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Prosthetic alignment and sizing in computer-assisted total knee arthroplasty

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Abstract We implanted 60 posterior stabilized total knee prostheses (P.F.C. Sigma, DePuy, Warsaw, USA). In 30 cases, we used a CT-free navigation system (Vector Vision, Brain LAB, Heimstetten, Germany), and in 30 matched-paired controls, we used a conventional manual implantation. We compared postoperative long-leg radiographs in the two groups. The results revealed a significant difference in favor of navigation. In addition, we compared the preoperative anteroposterior dimension of the femoral condyle with the postoperative value. While there were no significant differences in the preoperative anteroposterior dimension of the femoral condyle between the two groups, the postoperative value in the navigation group was significantly larger than that of the preoperative value. Therefore, surgeons using navigation systems should guard against the possibility of oversizing when determining the size of the femoral component.

Résumé Nous avons implanté 60 prothèses totales postéro-stabilisées du genou (P.F.C. Sigma, DePuy). Dans 30 cas nous avons utilisé un système de navigation sans scanner (Vector vision R, Laboratoire du Cerveau, Heimstetten, Allemagne) et dans 30 contrôles appairés nous avons utilisé une implantation manuelle habituelle. Nous avons comparé les grandes radiographies postopératoires des membres inférieurs dans les deux groupes. Les résultats ont révélé une différence notable en faveur de la navigation. De plus nous avons comparé la dimension antéro-postérieure du condyle fémoral avant l'intervention avec la valeur postopératoire. Tandis qu'il n'y avait pas de différence notable dans la dimension antéro-postérieure préopératoire du condyle fémoral entre les deux groupes, la valeur postopératoire dans le groupe de la navigation était nettement plus grande que la valeur préopératoire. Par conséquent les chirurgiens qui utilisent des systèmes de navigation doivent prendre garde à ne pas implanter un composant fémoral sur-dimensionné.

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Introduction

Accurate alignment of knee implants and ligament balance are essential for the success of total knee arthroplasty (TKA) [5]. A computer-assisted navigation system has been developed to improve the accuracy of the alignment of osteotomy and implantation, and the usefulness of this system has been reported by several authors [2, 3, 6–8, 10, 11, 13–15]. We introduced the CT-free navigation system in October 2002. This system is relatively new, and an accumulation of the clinical data has not been enough to assess its value in improving surgical accuracy. Therefore, the first purpose of the present study was to review our clinical experience and evaluate the accuracy of implantation and the usefulness of this system among our patient population. Secondly, during the course of our initial clinical experience, we noticed that the size of the selected femoral component tended to be larger than that suggested in preoperative planning. Thus, the additional purpose of the study was to examine the potential problem of an oversized femoral component in computer-navigated TKA.

Materials and methods

From October 2002 to May 2003, we implanted 36 posterior stabilized total knee prostheses (P.F.C. Sigma, DePuy, Warsaw, USA) using a CT-free navigation system (Vector Vision, Brain LAB, Heimstetten, Germany). In order to make a fair assessment and minimize the influences of clinical variables, computer-assisted TKA were indicated for the subjects without valgus deformity, severe bony defects, and rheumatoid arthritis. In subsequent radiological analysis, six patients were excluded because the quality of the radiograph was judged to be inadequate for accurate measurement. The remaining 30 patients diagnosed with osteoarthritis constituted the basis of this study. The results of this study group were compared to those of a matched-paired control group consisting of 30 subjects with total knee prostheses of the same type implanted by the same surgeon using a conventional manual technique during the study period. In selecting the subjects in the control group, age, gender, body size and preoperative status of the knee were matched to those of each subject in the navigation group. Patients comprised 25 women and five men with a mean age of 75.3 (50–91) years in the navigation group and 25 women and five men with a mean age of 73.3 (45–90) years in the manual group.

Radiological measurements

Several parameters were measured on postoperative anteroposterior and lateral long-leg weight-bearing radiographs for each patient. Lateral radiographs were taken with the patient standing while bearing weight equally on both feet with the knee at 30° of flexion and the hip at 45° of external rotation. The X-ray tube was directed perpendicularly to the lateral aspect of the patella at a distance of 260 cm. A 320 mA, 0.03-s exposure was used at 80–100 kV, depending on soft tissue thickness. Then, we measured the mechanical axis of the femur and tibia with both anteroposterior and lateral long-leg radiographs by overlaying the preoperative X-ray film on the postoperative film in order to detect the points of Oswald's definition [9] on the postoperative X-ray film. Five roentgenographic parameters of the component positioning angle were measured based on the four reference lines. All radiological measurement was performed by the first author (MT) who was blind to any other clinical information.

In the second part of the study, we compared both preoperative and postoperative anteroposterior dimension of the femoral condyle and prosthesis in both the navigation group and the manual group using lateral X-ray to assess the presence of a postoperative change in size. This size was defined as the distance between the anterior and posterior tangent of the femoral condyle, the lines being parallel to the femoral long axis. A posterior reference line was drawn at the midline between the two posterior tangent lines to the medial and lateral condyles (Fig. 1).

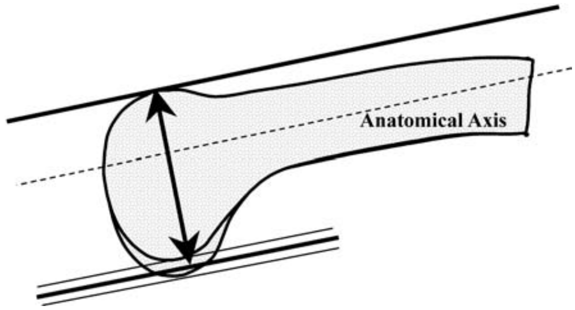

Fig. 1 Measurement of the anteroposterior dimension of the femoral condyle

The results were analyzed statistically using a statistical software package (Statview 5.0, Abacus Concepts, Berkeley, CA< USA). The differences in the number of cases at optimal angle between the navigation group and the manual group were analyzed using the chi-square test. The differences in the preoperative and postoperative anteroposterior dimension of the femoral condyle between the two groups were analyzed using the nonpaired Student's *t* test. Differences of $p<0.05$ were considered statistically significant.

Results

Coronal plane alignment

In the navigation group, the mechanical axis angle (MAA) was 179.4±1.9°, and in the manual group 179.2±2.6°. This angle, as well as the femoral and tibial component angles, showed no significant differences between the groups (Table 1). When we defined the optimal MAA as being in the range from 177 to 183°, we had 28 cases in the navigation group and 20 cases in the manual group with an optimal MAA ($p<0.05$). In terms of prosthetic alignment, we achieved 28 cases in the navigation group and 21 cases in the manual group with a femoral component angle in the optimal range between 88 and 92° ($p<0.05$). On the tibial side, we obtained 28 cases in the navigation group and 23 cases in the manual group with a tibial component angle in the optimal range between 88 and 92°.

Table 1 Mean values and standard deviation for positioning angles in the navigation group and in the manual group

	Navigation group	Manual group	*p* value
Mechanical axis angle	179.4±1.9°	179.2±2.6°	NS
Coronal femoral component angle	90.0±1.6°	90.2±2.1°	NS
Coronal tibial component angle	90.6±1.6°	91.0±1.9°	NS
Sagittal femoral component angle	90.0±1.9°	85.9±3.1°	<0.001
Sagittal tibial component angle	85.0±3.2°	82.9±2.0°	<0.001

Sagittal plane alignment

In the navigation group, the mean sagittal femoral component angle was 90.0±1.9° and in the manual group 85.9±3.1° ($p<0.001$). The mean sagittal tibial component angle was 85.0±3.2° in the navigation group and 82.9±2.0° in the manual group ($p<0.001$) (Table 1). In the navigation group, 26 cases achieved a sagittal femoral component angle in the optimal range between 88 and 92°, but there were only ten in the manual group ($p<0.001$). On the tibial side, the numbers with an optimal sagittal tibial component angle were13 cases and six cases, respectively.

Anteroposterior dimension of the femoral condyle

Finally, we compared the preoperative and postoperative sagittal anteroposterior dimension of the femoral condyle and prosthesis in both groups. The preoperative dimensions of the femoral condyle were 62.4±4.4 mm in the navigation group and 62.5±3.4 mm in the manual group. The postoperative values were 64.7±4.1 mm in the navigation group and 62.6±3.6 mm in the manual group ($p<0.05$).

Discussion

The initial clinical results of using navigation systems in TKA have been encouraging [3, 6, 7, 10, 14]. Saragaglia [10] conducted a randomized study and reported that a satisfactory alignment in the coronal plane, defined as a mechanical axis between 3° varus and 3° valgus alignment, was observed more often with the navigation system than with the conventional procedure (84 versus 75%). In a case-control study, Jenny et al. [6] compared 60 prostheses implanted with the navigation system to 60 prostheses implanted using conventional instruments. In the navigation group, 53 prostheses were judged to have a satisfactory coronal plane alignment, whereas this was only the case for 43 of 60 in the conventional group ($p<0.05$). Significant improvement in other positioning criteria (individual positioning of the components in the coronal and sagittal plane) has also been observed. However, all of those reports have dealt with the experiences with the Orthopilot navigation system (Aesculap, Tuttlingen, Germany) used in Europe and the USA. The first purpose of the present study was, therefore, to examine the usefulness of the relatively new navigation system (Vector Vision, Brain LAB, Heimstetten, Germany) in a Japanese population. In the Vector Vision navigation system, in comparison to the Orthopilot navigation system, tibial and femoral bone model morphing is performed by dragging along the structure of the bone surface to calculate the three-dimensional bone model. A CT-free navigation system with bone model morphing, instead of only using a few geometric landmarks, provides geometric and morphologic three-dimensional data without any preoperative or intraoperative images. This method relies mainly on data collected with a three-dimensional optical localizer in a relative coordinate system attached to the bones. Stindel [12] described that bone morphing is an accurate, fast, and user-friendly method that can provide morphogenic as well as geometric data. He suggested this method should be considered as an alternative to the CT-based method. Compared to techniques using only a few landmarks on the knee joint, the bone morphing approach can offer significant improvements because it enables the surgeon to plan a real and global tradeoff taking into account all morphologic and functional parameters, including knee balancing and accurate mechanical axis alignment.

In this study, the mean angle of femoral and tibial component position in the sagittal plane in the navigation group was more accurate and closer to the intended alignment than those in the manual group. Efficacy of the use of this system in our patient population was thus verified. In the manual group, on average, the femoral component was implanted in flexion by 4.1° while the tibial component was implanted with increased posterior inclination. Sparmann [11] conducted a randomized comparative analysis of navigated and conventional TKAs and showed a similar tendency of flexed orientation of the femoral prosthetic implantation in the manual group. He suggested that anterior bowing of the femur could be a causative factor of this malalignment. In the analysis of the navigated TKA, Stulberg [13] also showed a tendency of hyperextended orientation of the femoral component. Theoretically, in the presence of anterior bowing of the femur, anatomical axis of the distal femur (orientation of the intramedullary rod) deviates anteriorly to the mechanical axis of the femur (Fig. 2). Therefore, sagittal alignment of the femoral component in the manual group can be perpendicular to the anatomical axis of the distal femur although in slight flexion in relation to the mechanical axis of the whole femur.

In the second part of this study, femoral component sizes of the navigation group were found to be significantly larger than those of the manual group while there was no significant difference in the anteroposterior dimensions of the femoral condyle preoperatively. In our experience, the femoral component size selected in the navigation group tended to be larger than that determined by the preoperative templating while the selected size corresponded to preoperative planning in the manual group. The difference in femoral component sizing between the navigation and manual groups is thought to be due to the difference in sagittal alignment of the prosthesis. As shown in the first part of this study, the femoral prosthesis was positioned almost perpendicular to the mechanical axis in the navigation group resulting in a slightly extended alignment in relation to the anatomical axis of the distal femur. With the femoral component oriented in extension, the level of the anterior femoral cut was determined so as to avoid notching into the anterior cortex. Thus, the resulting size in the navigation group was selected as larger than that corresponding to the preoperative sagittal dimensions.

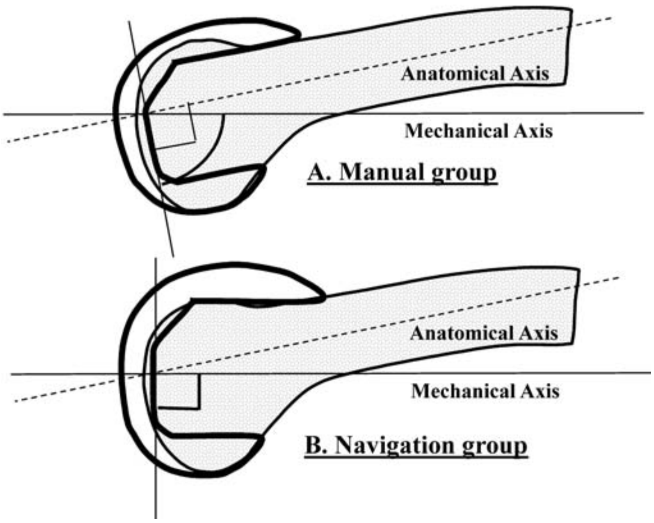

Fig. 2A, B Illustration of the relationship between the femoral component and the distal femur with the femoral anatomical and mechanical axis. **A** In the manual group, the femoral component is implanted perpendicular to the anatomical axis. **B** In the navigation group, the femoral component is implanted perpendicular to the mechanical axis

Tillett [16] reported that positioning of the femoral component in slight flexion or slight extension does not affect the longevity of the prosthesis. However, Insall [4] claimed that the correct sizing of components for TKA is an important factor in optimizing both function and long-term results of the prosthetic components. Daluga [1] described that an increase in the anteroposterior dimensions of the femoral component exceeding 12% adversely affected postoperative range of motion and significantly predisposed patients to anterior knee pain and a need for postoperative knee manipulations. The present study clearly shows that the femoral component size is calculated as larger than the preoperative dimensions when femoral anterior bowing is present. Therefore, although use of the navigation system can achieve improved accuracy in implantations, a system which follows a mechanical axis may lead to oversizing of the femoral component. Surgeons should therefore take into account preoperative anterior femoral bowing and evaluate the size of the femoral component carefully when using the navigation system.

In conclusion, the Vector Vision navigation system allowed a significant improvement in the accuracy of implantations in relation to the mechanical axis in our patient population. However, the present study also highlighted the potential problems of oversizing and extended positioning in the selection and orientation of the femoral component if anterior femoral bowing is present.

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