A Method for Location of Prosthetic and Orthotic Knee Joints

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When it is necessary to use a mechanical knee joint, whether it be in a below-knee prosthesis or a long-leg brace, ideally there should be no relative motion between the patient's limb and the appliance during its use. Because the human knee is not a single-axis joint, analogues of the human knee employing more than one axis of rotation have been developed but none have proven practical, owing largely to bulkiness, but to some degree to cost. At this time, therefore, we are faced with the problem of determining a method of placing the center of rotation of a single-axis mechanical knee joint with respect to the knee so that the least amount of relative motion will occur between the patient and the appliance.

This article describes a method of determining the optimum location of single-axis knee joints, based on data accumulated recently from X-rays and from cadaver dissection.

FUNCTIONAL CHARACTERISTICS OF THE KNEE

Both the medial and lateral condyles of the femur appear as helical curves, the radii of which become progressively smaller from anterior to posterior. Only a small portion of the surface of the femur is in contact with the tibia at any given moment. Weight, however, is distributed over a larger area by the menisci, which provide smooth contact at any position.

The knee structure is stabilized by cruciate and collateral ligaments, which control the range of motion of the joint and the relative positions of the articulating condylar surfaces. Because the medial and lateral condyles of the femur are not the

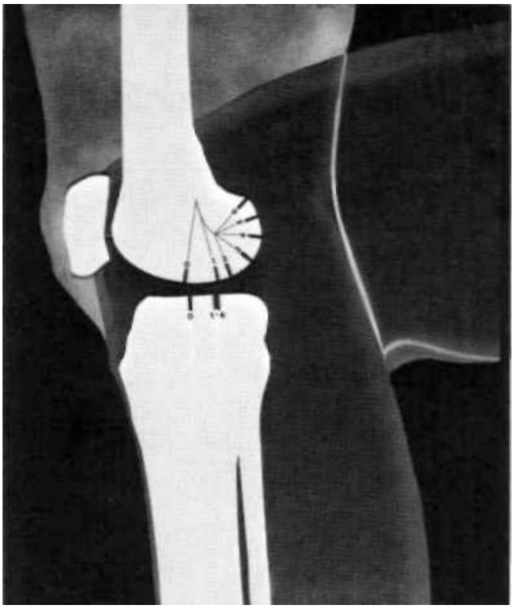

Fig. 1. Points of contact between the femoral condyle and the tibial plateau during knee flexion and extension. The majority of translation occurs in the first 15 deg of knee flexion from a position of hyperextension (point "0"). Successive flexion beyond this point concentrates the point of articulation between points 1 and 6. In prosthetics application, restriction of the knee to 10 deg before full extension confines the instantaneous center of femoral rotation between points 1 and 6.

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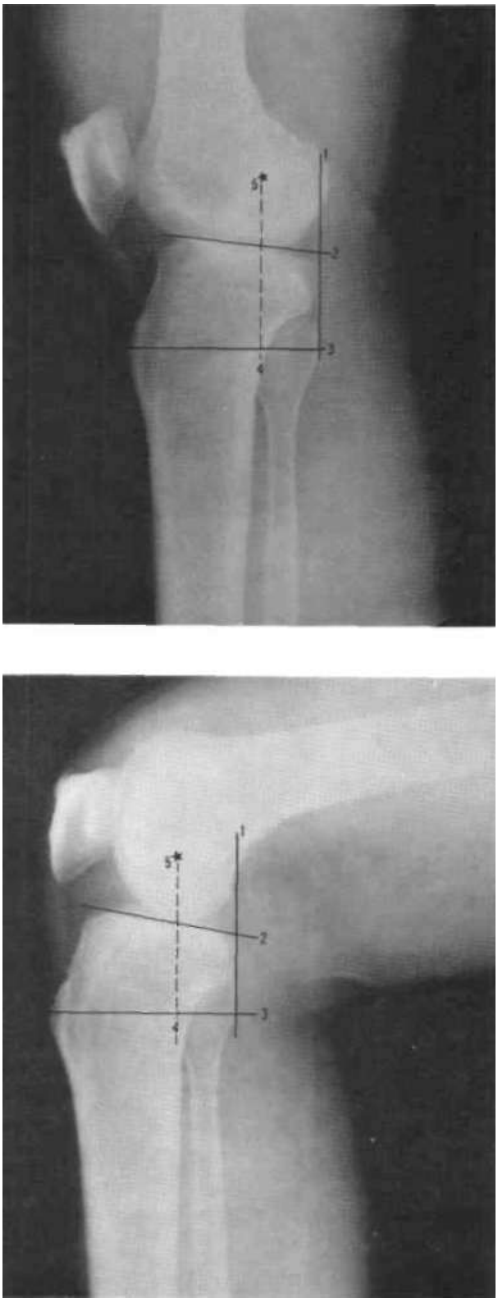

Fig. 2. Typical transverse soft-tissue X-ray views of a normal knee showing the vertical relationship of the posterior borders of the major bony knee segments with the knee in the extended position and in 90 deg of flexion.

TABLE 1

Cadaver	Sex	Measurements (in.)			
		Right		Left	
		Tibial Tubercle to Posterior Fibula	Medial Epicondyle to Lateral Epicondyle	Tibial Tubercle to Posterior Fibula	Medial Epicondyle to Lateral Epicondyle
1	M	2 5/8	3 1/8	2 5/8	3 1/8
2	M	2 7/8	3 1/8	2 7/8	3 1/8
3	M	2 5/8	3	2 5/8	3
4	M	2 5/8	3	2 5/8	3
5	M	2 5/8	3	2 5/8	3
6	F	2 1/4	2 1/2	2 1/4	2 1/2
7	M	2 3/4	3 1/8	2 3/4	3 1/4
8	M	2 3/4	3	2 3/4	3 1/8
9	M	2 3/4	2 7/8	2 3/4	2 3/4
10	F	2 3/4	3	2 3/4	3
11	F	1 3/4	2 1/2	1 3/4	2 1/2
12	F	2 3/8	2 5/8	2 3/8	2 5/8
13	M	2 3/8	2 3/4	2 5/8	2 7/8
14	F	2 1/8	2 1/2	2 1/8	2 1/2
15	F	2 1/8	2 1/2	2 1/4	2 1/2
16	F	2 3/8	2 5/8	2 3/8	2 5/8
17	M	2 3/4	3	2 3/4	3
18	M	2 5/8	2 7/8	2 5/8	2 7/8
19	F	2 5/8	2 7/8	2 5/8	2 7/8
20	M	—[a]	—[a]	3	3 3/8
21	M	2 3/4	3	2 5/8	3

[a] Right above-knee amputation.

same size, a transverse rotation of the femur takes place as the knee approaches full extension, causing the collateral and cruciate ligaments to tighten, and binding the femur and tibia tightly together in the weight-bearing position. Thus, as the knee begins to flex from the extended position and the femur rolls on the head of the tibia, the medial condyle rotates approximately 15 deg while the lateral condyle rotates approximately 20 deg. Then a slipping or gliding motion begins. Although the total flexion-extension range of the knee is approximately 160 deg, the first 110 deg is the most useful segment for prosthetic application, since this arc includes the full range required for walking (70 deg) and for sitting (100 deg).

The numbered references in Figure 1 show the areas on the femoral condyle and the tibial plateau where contact is made

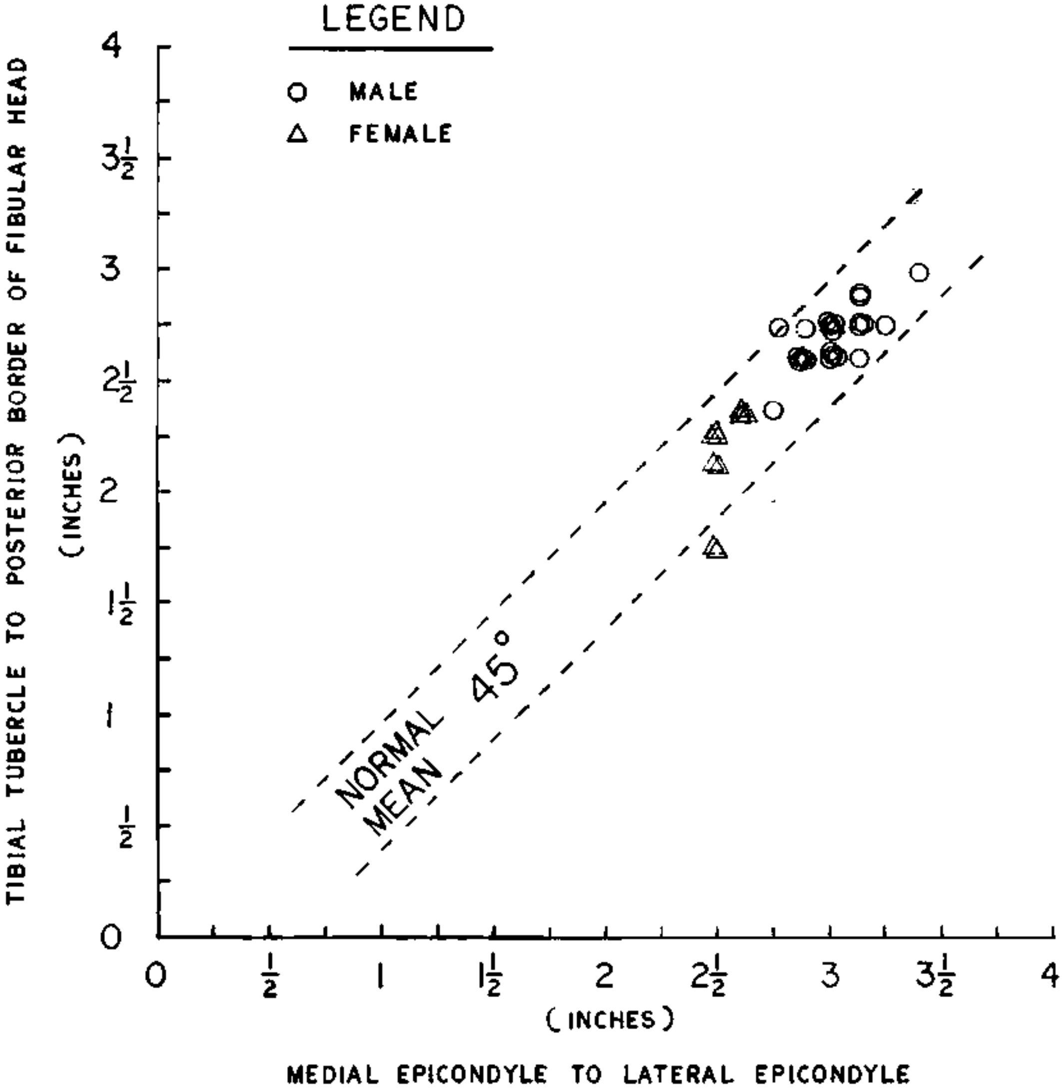

Fig. 3. Dimensional proportionality of widths at the femoral epicondyles related to the measurements between the tibial tubercle and the posterior border of the fibular head.

successively as the knee is flexed or extended. Points "0" on the femur and tibia indicate the contact relationship between the bones when the knee is in 5 deg hyperextension. During the first 20 deg of knee flexion, the condylar surfaces of the femur roll posteriorly on the tibia from point "0" to point "1." The greatest migration of the instantaneous center of rotation takes place during the first 15-20 deg of flexion. During the latter portion of the first 20 deg of knee flexion, a progressive sliding begins (between points "1" and "2"). Once the center of rotation reaches point "2," it remains relatively fixed during the remainder of the flexion range. This point is considered to be the optimum location for single-axis mechanical joints, especially if the knee is not permitted to extend fully. However, the usefulness of this point de-

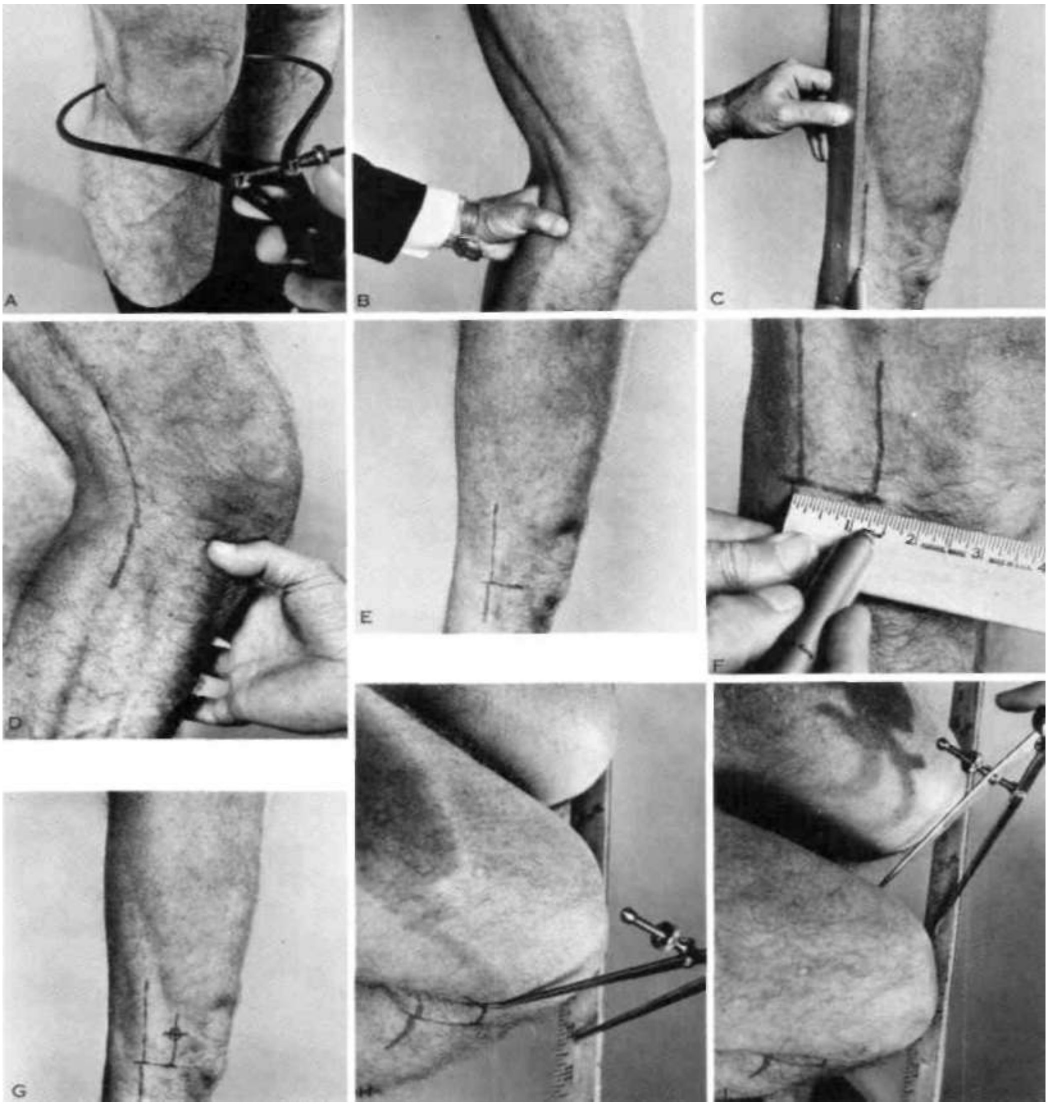

Fig. 4. Steps in locating functional knee center.

pends on one's ability to locate it by reference to external bony landmarks.

X-RAY STUDIES OF THE KNEE

X-ray studies of knee motion were undertaken in an attempt to find landmarks that had a constant relationship to the optimum center of rotation. Analysis of over 500 X-rays of the knee, such as those shown in Figure 2, taken in various phases of extension and flexion revealed that the posterior femoral condyles, the posterior tibial condyles, and the posterior border of the head of the fibula are in approximately vertical alignment throughout the useful range of flexion-extension (lines 1, 2, and 3). Although the patella and the anterior fleshy-knee outline appear to recede posteriorly under the tensions exerted by the quadriceps, the posterior aspects of the

TABLE 2

Mediolateral Dimension of Knee (in.)	Measurement from Posterior Border of Fibular Head Forward at Tibial Plateau (in.)
4 1/2	1 3/8
4 1/4	1 1/4
4	1 1/8
3 3/4	1
3 1/2	7/8

Example: Locating the functional center of knee rotation for a medial-to-lateral fleshy-knee measurement of 4 1/4 in. requires placing the vertical reference line 1 1/4 in. anterior from the posterior border of the fibular head and 1 1/4 in. above the tibial plateau on the vertical reference line.

femoral and tibial condyles and the posterior border of the fibula remain in the same relative posterior vertical alignment.

Because there is only very thin tissue covering the anterior border of the tibia and the tibial tubercle, they are easily palpable, and therefore should make better reference points than the poples.

ANALYSIS OF THE KNEE JOINT BY DISSECTION

The knee-joint measurements obtained from 21 adult cadavers are given in Table 1 and Figure 3. An analysis of these measurements indicates that the difference between the anterior-posterior measurements of the stump and the actual bone dimensions is approximately 3/4 in. The mediolateral dimensions vary approximately 3/4 in. between the external measurement and the actual epicondylar width.

LOCATION OF KNEE CENTER

Based upon the dimensional relationships shown in Table 1 and Figure 3, a method (Fig. 4) is advanced for locating the approximate functional knee center, using the figures in Table 2.

A. With the patient standing and leg extended, measure the knee width at the condyles.

B. With the patient standing, knee flexed and relaxed, locate the posterior border of the fibular head.

C. With the patient standing and the knee vertically extended, mark a reference line up the knee and lower thigh.

D. With the patient standing, leg unweighted and knee slightly flexed, locate the lateral tibial plateau by pressing into the knee with the thumb.

E. Keeping the thumb in position to maintain the exact location as the patient extends the knee, mark the tibial plateau level horizontally.

F. Using the applicable figure from Table 2, mark the measurement at the plateau level and extend a line vertically from that point toward the thigh.

G. Using the same measurement as in step F, mark the axis reference on the anterior vertical line horizontally.

H. To mark the knee center references on the medial side, have the patient sit with the medial aspects of the knees 1/2 in. apart, flexed at 90 deg. Place a straight edge across the patellas. Measure the distance from the straight edge to the lateral reference (step G) and mark the measurement on the medial side (I). Measure the distance of the lateral reference from the floor and mark the measurement on the medial side.

ACKNOWLEDGMENTS

Edward Peizer, Ph.D., Chief, Bioengineering Research Service, Veterans Administration Prosthetics Center, assisted the authors in the design and analysis of the knee data. Gabriel Rosenkranz, M.D., Medical Consultant, gave guidance and encouragement.

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