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ORIGINAL PAPER

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Minimally invasive unicompartmental knee replacement with a nonimage-based navigation system

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Abstract In a prospective study, two groups of 20 unicompartmental knee replacements (UKR) each were operated either using a CT-free navigation system or the conventional minimal invasive technique. Radiographic assessment of postoperative alignment was performed by long-leg coronal and lateral radiographs. The results revealed a significant difference between the two groups in favor of navigation. In the computer-assisted group, 95% of UKRs were in a range of 4–0° varus (mechanical axis) compared with 70% in the conventional group. The only inconvenience was a prolonged operation time (+19 min). Due to the limited exposure, the navigation system is helpful in achieving a more precise component orientation. The danger of overcorrection is diminished by real-time information about the leg axis at each step during the operation.

Résumé Dans une étude prospective, deux groupes de 20 prothèses unicompartimentales de genou ont été opérés soit en utilisant un système de navigation sans scanner, soit par une technique mini-invasive habituelle. L'estimation de l'alignement postopératoire a été faite avec des grandes radiographies frontales et sagittales coronales. Les résultats ont révélé une différence notable entre les deux groupes en faveur de la navigation. Dans le groupe aidé par ordinateur, 95% des cas étaient dans une gamme de 0° à 4° de varus comparé à 70% dans le groupe conventionnel. Le seul inconvénient était un temps d'opération prolongé (+19 min). En raison de l'exposition limitée, le système de navigation est utile pour donner une orientation plus précise aux implants. Le danger d'hypercorrection est diminué par l'information en temps réel sur l'axe du membre à chaque temps de l'opération.

Introduction

In several studies, excellent 10-year survivorships of unicompartmental knee replacement (UKR) have been reported [3, 4, 6]. A major advantage of UKR is that it can be performed through a small incision that need not be extended into the quadriceps tendon [1, 16]. Despite the favor of preserving undamaged soft tissue, the surgeon has a reduced overview and is in risk of component malpositioning [8].

Recently, navigation systems have been developed to improve the accuracy of component alignment in total knee arthroplasty (TKA), and the first follow-up results of computer-assisted TKA are promising [10, 15]. To our knowledge, for computer-assisted UKR, only one study is available in the literature. Jenny et al. [12] reported superior results when using a navigation system in UKR compared with the standard procedure. There are only a few previous papers focussing on postoperative alignment after conventional UKR [11], especially when using a minimally invasive technique [8]. Fisher et al. reported significant differences of the postoperative leg alignment when comparing the results of minimally invasive versus open UKR [8].

The aim of this prospective study was to analyze the accuracy of postoperative leg alignment and component orientation in minimally invasive, computer-assisted UKR when using a nonimage-based navigation system with specific fine adjustable cutting devices. We hypothesized that the computer-assisted procedure would prevent overcorrection and lead to a precise component orientation and thereby might improve patient long-term outcome.

Material and methods

In a prospective study between August 2002 and January 2003, two groups of 20 patients each were operated on with minimally invasive UKR either using a computer-assisted CT-free navigation

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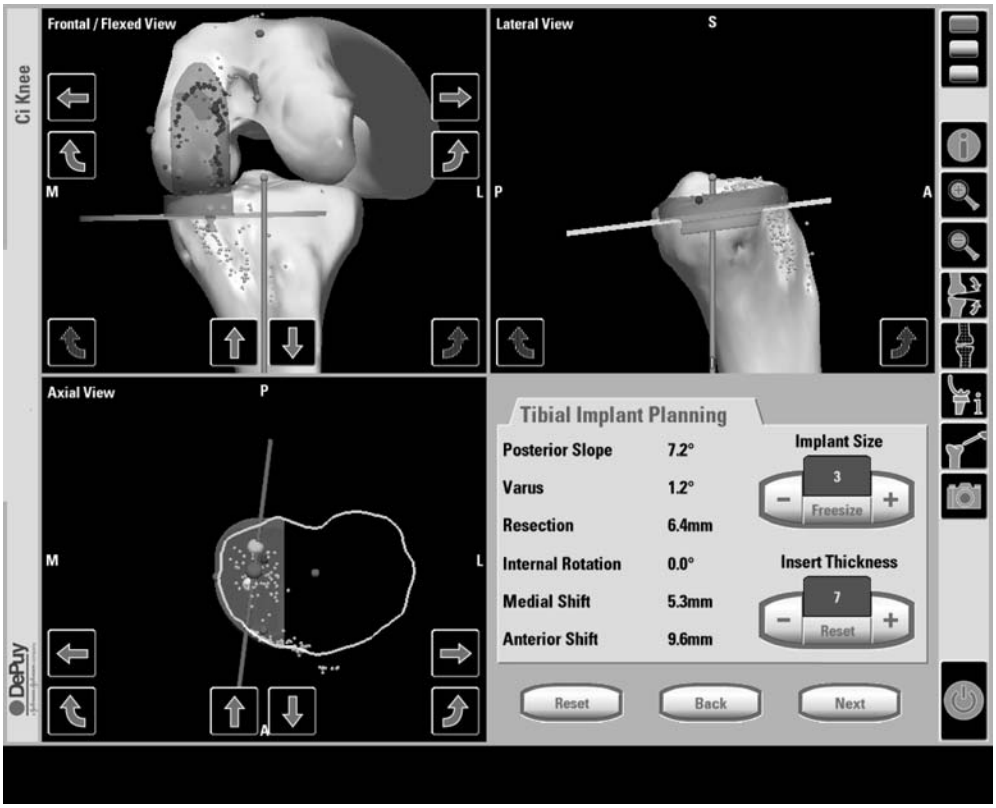


Tibial Implant Planning

Posterior Slope	7.2°
Varus	1.2°
Resection	6.4mm
Internal Rotation	0.0°
Medial Shift	5.3mm
Anterior Shift	9.6mm

Fig. 1 Planning module. The planning proposal for component orientation can be adapted in all planes to the surgeon's preferences

system (Ci-Navigation-System, DePuy I-Orthopaedics, Munich, Germany) or the conventional technique. The patients were dedicated to both groups by the weekday of operation. In both groups, the same implants (Preservation, DePuy Inc., Warsaw, USA) were used. All operations were performed by one team (LP and HB) experienced in computer-assisted and conventional UKR. Exclusions were defined regarding deformities greater than 10°, subluxation of the joint, instability due to the loss of the anterior cruciate ligament, and flexion contractures of more than 10°.

The patients in both groups were comparable regarding age, gender, and preoperative leg deformity. In the computer-assisted group (study group), 14 female and six male patients were included. The mean age was 65 (range: 49–73) years. and the mean preoperative deformity was 4.7° varus. In the conventional surgical technique (control group), 12 female and eight male patients were included with a mean age of 67 (range: 45–74) years and a mean preoperative deformity of 5.6° varus.

Operative technique

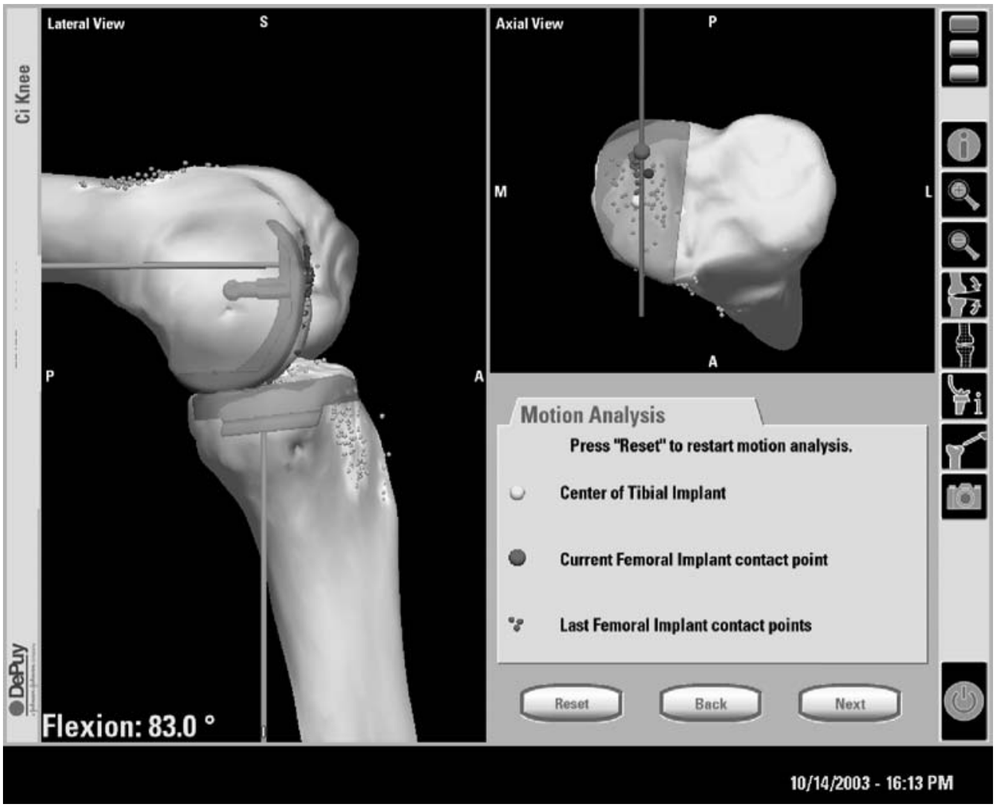
A 7–9 cm skin incision was made from the superior medial edge of the patella and extended distally, and the joint was exposed in the technique described by Repicci et al. [16]. The CT-free Ci-Navigation-System has an optical tracking unit that detects reflecting marker spheres by an infrared camera. The system is controlled by a draped, touch-screen monitor. Two reference arrays with passive marker spheres are rigidly attached to both the femoral and tibial bone through stitch incisions. Specific anatomic landmarks (e.g. the anterior cruciate ligament insertion, the borders of the medial plateau, and the medial and lateral malleolus) were determined at the beginning of the operation. The center of the hip was determined by a pivoting algorithm. Additional surface information was gained by sliding a pointer over the medial tibial plateau and the medial femoral condyle.

Based on these data, the system created an adapted bone model of the specific patient's anatomy and offered a planning proposal (Fig. 1) for component orientation. Prior to the first bone resection, the surgeon was informed about the expected leg axis, and the ligament laxity could be examined throughout the entire range of motion. Furthermore, the system provided a kinematics analysis (Fig. 2) informing the surgeon about the expected contact areas of the femoral component and the tibia tray.

The preservation instrument set offered a dedicated, fine, adjustable tibial cutting block. Orientation of the cutting plane was performed under real time visualization by the navigation system (Fig. 3). The tibial slope was adapted to the individual patient's slope. After the tibial cut was performed, the cutting plane was checked and documented by the verification function of the system. After acquiring information about the size of flexion and extension gap, the distal femoral cutting guide was fixed, and the surgeon was informed about the actual leg alignment by the navigation system. Then, the femoral multicutting block was adjusted and again the navigation system provided information about the actual position and potential deviations in the different planes. Final implant position, range of motion, achieved leg axis, and joint stability were examined and documented.

Statistical analysis

Axial limb alignment and component orientation were evaluated on standardized pre- and postoperative full-length weight-bearing radiographs by two independent observers two times on different days. The Kolmogorov-Smirnov test was used to evaluate if axial limb alignment followed a normal (Gaussian-shaped) distribution. No significant departures were identified. Limb alignment between both groups was compared using unpaired *t* tests. Level of statistical significance was determined for $p < 0.05$. The coefficient of variation was calculated to determine intra- and interobserver variability. Intraobserver variability for limb axis determination and interobserver variation were not significant.



Motion Analysis

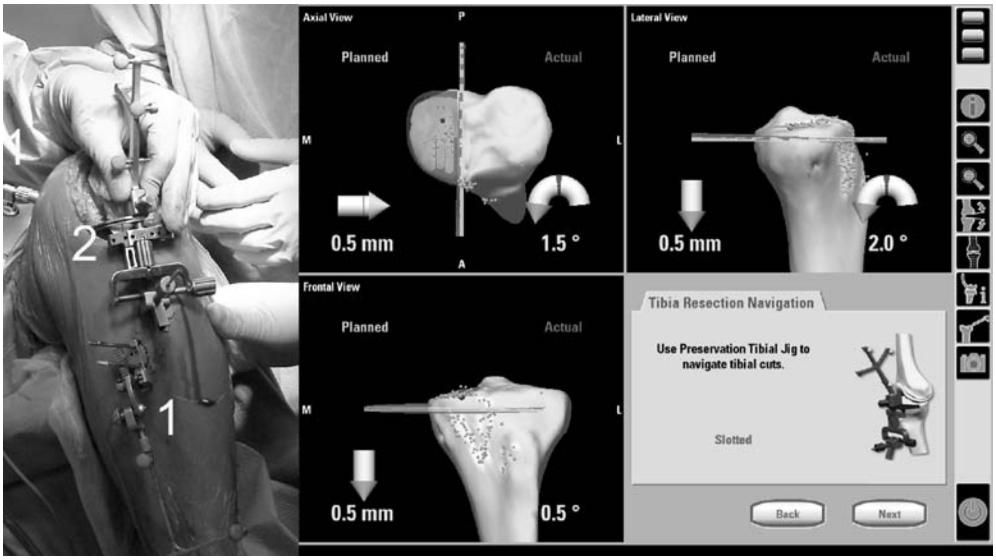
Press "Reset" to restart motion analysis.

○ Center of Tibial Implant

● Current Femoral Implant contact point

Last Femoral Implant contact points

Fig. 2 Analysis of kinematics before performing the first cut. The surgeon is informed about the contact area over the range of motion (*red line*)



Tibia Resection Navigation

Use Preservation Tibial Jig to navigate tibial cuts.

Slotted

Fig. 3 Intraoperative setting. Reference frames with reflecting marker spheres (*1*) are attached to the distal femur and proximal tibia. The cutting plane is visualized in the adapted bone model and in numerical values. The dedicated fine, adjustable, tibial cutting block (*2*) facilitates the plane adjustment

Results

Mechanical leg axis

In both groups, we aimed on a postoperative varus alignment of 2°. Mean preoperative coronal femorotibial angle was corrected from 4.7° varus to 1.6° varus (SD: 1.2°) in the navigated group. In the conventional group, a mean preoperative deformity of 5.6° was corrected to 1.4° (SD: 2.4°). In the navigated group, one case with a slight overcorrection (1° valgus) was found, while there were four patients (maximum 3° valgus) in the conventional group (Fig. 4). The results were statistically significant (p=0.008).

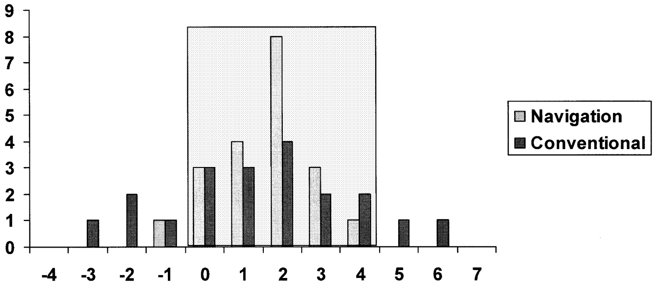


Fig. 4 Distribution of postoperative mechanical limb axis. Comparison between the computer-assisted (navigation) and the conventional group

Component alignment

Frontal plane alignment

For the coronal orientation of the tibial component, we found a mean angle of 89° (SD: 0.9°, range 88–91°) in the navigated group, while the mean angle in the conventional group was 88.7° (SD: 1.8°, range 85–92°) (*p*=0.04).

Mean deviation from the neutral axis was 0.7° (SD: 1.5°, range 2° valgus to 3° varus) in the computer-assisted group and 1.1° (SD: 1.9°, range: 2° valgus to 5° varus) in the conventional group (*p*=0.12).

Sagittal plane alignment

In the computer-assisted group, the mean flexion-extension alignment was 0.9° (SD: 2.5°, range: 4° flexion to 5° extension), while in the conventional group it was 1.7° (SD: 4.4°, range: 6° flexion to 10° extension) (*p*=0.028). The tibial slope was adjusted to the natural slope. In the study group, the posterior slope of the tibial component was 4.7° (SD: 1.4°), while in the conventional group it was 5.8° (SD: 1.6°).

Surgical procedure

No conversion from computer-assisted surgery to the conventional technique was required in this study. The mean time for surgery (skin to skin) was 77 min (SD: 14 min) in the computer-assisted group and 58 min (SD: 11 min) in the conventional group. There were no complications (e.g., infections, fractures) due to the fixation of the reference bases.

Discussion

In the last years, there has been a resurgence of interest in doing UKRs [13]. UKR has distinct advantages. It has been reported to be much less invasive than total knee replacement, preserving the undamaged soft tissue and articular structures and restoring the joint to more normal function [1]. The time needed for recovery is considerably less, particularly when a reduced or minimally invasive approach is used [1, 13].

Certain technical considerations must be fulfilled when performing UKR. Overcorrection of the deformity should be avoided. Many experienced surgeons advocate undercorrection of the mechanical axis by 2–3° [2, 4, 7, 9, 18] because overcorrection might result in mediolateral subluxation of the femorotibial articulation or in excessive force on the unresurfaced compartment with early secondary degeneration [5, 8].

Inaccurate implantation is a well accepted factor for early failure [4, 14, 17]. Most unicondylar systems offer a limited and potentially inaccurate instrumentation, which relies on substantial surgeon judgment for prosthesis placement [11]. Rates of inaccurate implantation of 30% have been reported with conventional instrumentation [19]. Minimally invasive UKR is a technically demanding procedure because the limited view may further alter the accuracy and reproducibility when accessing implant positioning and postoperative limb alignment.

Fisher and coworkers [8] compared the minimally invasive with the standard open UKR. They found a higher variance of postoperative limb alignment when using the minimally invasive technique (mean 3.5° varus, SD: 2°, range: 3° valgus to 8° varus) compared with the standard approach (mean 4.3° varus, SD: 1.2°, range 2° varus to 8° varus). Further, significant malalignment was seen for the tibial implant position in the frontal plane and for the femoral implant position in the lateral plane. However, in their study, the precision of the postoperative determination of component alignment was limited by the size of the radiographs (18 inches).

Using the Orthopilot-System, Jenny and Boeri [12] reported a significantly higher rate of correct component implantation in all planes. Sixty percent of the computer-assisted prostheses had a satisfactory alignment compared with 20% in the conventional group [12]. For the femorotibial mechanical angle, Jenny and Boeri reported a range of 5° varus to 4° valgus in the computer-assisted group compared with 10° varus to 10° valgus in the conventional group. These findings were comparable to our results. Aiming on a postoperative leg axis of 2° varus, 95% of patients in the navigated group and 70% in the conventional group were within a range of 0–4° varus leg axis.

Additional operating time is needed when using navigation systems in UKR. However, after an initial learning curve, the computer-assisted surgical procedure was increased by 29 min. The system is user friendly and does not require any special computer knowledge. Particularly, the fine, adjustable, cutting device for the tibia seems to be useful in achieving an exact adjustment. It facilitates plane adjustment and saves time otherwise needed for correction of the plane and new pin fixation. Further, the kinematics analysis appears to be useful, providing additional information before performing the first cut.

For the next software release, it will be essential to asses the position of the distal femoral cutting block. Actually, the orientation of the cutting block is determined by the tibial cut without direct control of the cutting plane. Therefore, the surgeon is at risk to transfer or enhance errors.

Computer-assisted, minimally invasive unicondylar arthroplasty with specific instruments leads to a superior accuracy in reconstruction of limb alignment. Additional information is provided by the real-time presentation of the achieved leg axis, component alignment, and contact areas of the components when using the kinematics analysis.

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