The Moment Arm of the Knee Extensor Mechanism

J.L. Krevolin¹,², M. Pandy¹, J. Pearce³

¹Department of Biomedical Engineering, University of Texas at Austin, Austin, Texas
²Sulzer Orthopedics Inc., Austin, Texas
³Bone and Joint Center, St. David’s Hospital, Austin, Texas

Introduction

The moment arm (MA) of the knee extensor mechanism has been reported by a number of researchers, although it has been defined and measured differently in these studies. The aims of this study were: (1) to quantify the MA of the knee-extensor mechanism, which is represented by the MA of the patellar tendon at the knee; and (2) to show that the MA of the patellar tendon is related to the size of the distal femur.

Methods

Six fresh-frozen, whole, cadaver legs were cut just below the greater trochanter of the femur, leaving the remainder of the leg intact. Each knee joint was inspected visually to ensure that it was "normal". Approximately eight centimeters of the quadriceps tendon was left intact. All passive soft tissue was removed from a portion of the tibia, beginning at the mediolateral line located at the center of the knee joint to a point 10 cm below the center of the knee. All ligamentous and capsular structures surrounding the knee, including the popliteal muscle, and joint capsule were left intact.

The femur was held stationary with its long axis horizontal and attached to a table. The leg was initially allowed to hang under its own weight with the knee flexion angle set at 90°. The specimen knee was loaded by attaching a flexible wire cable to the quadriceps tendon. The flexible cable was then attached to a programmable stepper motor which exerted a force on the quadriceps tendon and extended the knee. Spatial kinematic measurements were made using a four-camera, 60 Hz video system and retroreflective markers attached to the distal femur, proximal tibia and patella. The knee was extended at a rate of 3 deg/sec. The force transmitted from the cable to the quadriceps tendon was measured by a strain-gauged force transducer, which was attached directly to the cable.

Theory

The torque of a muscle force, which causes pure rotation of a body, is equal to the magnitude of the muscle force multiplied by some quantity that has the units of length. This quantity is often referred to as the “moment arm” of a muscle force. By considering the rate at which work is done by the muscle force to rotate the body about its instantaneous screw axis (ISA), it can be shown that the moment arm of the muscle force is equal to the perpendicular distance from the line of action of the muscle force to the ISA of the body, multiplied by the sine of the angle between these two lines [1].

The moment arm of the patellar tendon multiplied by the patellar-tendon force gives the torque of the patellar tendon that causes pure rotation of the tibia about the femur; and the torque of the patellar tendon multiplied by the angular velocity of the tibia relative to the femur gives the rate at which work is done by the patellar tendon to rotate the tibia about its ISA relative to the femur. Since the mass of the patella is much smaller than the mass of the tibia, the work associated with moving the patella is negligible compared to that associated with moving the tibia. It may be assumed further that the work done by the knee ligaments to move the tibia is much less than that performed by the patellar tendon. This is due to the fact that the torque of the patellar tendon about the ISA of the tibia is much larger than the torque exerted by each of the knee ligaments about this line. Thus, the moment arm of the knee-extensor mechanism is accurately described by the moment arm of the patellar tendon calculated with respect to the ISA of the tibia relative to the femur [1].
Results & Discussion

The peak values of the patellar-tendon moment arm ranged from 4 to 6 cm for the knees tested (Figure 1). The moment arm is maximum near 45° of knee flexion. Figure 2 shows the knee-extensor moment arm normalized by condyle size. The lines all coalesce. The differences in the normalized moment arm are very small, while the non-normalized moment arm differences are as large as 2 cm. This result suggests that the MA of the patellar tendon is related to the size of the distal femur.

Numerous estimates of the moment arm of the knee-extensor mechanism have been obtained from in vitro measurements [2-5] and from in vivo measurements [6,7] of the relative positions of the bones. These estimates account only for the relative positions of the bones in the sagittal plane. The results do not include, for example, the contribution of the axial rotation of the tibia which accompanies flexion-extension movements of the natural knee. To calculate the moment arm in three dimensions requires knowledge of the position and orientation of the ISA of the tibia relative to the femur under known conditions of loading and constraint.

A comparison between the moment arm results of this study and those reported previously by others is not possible because the method of measuring MA is different. In this study, the moment arm of the patellar tendon was measured with respect to the finite screw axis (FSA) of the tibia relative to the femur in three dimensions. The moment arm of the patellar tendon with respect to the axis of rotation of the knee has been measured [6]; however the results are based on the assumption that the relative movements of the bones are confined to the sagittal plane. Others [5,7] also measured the moment arm of the patellar tendon in the sagittal plane, but their values are based on the perpendicular distance between the line of action of the patellar-tendon force and the contact point between the femur and the tibia. The tibiofemoral contact point is not an appropriate point on which to base measurements of the patellar-tendon moment arm, since this point is itself rotating about the ISA of the tibia; multiplying the distance from the contact point to the patellar tendon by the magnitude of the patellar-tendon force does not produce a measure of the tendency of the patellar-tendon force to rotate the tibia about its ISA relative to the femur.

Significance

The fact that the knee-extensor moment arm remains roughly constant when normalized by femoral condyle size suggests that condyle size is an important variable to consider when modeling the knee. This finding suggests further that an average-size knee model may not be appropriate for describing the interactions between muscles, ligaments and bones at the knee. Quantitative comparisons of modeling and experimental results should be undertaken on a specimen-by-specimen basis.
Figure 2

Normalized Knee-Extensor Moment Arm

Knee Flexion (deg)