Tensile Forces in Knee Ligaments in Response to Hyperextension

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Disclosures:

Introduction: Mechanical functions of the knee ligaments have been reported so far [1-3]. Hyperextension is known as one of joint configurations in which ligamentous injuries frequently occur. However, the ligaments’ function in response to hyperextension still remains unclear because of a lack of biomechanical research. Therefore, the purpose of the present study is to measure the in-situ forces in knee ligaments and other soft tissues during knee hyperextension, for the assessment of their mechanical functions.

Methods: A 6-DOF robotic system consisting of custom made 6-axis manipulator with a 6-DOF universal force/moment sensor (UFS) [4] was used. All the actuators attached to the axes of the manipulator were position/velocity control-based actuators. A LabView-based control program runs on a windows PC to control the displacement of, and force/moment applied to cadaveric knee joints with respect to the knee joint coordinate system developed by Grood and Suntay (Fig. 1) [5]. Five intact human fresh cadaveric knee specimens were used in the present study. The mean age of the specimens was 83 years old ranging from 80 to 93 years old. They were subjected to two types of hyperextension test; the knee was hyperextended up to 10 N-m of extension moment with no proximal force application, and with 30 N of proximal force application respectively. The 6-DOF motion of, and force/moment applied to the intact knees were recorded during the tests. The 6-DOF intact knee motion was reproduced after a sequential transection of the oblique popliteal ligament (OPL), anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), lateral collateral ligament (LCL), posterior oblique ligament (POL), popliteofibular ligament (PFL), and joint capsule (Fig. 2). The change in 6-DOF forces and moments in response to the transection of a simple structure was used to calculate the in-situ force in the structure. In addition, the hyperextension tests were performed for the knee joints after the transection of the OPL.

Results: In response to 10 N-m of extension moment with no proximal force application, the OPL force was 44±10 N; higher than those in other structures with significant differences observed versus those in the PFL, LCL, MCL, POL, Capsule, and ACL (Fig. 3). Besides the OPL, the forces in the MCL, capsule and POL were relatively high as compared with those in other structures. It was surprising that the force in the ACL was 5.5 N, the lowest in all the structures. In-situ forces in all the structures remained almost unchanged in response to 10 N-m of extension moment combined with 30 N of proximal force. In response to the OPL transection, in-situ forces in all the structures except the OPL were increased with significant deference observed in the PFL and LCL.

Discussion: We found that the in-situ force in the OPL is tremendously high as compared with other structures during hyperextension. In the OPL transected knees, in-situ forces in the posterolateral structures were significantly increased. The results suggested that the risk of damage to the OPL may be higher than other structures in response to hyperextension. It is also suggested that the risk of secondary damage to other structures such as MCL, POL, Capsule, and PCL is increased after the transection of the OPL.

It is well known that the hyperextension induces ACL injuries, although we found that in-situ force in the ACL was very low in the present study. It is suggested that the ACL force is not increased in response to pure hyperextension moment. When the knee is subjected to hyperextension in daily activities, not only extension moment but also after forces and moments such as proximal force, internal-external moment, and varus-valgus moment were applied to the knee. The application of those forces and moment together with hyperextension may increase the ACL force.

Significance: The OPL is the primary structure for resisting to pure hyperextension moment, while the MCL, joint capsule, and POL are secondary structures. The force in the PFL, and LCL are significantly increased after the injury of the OPL.

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References: [1] Fujie et al., JBME, 2004, pp.54-61
Fig. 1 Knee joint coordinate system [5]
Fig. 2 The (a) anterior and (b) posterior aspect of the human right knee.
Fig. 3 In-situ forces in the soft tissues in the intact knee and OPL-transected knee joints in response to 10 Nm of extension moment.