ADDITIONAL ADVANTAGES OF LATERAL APPROACH IN LESS-INVASIVE TOTAL KNEE ARTHROPLASTY (TKA) USING COMPUTER-AIDED ROBOTIC SYSTEM

1 Le Minh Huynh and 1,2,# Yoon Hyuk Kim

1 Department of Mechanical Engineering, School of Engineering Kyung Hee University,
2 e-Spine Center, ILRI, Kyung Hee University,
# Corresponding Author; e-mail: yoonhkim@khu.ac.kr, tel: +82-31-201-2028, fax: +82-31-202-8106

SUMMARY
In this study, we developed a laboratory-level surgical robot system to cut the bone from the lateral direction of the knee joint to provide minimal invasive surgery (MIS) TKA and performed TKA experiments with saw bones of femur from the conventional approach as well as the MIS approach. The results were compared between two types of surgical approach such as the incision length, the processing time, the cutting quality, the cutting accuracy, and the movement of robot. We had considered that the lateral direction should be necessary to improve the current surgical robot system in knee arthroplasty surgery.

INTRODUCTION
Recently, computer-aided robotic systems, such as Robodoc® system and Makoplasty® system, have been used to enable surgeons to improve the accuracy of cutting and alignment in knee and hip arthroplasty. The incision is normally 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 required during cutting process. Currently MIS is the most popular keyword in the arthroplasty, and at this moment the MIS could not be performed common in the TKA using the robotic system. This MIS TKA could be achieved in lateral direction, and different cutting process also changes the robot configuration, which mainly affect the system accuracy. In this study, we investigated what additional advantages could be achieved in the bone cutting process laterally using laboratory-level less-invasive TKA surgical robot system.

METHODS
A surgical robotic system for TKA was developed in our laboratory [1]. The surgical robot system consisted of three subsystems: the pre-operative planning system, the navigation system, and the robot system. The pre-operative planning system determines the parts of bone to be removed and generates the moving path of cutting tool using virtual bones and implants. The navigation system measures the positions of the bone and the robotic system to transfer the planned cutting path to the robotic system. The cutting path is transformed to the joint angles in the robotic system at each time step by inverse kinematics analysis. The robotic system cuts the femur and tibia along the cutting path by controlling each joint as the inputted joint angle (Fig. 1). The Optotrak® 3020 (Northern Digital Inc, Canada) and a vertical articulated arm type robot with 6 DOF (AS3 Rockwell Samsung Automation Inc., Korea) were implemented for the navigation system and the robotic system.

In this study, two kinds of femoral cutting paths were planned: 1) the frontal approach (FA) where the cutting is performed from the frontal direction as conventional TKA and 2) the lateral approach (LA) where the cutting is performed from the lateral direction (Fig. 2). Bone cutting along each approach in femur was performed three times with saw bones. Then, the performances of FA and LA such as cutting accuracy, cutting time, quality of surface, range of motion in each joint of robotic system, and estimated incision length were compared.

RESULTS AND DISCUSSION
The accuracy was analyzed by measuring the lengths of edges of five planes of distal femur after three times of repetitive cuttings given in Fig. 2. The average cutting errors in LA, which were 0.2 ~ 0.7 mm, were smaller than those in FA, which were 0.6 ~ 1.9 mm (Table 1). Femoral cutting time were approximately 6 minutes in LA, which is shorter than 11 minutes in FA, while the cutting device moved at 3 mm/s in both cutting cases. The cutting surface in LA was smoother than that in FA as shown in Fig. 3. The range of motion in each joint of robotic system was 2.7°~ 52.7° in LA while that was 9.0°~ 96.8° in FA. Finally, estimated incision length by considering the working space of the cutting tool were 100~150 mm in FA and 60~70 mm in LA (Fig. 2).
The results indicated that the LA showed better performance than the FA in five different surgical outcomes in femoral cutting, which were the cutting error, the cutting time, the quality of cutting surface, the range of motion in each joint of robotic system, and estimated incision length. The shorter cutting time and the smoother surface in the LA could be obtained because the cutting tool moved perpendicular with cutting plane and follow relatively long path to cut entire plane in the FA. The smaller range of motion in each joint could be generated due to the characteristic of vertical articulated arm type robot appropriate for rotational movement than translational movement since the movement of the cutting tool in the LA was based on the rotation. Additionally, the better accuracy in the LA could be achieved due to the smaller range of motion of each joint. Though the LA was originally planned for the applicability to the MIS because of its smaller incision length, it has several additional advantages. Therefore, consideration of bone cutting from the lateral direction when using the robotic system should be necessary to improve the current computer-aided robotic surgical system.

CONCLUSIONS
In conclusion, a laboratory-level surgical robot system using a serial type robot manipulator with 6 DOFs could successfully perform the MIS TKA experiments by approaching from the lateral direction. Moreover, the LA TKA had several additional advantages for the cutting time, the quality of cutting surface, and the cutting accuracy. Therefore, consideration of bone cutting from the lateral direction should be necessary to improve the current surgical robot system in knee arthroplasty surgery.

ACKNOWLEDGEMENTS
This work was supported by 2009 National Agenda Project (NAP) funded by Korea Research Council of Fundamental Science & Technology (P-09-JC-LU63-C01).

REFERENCES

<table>
<thead>
<tr>
<th>Plane 1 (mm)</th>
<th>Plane 2 (mm)</th>
<th>Plane 3 (mm)</th>
<th>Plane 4 (mm)</th>
<th>Plane 5 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact length</td>
<td>30</td>
<td>22</td>
<td>22</td>
<td>12</td>
</tr>
<tr>
<td>FA</td>
<td>0.6</td>
<td>1.7</td>
<td>1.0</td>
<td>1.9</td>
</tr>
<tr>
<td>LA</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Figure 2: Two types of cutting planes: (a) Cutting planes of femur, (b) Conventional front-approach (FA) cutting, and (c) new MIS (Minimal Invasive Surgery) lateral-approach (LA) cutting.

Figure 3: Quality of cutting surface of distal femur in both FA and LA.