract: We investigated the concept that the knee has a fixed flexion-extension axis in the posterior femoral condyles and that this functional axis corresponds to the surgical epicondylar axis in vivo. We used a biplanar image-matching technique to perform the in vivo analysis of 9 normal knees to determine the location of the functional flexion-extension axis of the knee using an optimization technique. The functional flexion-extension axis passed through the sulcus of the medial epicondyle and the prominence of the lateral epicondyle. Flexion and extension of the knee could be represented as a rotation around a fixed axis, and this functional axis corresponded to the surgical epicondylar axis during a 0° to 90° flexion. This study assists more understanding of knee kinematics and provides useful information for the design and positioning of the prostheses used in total knee arthroplasty.
Key words: knee kinematics, flexion-extension axis, transepicondylar axis, in vivo, computer simulation.

Conventional understanding of knee kinematics suggested that the knee has no fixed flexion-extension axis. This was based on observations in the sagittal plane, which showed that the instantaneous center of rotation of the knee moved within the posterior femoral condyle during the flexion cycle [1-4]. In contrast, recent studies based on three-dimensional observation of the knee in cadavers have shown that knee flexion and extension can be better described as a rotation around a fixed flexion-extension axis in the posterior femoral condyles. This functional axis passes through the femoral origins of the medial and lateral collateral ligaments, coinciding with the transepicondylar axis [5-9]. This fixed flexion-extension axis theory is replacing the classical variable flexion-extension axis theory. However, to our knowledge, no study to date has ascertained that it applies in vivo.

The transepicondylar axis has been studied vigorously as a reliable reference axis of the distal femur, especially as a useful reference axis to determine the rotational alignment of the femoral component in total knee arthroplasty [7,10-14]. In total knee arthroplasty, setting the femoral component parallel to the transepicondylar axis optimizes tibiofemoral and patellofemoral articulation [15]. Berger et al [12] have proposed 2 transepicondylar axes: the clinical epicondylar axis and the surgical epicondylar axis. The former is a line connecting the prominence of the medial epicondyle, which is the attachment of the superficial fibers of the medial collateral ligament, with the lateral epicondylar

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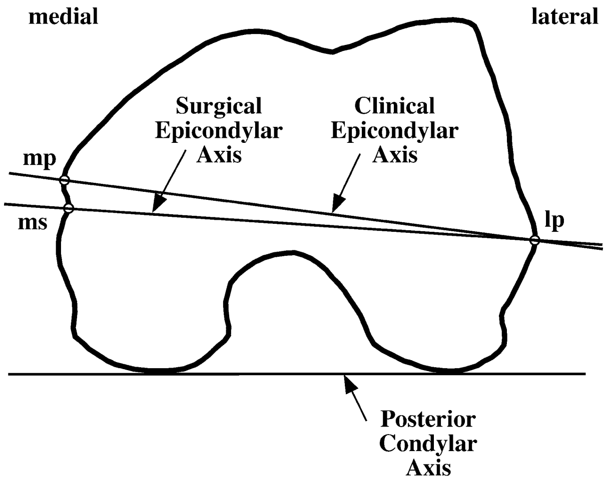

Fig. 1. Anatomical landmarks and reference axes in the distal femur. mp indicates prominence of medial epicondyle; ms, sulcus of medial epicondyle; and lp, prominence of lateral epicondyle.

prominence. The latter is a line connecting the sulcus of the medial epicondyle, which is the attachment of the deep fibers of the medial collateral ligament, with the lateral epicondylar prominence (Fig. 1). Furthermore, Berger et al [12] have shown that the surgical epicondylar axis is a more reliable and reproducible reference than the clinical epicondylar axis. However, it is not yet clear whether the surgical epicondylar axis coincides better with the functional flexion-extension axis of the knee [16].

To investigate three-dimensional knee kinematics under weight-bearing conditions in vivo, we developed a biplanar image-matching technique [17]. The purpose of this study is to locate a functional flexion-extension axis of the knee in vivo using an optimization technique and to test the hypothesis that the in vivo flexion-extension axis of the knee coincides with the surgical epicondylar axis. This study would assist more understanding of knee kinematics and would provide useful information for the design and positioning of the prosthesis used in total knee arthroplasty.

Materials and Methods

Simulation of Knee Motion Using a Biplanar Image-Matching Technique

Nine healthy male Japanese volunteers with an average age of 32 years (range, 25-43 years) were the subjects in this study. Computed tomography (CT) scan images of the left knee of each subject were made at levels ranging from 80 mm proximal to the joint to 80 mm distal to the joint (Hispeed Advantage, GE Medical Systems, Inc, Milwaukee, Wis). These scans were made at 2-mm intervals with a 1-mm-wide source beam so that the functional axis of lower extremity (the femoral head to midankle plafond axis) was perpendicular to the scanning plane. They were entered into a personal computer (Power Macintosh G3, Apple Computer, Inc, Cupertino, Calif). The bone outlines of the images for the femur, the tibia, and the fibula were digitized and entered into the computer. A three-dimensional bone model of the knee was constructed. Computed tomography scans of the subjects' left ankle joints were also made with the same scout view for detecting the center point of the joint [18].

Anteroposterior (AP) and lateral radiographs of the subjects' knees, taken at every 15° from 0° to 90° of flexion under weight-bearing conditions, were entered into the computer. Knee flexion angle was verified using lateral radiographs, and error within a range of 3° was permitted. Two x-ray beams were set so that the centerlines of

Fig. 2. A sample of the biplanar image-matching technique. A, Anteroposterior and lateral radiographs. B, A projection image of a three-dimensional knee model was matched by best fit onto both radiographs, and the position of 6 degrees of freedom was determined.