Lateral approach of computer-aided robotic system for less-invasive total knee arthroplasty

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Introduction: Total knee arthroplasty (TKA) became popular because of its advantages such as pain relief when the knee joint was degenerated or damaged. Recently, computer-aided robotic systems such as Robodoc® system and Makoplasty® system have been used to assist surgeons to achieve higher accuracy of cutting and alignment in knee. The incision is conventionally done at the anterior part of the knee and the cutting is performed from the frontal direction during the TKA because enough working space of the tools is necessary. Although minimal invasive surgery (MIS) is known to have many advantages in the arthroplasty, the MIS has not been commonly performed in the TKA using the robotic system at this moment. Since the MIS TKA could be achieved in lateral incision and cutting, the robot configuration needs to be changed for different cutting process. In this study, we evaluted the lateral bone cutting in comparison to the frontal cutting using a laboratory-level surgical robot system for the less-invasive TKA.

Materials & Methods: A surgical robot system for TKA developed in our laboratory was used in this study [1]. The system included three main modules: the pre-operative planning system, the navigation system, and the robot system. The pre-operative planning system is a powerful tool to create bone models from CT images, to plan removal part of bone and position of implant, and to define cutting plane and cutting path. The navigation system based on the Optotrak® 3020 (Northern Digital Inc, Canada) defines 3D positions of the bone and the robot system by registration process. The calculated cutting path data is transformed to the joint angles of the robot at each time step by inverse kinematics analysis. Finally, the vertical articulated arm type robot with 6 DOF (AS3 Rockwell Samsung Automation Inc., Korea) uses transformed angle data to execute bone cutting.

In this study, two kinds of cutting methods for TKA which planned on pre-operative planning system were investigated: 1) the frontal approach (FA) where the cutting is executed from the frontal direction and 2) the lateral approach (LA) where the cutting is executed from the lateral direction. In FA, the milling tool was moved zigzag along cutting path which chosen on the planning step and the cutting direction was perpendicular with cutting surface. In LA, the milling tool was approached on lateral side of knee joint through small incision on skin. The tool was swept around a center point at incision area and followed cutting path to remove bone part. The cutting was performed on five planes of femur and repeated three times for each cutting method. The six parameters (cutting time, cutting path length, cutting accuracy, range motion of robot, incision length, and quality of cutting surface) were compared between two methods.

Results: The cutting time for each experiment was approximately 6 minutes in LA while it was about 11 minutes in FA, where the lengths of cutting path were 726.7 mm in LA and 1230.0 mm in FA. The average cutting errors were 0.2 ~ 0.7 mm in LA and 0.6 ~ 1.9 mm in FA. The range motion of each robot joints is around 2.7°~ 52.7° in LA while that was 9.0°~ 96.8° in FA. The incision length measured base on movement of cutting tool were 60~ 70 mm in LA and 100~ 150 mm in FA. Finally, the surface after cutting in LA was smoother and shaper than that in FA.

Discussion: The results indicated that the LA showed better performance than the FA in femoral cutting. The shorter cutting time and path, less movement of robot joint and incision, and better accuracy and quality of cutting were obtained in the LA. Since the cutting tool was approached from the lateral side and swept around a center point at incision area, the incision could be reduced in the LA than in the FA. Moreover, soft tissue damages inside the knee joint during the cutting might be avoided. The less range motion of each joint of the robot system could affect to reduce the errors.

Therefore, the bone cutting from the lateral direction when using the surgical robot system needs to be considered to improve the current computer-aided and robot-assisted surgical system for TKA.

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References

[1] Kim YH et al., Int J Precis Eng Manuf 10: 25-29, 2009.