INTRODUCTION

Even in a uniaxial tensile test, the complex anatomy of the anterior cruciate ligament makes uniform loading of all fiber bundles almost impossible. Therefore, comprehensive observation of the ACL’s entire surface is necessary even when measuring local strains. To observe the ACL’s entire surface strain, we propose a photoelastic coating method. Preliminary experiments using this method on rabbit MCLs yielded significant results; further measurements were performed on the strain distributions over the ACL surface in a human knee at various knee angles.

MATERIALS AND METHODS

A specially designed apparatus, designated a knee motion simulator jig, was used to duplicate the natural motion of a knee whose medial and lateral femoral bone parts were removed in order to expose the ACL for observation. The jig was equipped with screws to lock the knee along all six potential axes of movement. Three fresh right cadaver knees (65, 70, 70 year old males) were used in this study. One of the knees was fixed horizontally in the simulator jig. The proximal end of the femur and the distal end of the tibia were firmly secured in the chucks, and all the locking screws were loosened. Two orthopaedic surgeons each moved the knee by hand through a range of motion. A palpation check was made to confirm that the correct relationship was being maintained between opposing articulating surfaces during free flexion-extension of the knee. The six scale indices were read and recorded from 0 to 120 degrees at 10 degree intervals. After this was done, the medial and lateral femoral bone parts and all soft tissues were removed, leaving only the ACL intact.

We have found a specific kind of polyurethane monomer (NIPPORAN 5230, NIPPON Polyurethane Co. Japan) to be suitable as a photoelastic coating due to its optically high fringe-sensitivity, its flexibility and great elasticity as well as its strong adhesive properties. The polyurethane was painted unto the ACL at 10 degrees of knee flexion. The simulator jig with the knee was mounted on a universal stand which allows three dimensional rotation, so that the exposed ACL might be viewed from any direction. The entire unit was put into a photoelastic observation apparatus. Using the average value of previously obtained data with respect to the 6 axes’ movements, the knee was flexed from 0 to 120 degrees at 10 degree intervals. As it was flexed, various motions along the other 5 axes were reproduced. At each stage of knee flexion, all locking screws were tightened to fix the knee's position. Then images of the photoelastic fringe patterns on the surface of the ACL as well as its deformations were recorded by a video camera. After the measurement has finished, the entire process was repeated for another knee.

RESULTS

Measurement and analysis gave both the isoclinic and isochromatic fringe patterns and therefore the principal strain lines and strain distributions along them in association with knee flexion. Figure 1 shows strain distributions drawn along selected principal strain lines when viewed from the medial and the lateral sides at several knee angles. The principal strain lines were close to the fiber directions. The strains along the principal strain lines were not necessarily uniform; large strains were observed near the femur and decreased rapidly near the insertions. Up to 90 degrees of knee flexion, a zero strain area was observed only on the medial side near the tibia, but the area was not fixed in size and its location depended upon the knee angle. Analysis of the fringe patterns which appeared supported the notion that the anterior and posterior sides of the ACL work reciprocally during knee motion. On the whole, the strains on the lateral side were larger than those on the medial side.

DISCUSSION AND CONCLUSIONS

To our knowledge, this is the first study to have demonstrated that the strain distribution patterns which appeared in the ACL were certainly not uniform even along the fiber directions in association with knee flexion. Our study has clearly shown that the line on which the peak strain was produced moved transversely. Two marked fibers belonging to the same bundle may show different strain patterns, thereby creating different results from the measurements at the discrete points. Yet the results we have obtained, which give an overall picture of the ACL’s strain and deformation, allowed us to make clear explanation of mutually incompatible results from previous clinical experiments. As our photoelastic measurement technique can identify the sites where strains are most concentrated, it would be useful for a detailed analysis of how the ACL may fail.

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