Newly Developed Navigation System for Minimally Invasive Total Knee Arthroplasty

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Introduction:

The navigation system was reported to improve the accuracy of bone resection and positioning of implants for total knee arthroplasty (TKA) [1]. In the other hand, one of its clinical problems was the surgical invasion such as larger skin incision and longer duration of operation [2]. Many surgeons usually expect the minimally invasive TKA and sometimes struggle to have the appropriate surgical exposure and the reference landmarks. In the present study, new navigation system was developed for the minimally invasive TKA, which was referred in the quite limited area, and evaluated about the precision of the osteotomized plane and its handling in compared with the commercialized system.

Materials and Methods:

The accuracy of new developmental navigation system (CT-based) was compared with image-free navigation system (BrainLAB).

This new system (Group N) only required the reference points from small limited area of the medial femoral condyle and proximal tibia through the skin incision to obtain the optical images. The surface of medial distal femoral condyle and intercondylar notch were used for surface matching (Figure 1A, B). The hip center was calculated using a pivoting algorithm by slowly rotating and crossing with the femur. The anatomical landmarks of the distal femur were registered with the medial and lateral epicondyle on the skin. The anatomical landmarks of the tibia were also registered with medial edge of tibial tuberosity, medial malleoli and lateral malleoli on the skin. The surface of anterior cortex of proximal tibia, medial edge, medial tibial plateau, and medial tibial tuberosity, were used for surface matching. The medial malleoli and lateral malleoli were registered with the surface matching technique from the skin (Figure 1C, D, and E). The information about lateral compartment was not necessary to be registered.

Figure 1. Surface registration point of group N
A, B: Group N requires the surface of distal plane, medial edge and posterior plane of medial condyle and lateral intercondylnar notch.
C, D, E: Group N requires the surface of medial plateau, medial edge, anterior cortex, medial tibial tuberosity, medial malleoli and lateral malleoli.

I. Bone model experiment

Three-dimensional geometrical bone model was generated from the previously obtained CT images of cadaveric knee with 3D image analysis software (Mimics, Materialise) and then constructed with 3D-CAD software (Imageware1.0, EDS). Bone cutting was achieved by using new navigation system (group N) and BrainLAB navigation system (group B) at the same time (Figure 2A). The alignment and position of cutting surface were evaluated by both navigation systems. The evaluation of alignment and position of distal femur were performed about flexion/extension, varus/valgus and bone resection volume. The evaluation of anterior femoral surface was performed about the position of flexion/extension, rotation and AP shift. In the osteotomized surface of proximal tibia, the position of proximal tibia was evaluated about posterior slope, varus/valgus angles and bone resection volume. In addition, the cutting surface was also measured using 3D surface scanner (Mitsutoyo, IPAPAN). The accuracy was evaluated by comparing the data from 3D surface scanner to these from the two navigation systems.

II. Clinical experiment

From January 2010 to May 2011, 30 TKAs in 29 patients (3 men, 26 women) were performed using both navigation systems. The mean age was 72±7.4 (range: 54-86) years, and the 24 knees had been diagnosed with osteoarthritis (OA) and 6 with rheumatoid arthritis (RA).

Registration was performed by two navigation systems as described above (Figure 2B,C). The time for registration was recorded and compared. Bone resection was performed under the direction of group B. The alignment and position of cutting surface were evaluated by both navigation systems respectively. Postoperatively CT-scans of the entire lower leg (from femur head to ankle joint) were performed and three-dimensional model leg was reconstructed from these data with 3D software. The alignment and position of the components were measured by the 3D software and these obtained data was compared and evaluated from these with the two navigation systems.

Mann-Whitney’s U test was used for continuous variables. A P-value of less than 0.05 was considered as statistically significant.

Figure 2. Two navigation systems
A: Two navigation systems were simultaneously analyzed on bone model experiment
B, C: In clinical experiment, two navigation systems were placed like bone model experiment. Registration was respectively performed using both navigation systems.

Results:

I. Bone model experiment

The deviation in group N / group B data to compared with 3D scanner measure data was 0.6±0.8/0.6±1.0 degree on coronal plane, 0.8±1.2/3.0±1.9 degree on sagittal plane, and 1.1±0.9/1.0±0.8 mm on bone resection at the cutting surface of distal femur. The deviation at the cutting surface of anterior femur was 0.1±3.0/2.1±1.3 degree on rotation, 1.7±0.1/2.0±0.6 degree on sagittal plane and 0.4±3.3/0.8±1.5 mm on bone resection. The deviation at the cutting surface of proximal tibia was 0.2±1.3/0.2±0.4 degree on coronal plane, 0.1±0.4/0.2±2.0 degree on sagittal plane and 0.6±1.7/1.1±0.2 mm about bone resection. The accuracy with both group N and group B was sufficient to perform the appropriate placement of components referred from the previous reviews.

II. Clinical experiment

The registration time of femur in group N / group B was 115.5±28.1 / 117.6±42.6 second, and the tibial registration time in group N / group B was 111.9±22.5 / 119.4±37.2 second. The total registration time in group N / group B was 227.4±46.6 / 237.1±63.9 second. There was no significant difference between two groups (p=0.60).

The deviation in group N / group B data in comparison with measured CT data was 1.1±1.2/0.9±1.1 degree on coronal plane, 2.5±2.0/4.2±2.7 degree on sagittal plane, and 1.1±2.9/0.1±1.6 mm on bone resection at the cutting surface of distal femur. The deviation at the cutting surface of anterior femur was 1.1±2.8/0.2±6.8 degree on rotation, 0.9±1.5/4.4±1.6 degree on sagittal plane and 0.9±1.6/1.6±6.6 mm about bone resection. The deviation at the cutting surface of proximal tibia was 0.5±1.2/0.4±1.3 degree on coronal plane, 0.8±2.0/1.5±0.9 degree on sagittal plane and 0.9±2.9/0.7±2.5 mm with bone resection.

Discussion:

Our navigation system strongly achieved that the alignment error was less than 2 degree and the position error was less than 2 mm in other than sagittal plane of femur. This error was quite small deviation but this might be caused from the overestimated width of the anterior cortex bone. The rotation of femoral component was more precisely regulated than the Group B and thus our system would avoid the patellofemoral complications.

Significance:

Our newly developed navigation system had enough accuracy for the bone resection of the knee even in small limited registration area and moreover in a short time.

References: