Cutting and implanting errors in minimally invasive total knee arthroplasty using a navigation system

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Abstract

Purpose The purpose of this study was to evaluate the accuracy of bone cutting and implantation in minimally invasive total knee arthroplasty with image-free navigation.

Methods The alignment of the tibial and femoral bone resection was measured in 40 knees during surgery. The alignment measurement was repeated after cementing the tibial and femoral components. We evaluated the cutting error and the implanting error.

Results The mean tibial cutting errors were 0.5 and 0.7° in the frontal and sagittal planes, respectively. The mean femoral cutting errors were 0.5 and 0.9° in the frontal and sagittal planes, respectively. The mean tibial implanting errors were 1.0 and 0.9° in the frontal and sagittal planes, respectively. The mean femoral implanting error was 0.7° in the frontal plane.

Conclusions Computer-assisted navigation was useful in checking the alignment of both bone cut and cementation.

Introduction

Computer-assisted navigation systems were introduced to improve component alignment accuracy in total knee arthroplasty (TKA). Many cohort studies have shown improved prosthetic radiographic alignment associated with the use of computer-assisted navigation when compared to standard instrumentation [1–4]. The use of computer-assisted surgery has also reduced the risk of malalignment associated with minimally invasive surgery (MIS) [5, 6], which has potential issues with component malpositioning arising from the

limited surgical view [7]. However, there were still errors in component alignment with computer-navigated TKA associated with the jig cutting setting, bone cutting and component implantation [8–11]. Navigation systems recommend checking for alignment of the bone cutting surface just after cutting the bone. In addition, they recommend checking for the lower limb alignment only after the trial or final components are introduced. The importance of the final positioning of the femoral and tibial components seems to be particularly underestimated [9]. However, we can use the navigation system at the time of the final tibial and femoral component implantation. There is little published information available regarding bone cut accuracy and implant fixation in TKA performed with the combined techniques of computer-assisted navigation and MIS [12].

The purpose of this study was to evaluate the accuracy of bone cutting and implantation in MIS TKA with image-free navigation. Our hypothesis was that navigation could be useful to check the alignment of both bone cut and cementation. In addition, we evaluated postoperative radiographic and intraoperative navigation alignment measurements.

Materials and methods

This prospective study involved 40 consecutive patients who had a primary TKA. MIS was performed in all knees through a mini-midvastus approach without patellar eversion by one experienced surgeon. Posterior stabilised (PS) designs were used for all cases, and all components (Columbus, Aesculap, Tuttlingen, Germany) were fixed with cement. The navigation system used for the measurements was the image-free navigation system (OrthoPilot, Aesculap, Tuttlingen, Germany). There were 12 men and 28 women with a mean age of 74 years (range 58–88 years) and a mean body mass index of 26.6 kg/m² (range 19.1–39.8 kg/m²). The diagnosis for all patients was

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knee osteoarthritis. The mean $\pm$ standard deviation (SD) pre-operative mechanical axis deviation in degrees of valgus was measured at $11.1 \pm 6.5^\circ$ of varus alignment (range 20° of varus to 6° of valgus). The tibial and femoral cuts were targeted to be perpendicular to the mechanical axis in the coronal and sagittal planes using the tibia first gap technique [13]. The saw blade thickness used was 1.27 mm. The alignment of the tibial bone resection plane in the frontal and sagittal planes was measured with the instrumented probe positioned on the proximal tibial cut and was recorded from the navigation system screen. The alignment of the femoral bone resection plane in the frontal and sagittal planes was measured using the instrumented probe. The orientations of these resection planes were recorded with a resolution of 1° . The tibial component was cemented. The cement mantle was digitally pressurised into the cancellous bone before component insertion. Tibial component alignment was measured by the same instrumented probe after impaction (Fig. 1a). The patellar component was cemented, and then the femoral component was cemented. After impaction, femoral component alignment was also measured with the instrumented probe. The probe was then positioned on the most distal part of the femoral component condyles. (Fig. 1b). Only the alignments in the coronal plane for the femur and the frontal and sagittal planes for the tibia were recorded due to the shape of the components. The mechanical axis measurement was recorded after implanting all components and was measured without applying any axial force.

The cutting error was defined and measured as any deviation between the cutting surface and the planned angle in the frontal and sagittal planes. The deviation between the component alignment and the corresponding cutting surface was calculated and defined as implanting error. Full-length standing anteroposterior and lateral radiographs were completed three weeks after surgery to determine the alignment of the components. We assessed the frontal femoral component angle, the frontal tibial component angle, the sagittal tibial component angle and the tibiofemoral angle, as described previously [6]. The deviations between the radiographic and intraoperative component angles were calculated, and we defined these deviations as the radiographic error. The mean absolute error of the mechanical leg axis was also evaluated.

Statistical analysis

The relationships between alignment parameters were analysed by Spearman's rank correlation, with the level of significance set at 0.05.

Results

The mean absolute tibial cutting error was $0.5 \pm 0.6^\circ$ ($0.1 \pm 0.8^\circ$ varus, range 3° varus to 1° valgus) and $0.7 \pm 0.7^\circ$ ($0.4 \pm 1.0^\circ$

Fig. 1 Intraoperative navigation measurements of the tibia (a) and the femur (b) after implanting

anterior slope, range 1° posterior slope to 2° anterior slope) in the frontal and sagittal planes, respectively. The mean absolute femoral cutting error was $0.5 \pm 0.5^\circ$ ($0.3 \pm 0.6^\circ$ valgus, range 1° varus to 1° valgus) and $0.9 \pm 0.7^\circ$ ($0.5 \pm 1.1^\circ$ anterior slope, range 2° posterior slope to 3° anterior slope) in the frontal and sagittal planes, respectively. The mean absolute tibial implanting error was $1.0 \pm 0.9^\circ$ ($0.6 \pm 1.2^\circ$ valgus, range 1° varus to 3° valgus) and $0.9 \pm 0.9^\circ$ ($0.2 \pm 1.3^\circ$ anterior slope, range 2° posterior slope to 3° anterior slope) in the frontal and sagittal planes, respectively. The mean absolute femoral implanting error was $0.7 \pm 0.6^\circ$ ($0.2 \pm 0.9^\circ$ varus, range 2° varus to 2° valgus) in the frontal plane. We found no cutting or implanting error that was greater than 3° . The mean absolute tibial radiographic error was $0.8 \pm 1.0^\circ$ ($0.5 \pm 1.1^\circ$ varus, range 3° varus to 2° valgus) and $1.3 \pm 1.1^\circ$ ($0.9 \pm 1.5^\circ$ posterior slope, range 4° posterior slope to 3° anterior slope) in the frontal and sagittal planes, respectively. Only one knee showed sagittal tibial plane radiographic error of more than 3° . The mean absolute femoral radiographic error was $1.0 \pm 0.9^\circ$ (range 3° varus to 3°

Table 1 Cutting error

	Bäthis et al. [1]	Yau et al. [14]	Kim et al. [12]	Nakahara et al. [10]	This study
Femur					
Frontal alignment (°)	0.6 ^a	0.8 ^a	0.1	0.5	0.3 (0.5 ^a)
Sagittal alignment (°)	1.4 ^a	1.6 ^a	0.7	1.6	0.5 (0.9 ^a)
Tibia					
Frontal alignment (°)	0.5 ^a	1.3 ^a	0.3		0.1 (0.5 ^a)
Sagittal alignment (°)	1 ^a	1.3 ^a	0.3		0.3 (0.7 ^a)

^aAbsolute values are expressed

valgus) in the frontal plane. The mean absolute error of the mechanical leg axis was $1.9 \pm 1.2^\circ$ (range 5° varus to 3° valgus). In four cases (10 %), radiographic errors for the mechanical leg axis were more than 3° .

Positive correlations were found between the femoral cutting surfaces and the angle planned in the frontal and sagittal planes ($R^2=0.358$, $p<0.001$; and $R^2=0.194$, $p=0.006$, respectively). The tibial cutting surface showed a significant positive correlation with the angle planned in the sagittal plane ($R^2=0.215$, $p=0.004$); however, there was no correlation between the tibial cutting surface and the angle planned in the frontal plane ($R^2=0.006$, $p=0.612$). There was a positive correlation between the frontal alignment of the femoral component and the corresponding cutting surface ($R^2=0.408$, $p<0.001$). A positive correlation was found between the sagittal alignment of the tibial component and the corresponding cutting surface ($R^2=0.144$, $p=0.018$). There was no correlation between the frontal alignment of the tibial component and the corresponding cutting surface ($R^2=0.007$, $p=0.604$). There was also no correlation between the navigation and radiographic measurements in terms of the postoperative mechanical axis, frontal femoral frontal alignment, or tibial frontal and sagittal alignments ($R^2=0.004$, $p=0.689$; $R^2=0.003$, $p=0.744$; $R^2=0.111$, $p=0.564$; and $R^2=0.069$, $p=0.100$, respectively).

Discussion

This study showed no cutting or implanting errors of more than 3° , but 10 % of the cases showed radiographic errors of more than 3° . Our results were comparable to previous studies when

evaluating cutting error [1, 10, 12, 14] (Table 1), implanting error [9] (Table 2) and radiographic error [15, 16] (Table 3). Our study is the first to evaluate all types of errors (cutting, implanting and radiographic error). Choi et al. [16] reported the correlation between postoperative navigation and radiographic alignment. However, the frontal femoral and tibial alignments were measured by the instrumented probe of the navigation system positioned onto the relevant bone cuts after a final cut of the femur or tibia without implanting the components in this study. Our study and the study by Catani et al. [9] checked the component alignment after component implantation. Previous studies evaluated the standard TKA except the study by Kim et al. [12] who used the MIS technique. We used the surgical instruments specifically designed for MIS; however, Kim et al. [12] used the standard surgical instruments because MIS instruments were not available at their institute. Our study together with that of Kim et al. [12] showed that accuracy could be achieved with MIS TKA using computer-assisted navigation. Our study demonstrates that the surgical instruments designed for MIS provided accuracy which was similar to that achieved with the standard instruments.

The bone cut measurements in our study showed significant correlation between the targeted and the actual alignments in the frontal and sagittal planes for the femur and in the sagittal plane for the tibia. However, a more accurate procedure is required in the tibial frontal plane. Techniques which included avoiding the movement of cutting blocks and the deflection of the saw blade at the time of bone cut produced greater accuracy. Several previous studies reported that a considerable amount of error could occur in the process of bone cutting with the oscillating saw systems [1, 8, 10, 12, 14]. A cadaver study

Table 2 Implanting error

	Catani et al. [9]	This study
Femur		
Frontal alignment (°)	0.2	0.2 (0.7 ^a)
Tibia		
Frontal alignment (°)	0	0.6 (0.9 ^a)
Sagittal alignment (°)	0.2	0.1 (0.9 ^a)

^a Absolute values are expressed**Table 3** Radiographic error

	Yaffe et al. [15]	Choi et al. [16]	This study
Mechanical leg axis (°)	2.7	2.3	1.1 (1.9 ^a)
Femur			
Frontal alignment (°)			0.1 (1.0 ^a)
Tibia			
Frontal alignment (°)			0.5 (0.8 ^a)
Sagittal alignment (°)			0.8 (1.3 ^a)

^a Absolute values are expressed

showed that the maximum cutting error relative to the cutting guide was in the range of 1.5–2° for varus/valgus and in the range from 3 to 4° for flexion/extension [17]. Although we can recut the bone to achieve the planned alignment after checking cut surface alignment with the navigation system, we had no need for this correction in this series. Component implantation was achieved accurately in the frontal plane for the femur and sagittal plane for the tibia. However, a more accurate procedure is required for the tibial component in the frontal plane, during bone cutting. A final alignment check should be made after component implantation and before the cement hardens. Component alignment could then be corrected after the probe check.

Most studies reported more accurate alignment with fewer outliers using navigation [1, 2]. However, Bauwens et al. [18] reported that the alignment of the mechanical axes was similar in the navigation and conventional surgery groups in a meta-analysis of 33 studies. The reason for the contradictory results might rest in the implanting and/or radiographic error, which Bauwens et al. [18] did not assess. Ninety-eight per cent of patients had a frontal tibiofemoral angle that was within 3° of the ideal with radiographic measurement in our study. However, we confirmed that all cases showed angles that were within 3° on the intraoperative navigation screen. This may have occurred because the joint was unloaded intraoperatively and was weight-bearing postoperatively when the radiographs were taken. This difference in loading conditions would influence the lower limb alignment measurement in the radiographs. Another possible explanation for radiographic error is that postoperative knee flexion contracture may have been present at the time of radiographic evaluation, but would not have been present intraoperatively.

Limitations of this study include a small sample size and the different loading conditions between intraoperative navigation and postoperative radiography. Additional studies comparing the navigation or radiographic measurements to measurements using a three-dimensional imaging procedure will be needed [16].

In conclusion, our hypothesis was supported. It would be useful to check the alignment of both the bone cut and cementation using navigation.

Conflict of interest The authors declare that they have no conflict of interest.

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