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# THE EFFECT OF QUADRICEPS LOADS AND KNEE POSITION ON STRAIN MEASUREMENTS OF THE TIBIAL COLLATERAL LIGAMENT

## *An Experimental Study on Human Amputation Specimens*

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The tibial (medial) collateral ligament is the one most frequently affected in minor injury and rupture (Moseley 1956, Smillie 1970). These injuries are usually the result of a severe deformation from forced abduction at the knee joint (Bristow 1939, Campbell 1939). Patients and athletes are commonly implored to "build up the quads to protect the knee!". Considerable hours are spent in the gymnasium by the trainer and athlete or in the hospital by the physical therapist and patient strengthening the quadriceps muscles. Klein (1969) stated that the best protection for the ligament is the development of balanced muscular strength. In particular it is considered that protection for the tibial collateral ligament is accomplished to some degree by the strength of the quadriceps femoris muscle. Although these *a priori* conclusions are widely held, there have been no experimental studies of the effects of quadriceps loading on strain measurements of human knee ligaments. Can it be shown that in the presence of an abducting force at the knee joint, strain in the medial collateral ligament is diminished by quadriceps loading? One of the goals of this investigation is to provide objective data which may answer this question.

A study of the literature reveals conflicting statements about the tautness of the various ligaments of the knee with different physiologic positions of the joint. As regards the tibial collateral ligament, some writers have stated that it or some portion of it is taut in all positions of flexion or extension (Fick 1911, Horotwitz 1938). Other authors have written that the ligament is taut in extension and relaxed in flexion (Bennett 1931, McMurray 1919, Murphy 1932, Steindler 1935). Such conflicting statements seem to have contributed to the motivation of Brantigan & Voshell (1941) and of Edwards et al. (1970) for their investigations on the four major ligaments of the knee joint. The work of Edwards et al. included quantitative experimental and analytical determinations of relative strain in the ligaments as a function of knee flexion angle. Because of the long controversy about knee ligament function and the clinical importance of the tibial collateral ligament, we have made similar studies to those of Edwards et al., using a somewhat different experimental technique. This paper reports findings that basically support those of Edwards et al. and also provides additional information about the effects of quadriceps loading on tibial collateral ligament strain.

## METHODS

### *Specimens*

Five above-knee amputations from four patients aged 61–67 were used in this study. The amputations were all done for atherosclerosis, severe ischemia, or gangrene which did not involve the knee joints, all of which were grossly normal.

### *Experimental Apparatus*

*Strain Gage and Attachments:* Strain is a ratio of the change in a dimension of a body and its original dimension. A body of initial length $L_0$ undergoes a change of dimension to length L. The strain can be expressed mathematically as follows: Strain $= (L - L_0)/L_0 = L/L_0$. The measurement of this variable can be made with a strain gage. We chose a SR–4 gage. This consists of a short length of fine wire, the resistance of which varies with the elongation of the wire. The gage is attached to the body tested and is directly sensitive to changes in dimensions in the body in the direction of the wire. The resistance changes are identified electrically including the strain gage as part of a Wheatstone Bridge Circuit. The gage

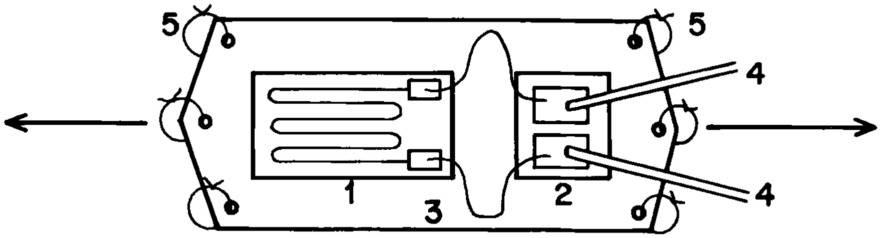


*Figure 1. Diagram of strain gage mounting for measuring strain in direction indicated by arrows. 1: strain gage; 2: wiring terminals; 3: stainless steel shim; 4: wiring to bridge circuit; 5: sutures to tendon.*

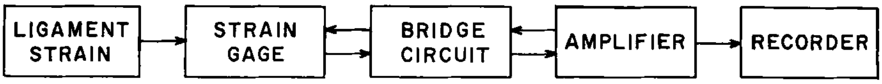
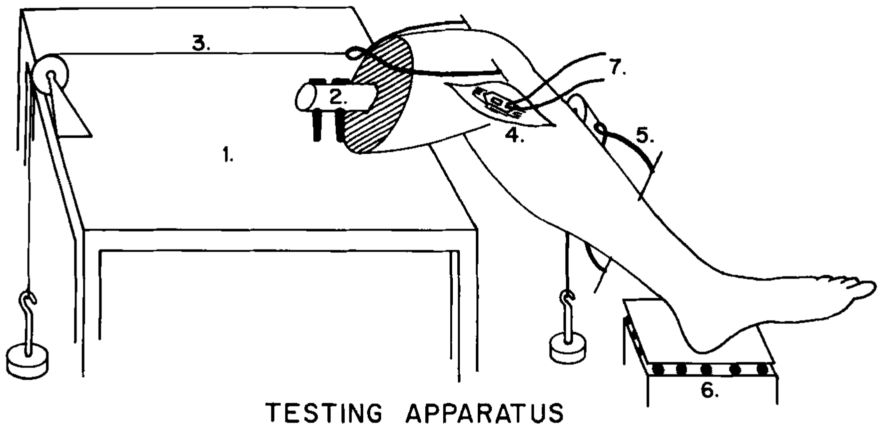


*Figure 2. Functional block diagram of the testing system.*

and wiring terminals were fixed to a .076 mm thick stainless steel shim using epoxy. The leads were soldered to the terminals and the metal trimmed to the desired shape and size (Figure 1).

*Electrical Equipment:* In addition to the above, a bridge circuit, an amplifier, and a recorder were used. We employed a special bridge circuit designed for use with a 120 ohm strain gage. The amplifier which supplied the current to the bridge circuit and measured the returning signal was a Model 7702B Hewlett-Packard Oscillographic recording system. The basic functional-electrical system is shown in block diagram (Figure 2).

*Testing and Loading Platform:* We constructed a platform which would allow us to fix the specimen, apply a load to the patella tendon and an abduction force on the lower leg. The quadriceps load was applied along the direction of the pull of the muscle through a system of pulleys and weights attached to the patella through a Steinmann pin. The abducting force was applied to a Steinmann pin in the tibia. These forces were applied with the knee in varying degrees of flexion at the same time that the effect of gravity on the leg was eliminated. This was accomplished with the use of a vertically adjustable platform with a minimal



TESTING APPARATUS

1. SUPPORT TABLE
2. FEMUR BOLTED TO TABLE
3. TRACTION ON PATELLA
4. GAGE ON TENDON
5. ABDUCTING FORCE ON TIBIA
6. MINIMUM FRICTION PLATFORM
7. WIRES TO BRIDGE CIRCUIT

*Figure 3. Diagram of specimen and mechanical system for testing.*

friction top. The top was made of two plywood boards separated by marbles, which served as ball bearings. The entire setup is shown diagrammatically in Figure 3.

*Procedure*

*Handling and Preparation of Specimens:* The specimens were refrigerated immediately and tested within 48 to 72 hours.

We dissected the above-knee amputated legs and carefully exposed the tibial collateral ligament. The strain gage was then carefully sutured to the anterior parallel fibers of the tibial collateral ligament. The dissection was kept moist by constant drip of normal saline. Once the gage was working, desiccation was prevented by the repeated application of moist sponges over the exposed tissues. The amputated leg was then fixed to the platform with bolts through the femur. A Steinmann pin was drilled through the patella transversely and the traction apparatus was mounted. The force of the quadriceps does not act directly along the line of the femur but slightly medially (Steindler 1955). The traction on the patella was, therefore, directed at an angle of six degrees medial to the shaft of the femur. A similar traction setup was fixed to the tibia at a point 30 cm below the joint line with the force applied in a lateral direction.

*Testing:* The experiment was divided into three parts.

*Part 1:* Effects of knee position alone upon tibial collateral ligament strain with the leg in an unloaded position, that is, with no force on the patella and with no abducting force on the tibia.

The knee was flexed and extended through a normal range of motion. Recordings of the ligament strain were made at angles of flexion of 0 to 90°, including 15° intervals. Full extension was considered to be 0° of flexion.

*Part 2:* Effects of quadriceps loading on tibial collateral ligament strain with the knee in different positions.

Essentially the same procedure was carried out as that described in Part 1 above. In this case, however, each series was run three times with an increasing load on the patella. Strain measurements were made with quadriceps forces of 9, 18 and 32 kg.

*Part 3:* Effects of quadriceps loading on tibial collateral ligament strain with abduction forces applied to the joint while the knee was in different positions.

An abduction force was applied to the tibia to produce a valgus deformity. The test series as described in Part 2 above was re-run with forces up to 9 kg applied laterally to the tibia. The upper limits of the loading that was chosen for the patella tendon and the tibia were determined by the mechanical limitations of the apparatus.

## RESULTS

The results are presented as averages of the data from the test specimens.

*Part 1:* Values of strain were collected as a function of knee flexion angle with no force on either the quadriceps or the tibia. These values were analyzed as relative strain in terms of per cent of the maximum elongation. One hundred per cent elongation (maximum elongation) in all cases was taken at full extension. For comparative purposes this is plotted in Figure 4 along with the theoretical and experimental curves obtained from the report by Edwards et al. (1970).

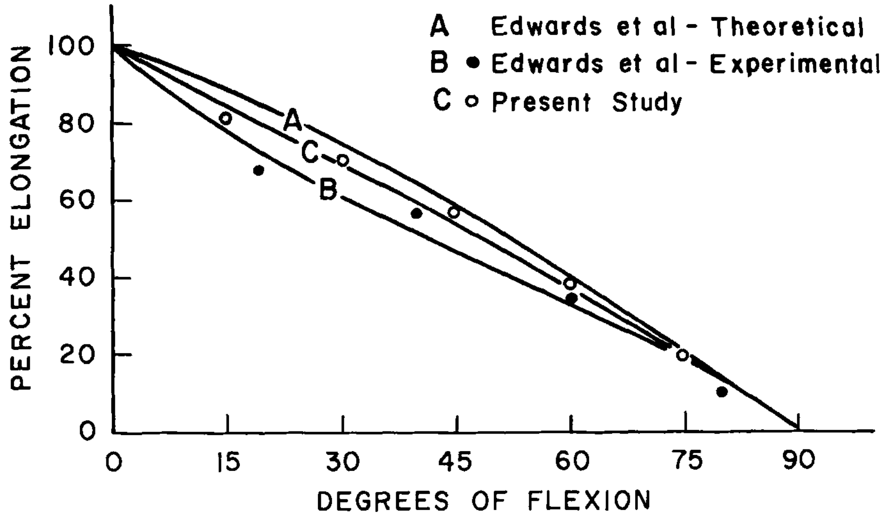


*Figure 4. Averages of relative ligament strain as a function of knee flexion angle of the knee, compared with the study by Edwards et al. (1970).*

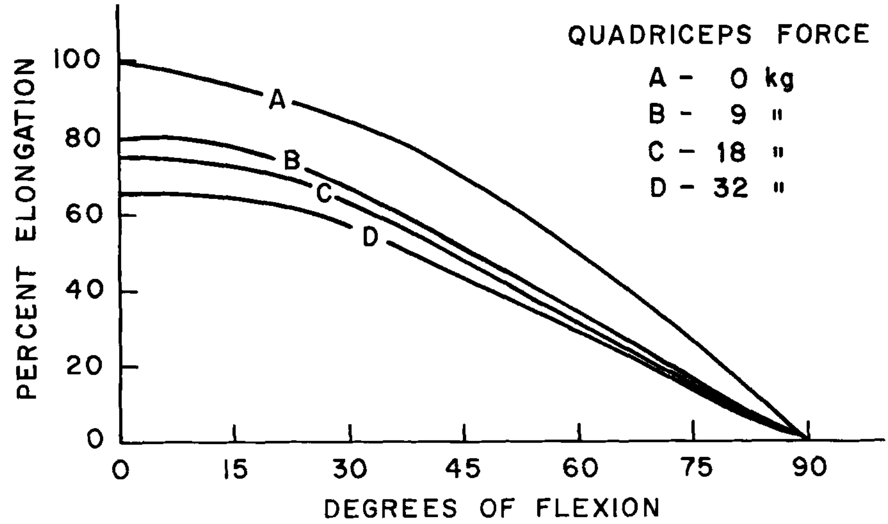


*Figure 5. Averages of relative ligament strain as a function of knee flexion angle with varying quadriceps forces.*

*Table 1. Average percentages of relative ligament strains as a function of knee flexion angle with varying quadriceps forces.*

| Quadriceps force in kg | Degrees of flexion 60° | 45° | 30° | 0° |
|---|---|---|---|---|
| 0 | 47 % | 73 % | 83 % | 100 % |
| 9 | 36 % | 55 % | 70 % | 80 % |
| 18 | 30 % | 49 % | 66 % | 75 % |
| 32 | 30 % | 41 % | 59 % | 65 % |

*Part 2:* As in the first part, values of strain were collected through the full range of knee flexion. In addition, however, there was the variable of different forces being applied to the patella tendon in the direction of pull of the quadriceps mechanism. The resulting four curves are shown in Figure 5. This graph shows curves for quadriceps loads of 0, 9, 18 and 32 kg. The numerical data is given in Table 1. It can be seen that progressively lower levels of strain are recorded in the ligament as a greater load is applied to the quadriceps mechanism.

*Part 3:* Values of strain were collected with different loads on the quadriceps mechanism and abducting forces up to 9 kg applied to the tibia. This load applied to the tibia abducted the leg at the knee joint and tended to force it into a valgus deformity. This was done with the knee in three separate angles of flexion (0°, 60° and 90°). In this part the values of strain are presented in mm of pen deflection of the recorder rather than in percentages as in Part 1 and Part 2. The individual values are present in Table 2. They are also given in three graphs, one for each of the three positions in which the knee joint was tested. See Figures 6 through 8. All three of these graphs show decreasing strain of the ligament with increasing quadriceps loads and a tendency for increasing strain with increasing abduction force.

## DISCUSSION

A major goal of this investigation was to determine the relationship between the loads (strength) of the quadriceps femoris muscle and strain in the tibial collateral ligament. In both the unstressed knee and the knee with a valgus (abducting) load, it was shown that in every instance the greater the load of the quadriceps patella tendon mechanism, the smaller the recorded strain on the tibial collateral

*Table 2. Averages of strain (mm pen deflection) as a function of abducting force on the tibia for each quadriceps force and three angles of knee flexion. The numbers in parentheses are the ranges of each of the means.*

| force kg | Abducting force on tibia in kg | | | | | |
|---|---|---|---|---|---|---|
| Quadriceps | 3 | 5 | 7 | 10 | 15 | 20 |
| Knee flexion 90° | | | | | | |
| 0 | 3 (3 – 4) | 4 (4 – 6) | 7 (7 – 8.5) | 14 (12.5–14.5) | 22.5 (19.5–22.5) | 23.5 (22 –25.5) |
| 9 | 1.5 (1 – 2.5) | 2.5 (1.5– 4.5) | 5 (3 – 7) | 11.5 (10.5–13) | 19 (15.5–22.5) | 22 (21 –24) |
| 18 | 0 | 1 (1 – 1.5) | 2.5 (2 – 3.5) | 6.5 (4 – 8.5) | 15 (10 –19.5) | 16.5 (15 –20) |
| 32 | 0 | 0 | 1.5 (1 – 2) | 5.5 (4.5– 6.5) | 14.5 (12 –17) | 15.5 (14.5–17.5) |
| Knee flexion 60° | | | | | | |
| 0 | 4.5 (3 – 7) | 8.5 (6.5–10) | 12.5 (10 –14.5) | 16.5 (15 –18.5) | 19 (17 –21) | 21 (19.5–22.5) |
| 9 | 2 (1 – 4) | 6.5 (4.5– 7.5) | 11 (9 –14) | 15 (13.5–17) | 17.5 (16 –19) | 18.5 (17 –20.5) |
| 18 | 1.5 (1 – 2.5) | 4.5 (3 – 7) | 7 (5 –11) | 8 (5.5–12) | 12.5 (10.5–14.5) | 14 (11 –17.5) |
| 32 | 1 (.5– 2) | 3 (1.5– 5) | 5.5 (4 – 8.5) | 7 (5.5–10.5) | 10.5 (9 –13) | 13.5 (12 –17) |
| Knee flexion 0° | | | | | | |
| 9 | 16 (14.5–18) | 20 (18 –22) | 24.5 (22.5–27.5) | 28 (24 –32) | 31 (29 –34) | |
| 18 | 18 (16.5–20) | 19.5 (16.5–28) | 20 (17 –24) | 22 (20 –25) | 26 (24 –27) | 32 (28.5–33.5) |
| 32 | 16 (14 –18) | 17 (15 –20) | 17 (15 –19.5) | 18.5 (17 –20) | 21.5 (20 –22.5) | 24.5 (22 –27) |

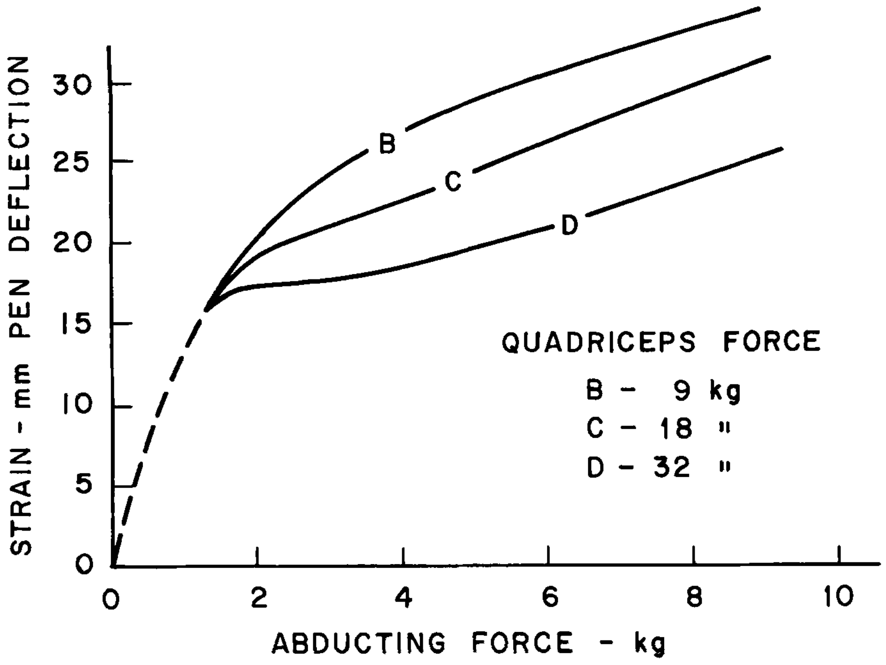


*Figure 6. Knee position is 0° flexion. Graph shows ligament strain as a function of abducting force with varying quadriceps forces.*

ligament. Tests in Part 2 show this to hold true for the entire range of knee flexion observed without an abduction force applied to the tibia (Figure 5). This pattern is also observed in Part 3 of the experiment where tests were performed with an abduction load on the lower leg. The larger forces on the quadriceps mechanism resulted in lower values for ligament strain (Figures 6, 7 and 8). Moreover, this pattern persisted in all ranges of flexion tested up to 90°. Therefore, experimental evidence is provided which we think strongly supports the coaches, physical therapists, physiatrists, and surgeons who say "Build up those quads to protect your knee!".

The findings obtained here, relevant to the question of when the tibial collateral ligament is tightest, agree with the findings of Edwards et al. (1970), and with Murphy (1932), Steindler (1935), Bennett (1931), and McMurray (1919). There is a progressive decrease in length of the tibial collateral ligament as the knee is flexed. This statement applies to the anterior parallel fibers of the tibial collateral ligament to which the strain gage was attached.

Because the design of this study recorded per cent of elongation to just 90° of flexion, it was necessary to alter the graphs of Edwards et al. (1970) to allow for comparison. In their study the knee was flexed to 130° at which their zero percentage or minimum elongation was reached. Since the findings are all expressed in relative elongation, it was possible to recalculate their data to show percentage of elongation had they stopped at 90° flexion. It is these recalculated experimental and theoretical values that are plotted in Figure 4.

In the experimental design it was necessary to take into account the viscoelastic properties of the ligament. This time-dependent response of collagen material comes into play after the immediate deformation which follows application of a load. Viscosity again comes into play when the material does not return immediately to its original dimensions after removal of the load. These problems were minimized by several aspects of the experimental design. Tests were conducted with the smaller forces applied first and subsequent ones by serial addition. The specimens were not kept in the loaded condition any longer than necessary. Finally, after each test with large loads, the

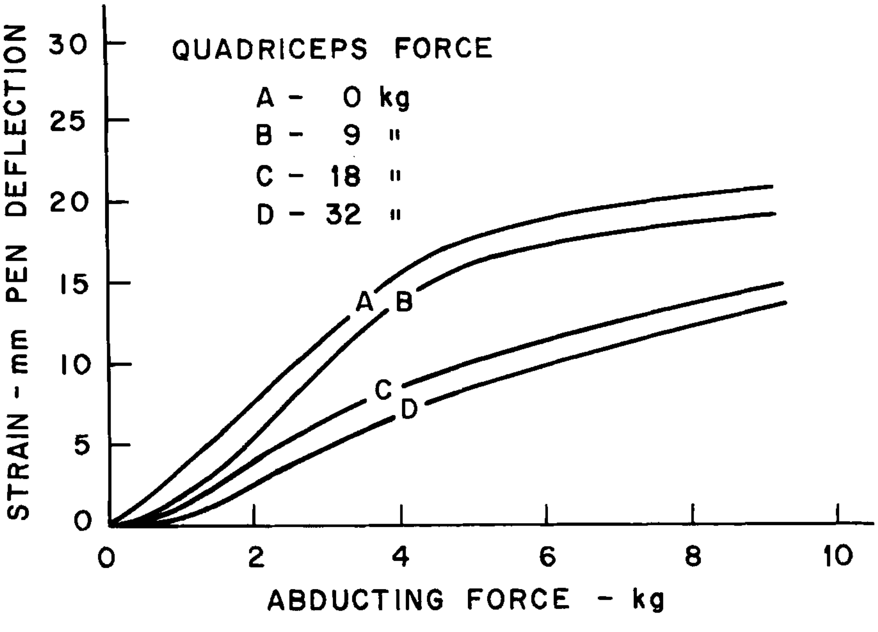


*Figure 7. Knee position is 60° flexion. Ligament strain as a function of abduction force with varying quadriceps forces.*

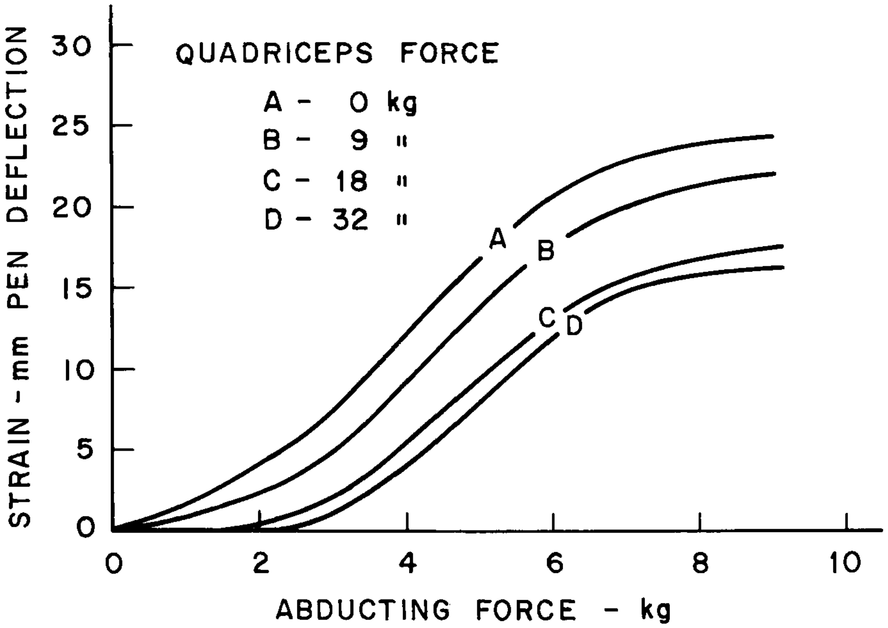


*Figure 8. Knee position is 90° flexion. Ligament strain as a function of abduction force with varying quadriceps forces.*

leg was maintained in an unloaded condition for three to five minutes before the next set of forces was applied.

It should be noted that relatively small forces were applied in these studies and consequently small strains were recorded in the ligaments. In the injuries of organized athletics, particularly football, and also in the course of routine activities, knees may be subjected to forces greater than the experimental loads applied to the tibia in this work. The knee, however, is also afforded more protection in the intact, living human. Quadriceps strengths of 200 to 400 pounds have been reported by Klein (1969). The range of quadriceps loading applied in this investigation, the upper limits of which were 32 kg, falls in the lower portion of the over-all possible range. This experimental design has not taken into consideration the effects of hamstring muscle loading on tibial collateral ligament strain. They, too, are of considerable importance in knee function. Their relation to injury and rehabilitation has been pointed out by Klein (1969).

Even with these differences between the experimental situation and the real life situation, certain conclusions appear to be justified by the findings. The strain in the tibial collateral ligament is greatest with the knee in full extension. This strain decreases progressively with flexion of the joint. Abduction forces on the tibia in various degrees of flexion of the joint increase the strain of the tibial collateral ligament. Increasing magnitudes of loads on the quadriceps mechanism in the presence of abducting forces on the tibia result in diminished strain in the tibial collateral ligament.

## SUMMARY

Strain measurements were made in the tibial (medial) collateral ligaments of five amputated legs using electrical devices and strain gages. The effect of several variables on the recorded strain of the ligaments was observed. These variables included the angle of knee flexion, simulated physiologic loading of the quadriceps mechanism, and abducting forces on the tibia. The following results were obtained:

1. Strain on the tibial collateral ligament is minimum at full flexion and increases as the knee extends.
2. The greater the load applied to the quadriceps mechanism, the less the strain in the ligament in various positions of flexion and extension.
3. The greater the abducting force on the tibia, the greater the strain in the ligament.
4. The greater the load on the quadriceps mechanism, the less the strain in the ligament due to the abducting force applied to the tibia.

A major conclusion supported by this investigation is that quadriceps mechanism can be shown experimentally to be a factor in decreasing strains on the tibial collateral ligament, both with and without abducting forces (valgus deformity) being imposed on the knee joint.

## ACKNOWLEDGMENT

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