A new computer-aided and robot-assisted surgery for anterior cruciate ligament reconstruction

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Introduction: Anterior cruciate ligament (ACL) reconstruction is the most common surgery for people whose ACL is damaged. In order to restore the function of the knee joint after the reconstruction surgery, the position and direction of tunnel which the graft passes through should be carefully planned and the tunnel needs to be accurately drilled by the planning. It is known that a computer-aided and robot-assisted surgical technologies could help to achieve better surgical outcomes. The CASPAR® system has been used for single-bundle ACL reconstruction [1]. In this study, a novel computer-aided and robot-assisted surgical system for ACL reconstruction was provided to determine position and direction of tunnel based on CT images and to perform drilling it for both single-bundle and double-bundle ACL reconstructions.

Materials & Methods: A surgical robot system for the ACL reconstruction was developed based on a system in our laboratory [2]. The system consists of three main modules: the pre-operative planning system, the navigation system, and the robot system. The pre-operative planning system provides patient-specific bone model, assists surgeon to determine the position and direction of tunnel for graft, and transfers the planned data to the navigation system and the robot system. The navigation system based on the Optotrak® 3020 (Northern Digital Inc, Canada) measures 3D positions of the bone and the robot system by registration process. The robot system based on the vertical articulated arm type robot with 6 DOF (AS3 Rockwell Samsung Automation Inc., Korea) performs drilling tunnel on tibia and femur by moving drilling tool along the planned path.

In this study, both single-bundle and double-bundle ACL reconstructions were tested on saw bones. In the single-bundle reconstruction, a tunnel which started from below tibial head on the lateral side of bone to femoral head was planned and drilled. In the double-bundle reconstruction, two tunnels for two grafts to replace for the anteromedial (AM) bundle and posterolateral (PL) bundle of the original ACL were planned and drilled. Each test was performed three times with saw bones for both reconstructions and the planning time, drilling time, and accuracy of tunnel were investigated.

Results: The results showed that the planning time was 10 ~ 15 minutes for both reconstructions. The drilling time for single-bundle reconstruction was approximately 60 ~ 70 seconds while the drilling times were 60 ~ 70 seconds for AM tunnel and 50 ~ 60 seconds for PL tunnel for the double-bundle reconstruction. The average errors of length and diameter of tunnel for the single-bundle reconstruction were 0.5 ~ 1 mm and 0.6 ~ 1.1 mm, respectively, while those for the doucle-bundle reconstruction were 1.0 ~ 1.3 mm and 1.2 ~ 1.8 mm, respectively. The errors of drilling points in comparision to the planned data were 0.6 ~ 0.9 mm for single-bundle reconstruction and 0.9 ~ 1.4 mm for double-bundle reconstruction. The errors of tunnel angle were about 1.3o for single-bundle reconstruction and 0.8o ~ 1.3o for double-bundle reconstruction.

Discussion: The results showed that the developed laboratory-level computer-adied and robot-assisted surgical system using the pre-operative planning system and the serial type robot manipulator with 6 DOFS performed both single-bundle and double-bundle ACL reconstruction within an acceptable accuracy and presented feasibity of the surgical robot system. The system has several advantages: the pre-operative planning system could consider tunnel position and direction to reduce the soft tissue damage and the robot system could shorten the drilling time and improve the drilling accuracy. However, the experiments in this study were done using saw bone. Therefore, the cadaveric study for ACL reconstruction using the developed robot system is necessary in the future.

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References

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