Analyzing the Role of Patellar Tendon Force During Flexion of the Knee

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Abstract—The mechanics of the knee was analyzed in the sagittal plane to study the role of patellar tendon in resisting a flexing load and in translating the tibia anterior or posterior to the femur. The effect of load placement at different positions distal to the tibial surface was analyzed during the flexion range 0–120°. Data for orientation and moment arm of the patellar tendon during the flexion range was taken from experiments on cadaver knees available in the literature.

The results and analysis suggest that during quadriceps strengthening exercises distal placement of flexing loads on the tibia, in comparison to more proximal placements, results in larger muscle forces. However, such loads are also associated with larger translations of the tibia relative to the femur, thus, loading the cruciate ligaments. Particularly, the anterior cruciate ligament is predisposed to loading due to load placements far distal on the tibia in the low–to–mid flexion range. Therefore, rehabilitation exercises requiring protection of the ligament need attention for the position of external flexing load on the tibia as well as the flexion angle at which the exercise is performed.

Index Terms—knee biomechanics, rehabilitation of the anterior cruciate ligament, quadriceps contraction, knee moment arms, tibial translation.

I. INTRODUCTION

Several investigators have estimated moment arms and orientations of the patellar tendon at the knee using theoretical or experimental approach for the intact or replaced knee [1–5]. The tendon transmits forces of the quadriceps muscles through the knee extensor mechanism to the tibia [6]. The tendon force provides extending moment at the knee as well as force components that can translate the lower bone (or tibia) relative to the upper bone (or femur) [6].

During the knee flexion, moment arm available to the patellar tendon force varies due to changing location and orientation of the tendon as well as due to changing location of the point from which the moment arm is measured, such as, the tibio-femoral contact point or the joint centre of rotation [1–6]. The moment arm of the tendon normally remains small and varies non-linearly from more than 4 cm in extension to less than 4 cm in high flexion [1]. The tendon orients anteriorly in extension and posteriorly in high flexion, with an overall variation of nearly 20° during 0–120° flexion [1].

In early–to–mid flexion range, the patellar tendon force has a component parallel to the tibial surface directed anteriorly, which can pull the tibia anterior to the femur, thus, stretching the anterior cruciate ligament (ACL) [6]. In mid–to–high flexion range, the patellar tendon force has a component parallel to the tibial surface directed posteriorly, which can pull the tibia posterior to the femur, thus, stretching the posterior cruciate ligament (PCL) [6]. These anterior or posterior force components of the tendon can be large in certain strenuous activities and could lead to serious consequences for the subject as the knee ligaments, particularly the ACL, are injured frequently during situations involving large tibial translations [6–8].

The purpose of this study is to analyze the role of the patellar tendon in several flexion positions of the knee in terms of its ability to resist an external flexing moment and its ability to translate the tibia relative to the femur, thus, loading the cruciate ligaments.

II. METHODS

Mechanics of the knee was analyzed in the sagittal plane during 0–120° flexion of the joint. With reference to Fig. 1, mechanical equilibrium of the joint was considered due to four types of forces, namely, a force in the patellar tendon (P), a ligament force (L), a tibio-femoral joint contact force (C) applied by the femur normal to the tibial surface and a flexing load (R) applied externally on the tibia acting parallel to the tibial surface.

The anatomical posterior direction was defined along the positive x-axis. Also, the tibial surface was taken to be flat and parallel to the x-axis.

Equilibrium of moment was given by (1); equilibrium of forces parallel to the tibial surface was given by (2) and equilibrium of forces perpendicular to the tibial surface was given by (3).

In (1), the rotational contribution of the ligament force, due to either the ACL or the PCL, was ignored because the moment arms available to the ligaments through most of the flexion range are relatively much smaller, 1 cm or less [1]. Also, the frictional effect between the bones in the natural intact joint, being negligible [9], was ignored.
The mechanics of the knee was analyzed in the sagittal plane to study the role of patellar tendon in resisting a flexing load and in translating the tibia anterior or posterior to the femur. The analysis suggests that the force in the patellar tendon varies directly with the distance of the external flexing load placed distal to the tibial surface. This effect is uniform throughout the joint flexion range. Further, depending on the position of the flexing load on the tibia, in the low-to-mid flexion range the tibia translates anterior to the femur, while in the mid-to-high flexion range the tibia translates posterior to the femur.

Two critical factors that may require special attention to protect the ACL during rehabilitation exercises are the flexion angle and the position of the flexing load below the tibial surface.

### III. RESULTS

Fig. 2 shows the \( P / R \) ratio calculated during flexion with \( M_R = 20, 30, 40 \), and 50 cm.

Fig. 3 shows the \( T / R \) ratio calculated during flexion with \( M_R = 20, 30, 40 \), and 50 cm.

### IV. ANALYSIS

#### The Role of the Patellar Tendon in Resisting a Flexing Moment:

With reference to table 1, the moment arm available to the patellar tendon was around 4 cm near extension, increased with flexion angle until around 40° to an average value of 4.7 cm and then decreased in higher flexion to remain below 4 cm after 80° flexion. In comparison, the moment arm of the external load could be around 40 cm or more during normal activities. As a consequence, the force \( P \) would be much larger than \( R \) and it would vary with the position of \( R \) below the tibial surface as suggested by (1) and demonstrated by the calculations in Fig 2. With increase in \( M_R \), \( P/R \) ratio in Fig. 2 increased uniformly throughout the flexion range. During quadriceps strengthening exercises, distal placement of \( R \) may be required for the muscle exercises to be effective. However, such distal placements could have detrimental effects on the ACL loading as suggested by the analysis given below.

#### The Role of the Patellar Tendon in Translating the Tibia Anterior or Posterior to the Femur:

With reference to Fig. 3, the \( T/R \) ratio was negative in early flexion for all positions of \( R \) below the tibial surface. The \( T/R \) ratio became positive with increasing flexion. This suggests that the tibia would translate initially anteriorly and then posteriorly during flexion depending on the position of \( R \). Accordingly, the ACL would be stretched for negative values and PCL would be stretched for positive values of \( T/R \). Neither ligament would stretch for \( T/R=0 \).

For external loads placed far distal to the tibial surface, the flexion range with negative values for \( T/R \) was increased, e.g., for \( M_R=20 \) cm, \( T/R \) was negative for the flexion range 0-15°, while for \( M_R=50 \) cm, this flexion range was increased to 0-54°. This observation suggests that the quadriceps exercises performed with the external load placed far distal to the tibial surface could stretch the ACL up to nearly the mid flexion range. Further, since most of the normal activities, like walking, jogging, stair climbing, involve low–to–mid flexion range at the most [10–12], anterior translation of the tibia and, thus, loading of the ACL would be expected during such activities.
Fig. 1. The flexing moment due to the external load (R) on the tibia is balanced by an extending moment provided by the patellar tendon force (P). The external force is balanced by the internal forces P, L and C.

Fig. 2. The patellar tendon force per unit of the external load (P/R) plotted during 0–120° flexion for values of MR = 20, 30, 40 and 50 cm.

Fig. 3. The net tangential force arising due to the patellar tendon force and the external load was calculated as T / R during 0–120° flexion for values of MR = 20, 30, 40 and 50 cm.
REFERENCES


