

**ENVELOPES OF PASSIVE MOTION IN THE INTACT
TIBIOFEMORAL JOINT: AN *IN VITRO* STUDY**

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INTRODUCTION

The kinematics (i.e. passive motions) of the knee are determined and constrained by the articular surfaces and soft tissues of the tibiofemoral joint [1]. Knee kinematics may be characterized by measuring the envelopes of passive motion which are described, for each DOF over a range of flexion, by the positive and negative limits of displacement about a neutral position, under a prescribed load. It is crucial to understand the kinematics of the intact tibiofemoral joint because the envelopes of passive motion could serve as a gold standard for validating computational models of the knee as well as evaluating the effectiveness of innovative and established surgical techniques. Therefore, the objective of this study was to define the envelopes of passive motion for internal-external (I-E) rotation, varus-valgus (V-V) rotation, anterior-posterior translation (A-P), and distraction (D) translation of the intact tibiofemoral joint.

METHODS

Six fresh-frozen, cadaveric knees were included in this study. Specimens were free from degenerative arthritis, chondrocalcinosis, osteophytes, meniscal tears, ligament tears, and evidence of previous surgery to the knee. Each knee was prepared by first removing all tissue more than 15 cm proximal and 12 cm distal to the joint line and second removing all remaining subcutaneous fat. The fibula was rigidly fixed to the tibia using a transverse screw to retain the rigidity of both the tibiofibular joint and the insertion of the lateral collateral ligament. Following dissection, each knee was aligned in a six DOF load application system (LAS) [2] so that the flexion-extension (F-E) and I-E rotation axes of the LAS were coincident with the F-E and longitudinal rotation axes of the tibiofemoral joint. Next the femur and tibia were potted in methylmethacrylate within square aluminum tubes to fix the position and orientation of the knee relative to the LAS.

The prescribed loads used to define the envelopes of passive motion were set so that the soft tissues of the knee were loaded to the onset of their high-stiffness regions. The prescribed loads for each DOF were ± 3 N m for I-E [1], ± 5 N m for V-V [3], ± 45 N for A-P [4], and 200 N for D [5]; a -5 N compressive load was used as a negative reference for D. Prior to measuring the envelopes of passive motion, the knee was subjected to a preconditioning protocol consisting of first cycling the knee five times between ± 2.5 N m in flexion-extension (F-E) and then extending the knee to 2.5 N m to define 0° of flexion [6]. Next the knee was moved to a flexion angle randomly selected from 0°, 60°, and 120° and cycled five times [2] between the loading limits previously listed for each DOF in a random order. This procedure was repeated for the other two flexion angles also in a random order.

After the knee was preconditioned, the envelopes of passive motion for I-E, V-V, A-P, and D were determined for a range of flexion angles from 0° to 120° in 30° increments using the prescribed loads listed above. First, the knee was moved to a randomly selected flexion angle. Second, for a randomly selected DOF, the prescribed positive load was applied followed by the prescribed negative load; both resulting positions were recorded. The knee was then unloaded, and the resulting position was recorded. Next, the prescribed negative load was applied followed by the prescribed positive load; again, both positions were recorded. Finally, the knee was unloaded and the position was again recorded. The neutral position was defined as the average of the two recorded positions of the unloaded knee. The positive and negative limits were defined as the difference between the average of the two recorded positions of the knee under the prescribed positive and negative loads respectively and the neutral position. This procedure was repeated for all randomly-ordered combinations of the flexion angles and DOFs. Each limit was described by the mean and range of that limit for the six cadaveric knees at the 5 flexion angles.

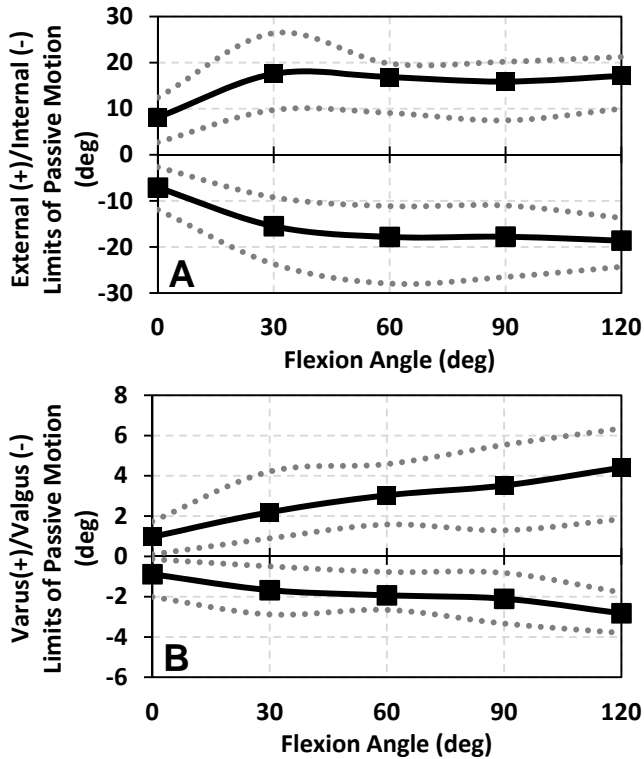


FIGURE 1. MEAN (BLACK) AND RANGE (GRAY) OF LIMITS OF THE (A) I-E AND (B) V-V ENVELOPES OF PASSIVE MOTION OF THE INTACT TIBIOFEMORAL JOINT

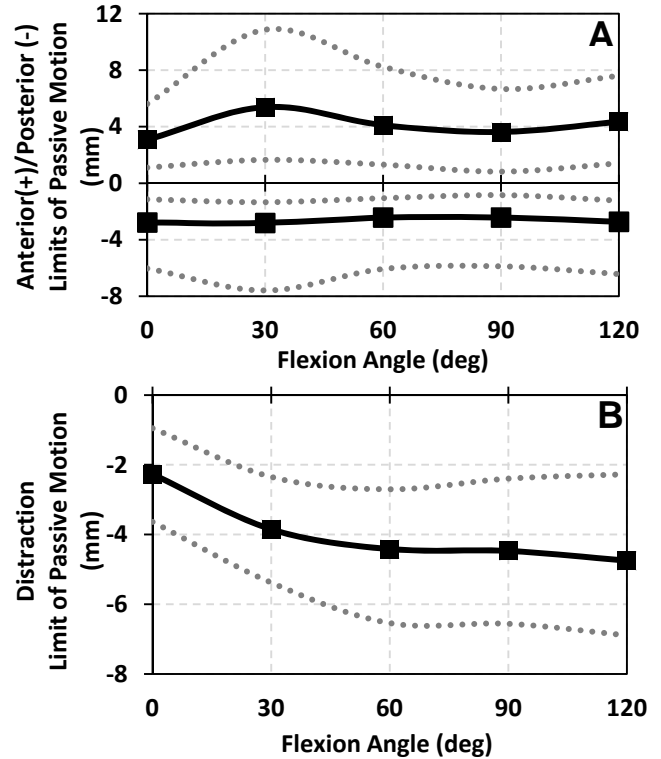


FIGURE 2. MEAN (BLACK) AND RANGE (GRAY) OF LIMITS OF THE (A) A-P, (B) D ENVELOPES OF PASSIVE MOTION OF THE INTACT TIBIOFEMORAL JOINT

RESULTS

Both the external and internal limits increased from 0° to 30° flexion and remained nearly constant to 120° flexion (Figure 1A). The range of the I-E limits was greater between 30° and 60° flexion than near 0° and 120° flexion. Both the mean varus and valgus limits increased with flexion (Figure 1B). The range of the varus limit increased with flexion while the range of the valgus limit remained nearly constant throughout flexion. The mean and range of the both the anterior and posterior limits were greatest at 30° flexion, but remained nearly constant throughout the rest of flexion (Figure 2A). Both the mean and range of the distraction limit increased with flexion (Figure 2B). In three of the four DOFs (I-E, V-V, D), the mean limits were greater in magnitude at 120° than at 0° flexion.

DISCUSSION

This study quantified the envelopes of passive motion in four DOFs (I-E, V-V, A-P, and D) of the intact tibiofemoral joint. These results agree with those studies [1, 3-5] because the data collected lies within the ranges presented here. This study builds on these previous studies because all four DOFs were investigated in a single set of specimens over a large range of flexion angles.

A limitation of this study was that the major muscles crossing the knee were transected in order to mount the knee in the LAS, so that the contributions of the passive stiffness of these muscles were not included. Because the ligaments and joint capsule of the knee are the primary stabilizers in I-E, V-V, A-P, and D, the loss of the passive stiffness of the surrounding muscles was likely small.

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