Relationship between cutting errors and learning curve in computer-assisted total knee replacement

Alfonso Manzotti · Pietro Cerveri · Elena De Momi ·
Chris Pullen · Norberto Confalonieri

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Abstract Computer-assisted total knee replacement (TKR) has been shown to improve radiographic alignment. Continuous feedback from the navigation system allows accurate adjustment of the bone cuts, thus reducing errors. The aim of this study was to determine the impact of experience both with computer navigation and knee replacement surgery on the frequency of errors in intraoperative bone cuts and implant alignment. Three homogeneous patient groups undergoing computer assisted TKR were included in the study. Each group was treated by one of three surgeons with varying experience in computer-aided and knee replacement surgery. Surgeon A had extensive experience in knee replacement and computer-assisted surgery. Surgeon B was an experienced knee replacement surgeon. A general orthopaedic surgeon with limited knee replacement surgery experience performed all surgeries in group C. The cutting errors and the number of re-cuts were determined intraoperatively. The complications and mean surgical time

were collected for each group. The postoperative frontal femoral component angle, frontal tibial component angle, hip–knee–ankle angle and component slopes were evaluated. The results showed that the number of cutting errors were lowest for TKR performed by the surgeon with experience in navigation. This difference was statistically significant when compared to the general orthopaedic surgeon. A statistically significant superior result was achieved in final mechanical axis alignment for the surgeon experienced in computer-guided surgery compared to the other two groups (179.3° compared to 178.9° and 178.1°). However, the total number of outliers was similar, with no statistically significant differences among the three surgeons. Experience with navigation significantly reduced the surgical time.

Introduction

Mal-alignment can adversely effect the longevity of the knee prostheses with early wear and implant loosening, both linked to suboptimal implant position [10, 12, 19]. Greater than 3° varus or valgus mal-alignment in total knee replacement (TKR) can result in higher failure rates whilst correct alignment has been associated with improved clinical outcome [7, 11, 19]. Several authors have shown that traditional hand-guided alignment systems can produce potential errors in the bone cutting process even when used by experienced surgeons [1, 2, 14, 16–18, 21]. Recently, Manley et al. showed that patients undergoing TKR in low volume hospitals (1–25 procedures/year) had a higher risk of early revision at five and eight years compared with those performed in the highest volume hospitals (>200 procedures/year) [15].

Total knee replacement performed with computer-aided alignment appears to produce superior radiological results

A. Manzotti · N. Confalonieri
1st Orthopedic Department, C.T.O. Hospital,
Via Bignami 1,
20100 Milan, Italy

P. Cerveri · E. De Momi
Bioengineering Department, Politecnico di Milano,
Milan, Italy

C. Pullen
St Vincent's & Mercy Private Hospital,
Grey Street,
East Melbourne, Victoria, Australia

A. Manzotti (✉)
Via S. Pertini 21,
20040 Cambiago Milan, Italy
e-mail: alf.manzotti@libero.it

compared with hand-guided techniques. These computer-assisted systems have been shown to improve both mechanical alignment and reduce outliers [3, 5, 24]. Both these outcomes are linked to a potential decrease of the TKR revision rates. Computer navigation provides continuous feedback during all phases of the knee replacement surgery providing an opportunity to correct any bone cutting errors. It has been suggested that computer navigation could be used as a teaching tool and result in superior results even for the occasional TKR surgeon [1, 4, 8]. In 2008, Yau et al., in a retrospective study, failed to show any improvement in postoperative alignment using a computer-assisted technique in a low volume knee practice [25]. In 2005, Daubresse et al. hypothesised that the learning curve for a computer navigated TKR technique can not be any longer than that of the free-hand technique, even in a community hospital [6].

The aim of this study was to determine the impact of experience both with computer navigation and knee replacement surgery on the frequency of errors in intra-operative bone cuts and implant alignment.

Materials and methods

A prospective study was undertaken with 75 patients undergoing computer-assisted TKR who were divided into three equal groups. Group A had their operations performed by a surgeon experienced in both knee replacement (more than 70 TKRs/year) and computer navigated surgery (more than 250 CAS-TKRs implanted). The surgeon for group B patients was experienced in knee replacement (more than 70 TKRs/year) but had not previously performed computer-guided surgery. A general orthopaedic surgeon performed all TKR in group C. This surgeon had a low volume TKR experience (less than 20 TKRs/year) and no previous experience with computer-guided surgery. The same computer navigation system (Vector Vision, version 1.52; BrainLAB, Munich, Germany) was used in all TKRs. The prosthesis used in all patients was the same (Genesis II; Smith and Nephew, Memphis, USA). Strict inclusion criteria were used in the study, including patients with primary osteoarthritis only, a body mass index of less than or equal to 35, a maximum mechanical axis deformity of less than 15° and at least 90° of knee flexion. All three surgeons in the trial were excluded from any involvement in the operation of the other two.

A standardised operative approach was taken for all TKRs. In all cases the midline patellar skin incision was pre-drawn to a length ranging from between 13.5 cm and 15.5 cm. A medial para-patellar arthrotomy was extended proximally to the quadriceps tendon in all patients. The patellar was retracted laterally in each case. All prostheses

were implanted using the same dedicated instruments including cutting blocks specifically designed for computer navigation. The cutting blocks were fixed with a combination of treated and smooth pins in all patients. All implants were cemented. No patients underwent patellar resurfacing. The same pre and postoperative rehabilitation protocols were used in all three groups. Early weight bearing was encouraged in all patients if tolerated.

For each implant the tibial and femoral cutting errors and the number of re-cuts were recorded. A cutting error occurred when the planned angle of the bone cut as measured by the cutting block differed from the angle seen after sawing. The cutting error was measured in both the frontal and sagittal plane for the tibia and femur, giving four measurements. According to a predetermined surgical protocol a re-cut was required if the cutting error was greater than or equal to 3°. The number of complications and the mean surgical time (time between skin incision and tourniquet release) were measured for each group.

Fig. 1 Frontal femoral component (fFC) angle (α)

Standing radiographs were obtained six months postoperatively with the knee in maximum extension, the patella pointing forward and both hips and ankles visible on the film. The lateral radiographs were taken with the knee in 30° of flexion on a radiographic film (20×40 cm). The radiographs were taken with a standardised protocol and magnification. If mal-rotation was detected the radiographs were repeated. An independent radiologist assessed all radiographs.

Fig. 2 Hip–knee–ankle (HKA) mechanical axis (α)

Fig. 3 Frontal tibial component (fTC) angle (α)

The frontal–femoral–component angle (fFC) (Fig. 1), the frontal–tibial–component angle (fTC) (Fig. 2), the hip–knee–ankle angle (HKA) (Fig. 3) and the sagittal orientation of components (slopes) were all measured. These parameters were used to evaluate the quality of the

Fig. 4 Tibial slope (TS) angle (α)

Fig. 5 Femoral slope (FS) angle (α)

surgical outcome. The fFC is the angle between the mechanical axis of the femur and the transverse axis of the femoral component. The fTC is the angle between the mechanical axis of the tibia and the transverse axis of the tibial component. The slopes of the tibial (TS) (Fig. 4) and femoral (FS) (Fig. 5) components were defined as the angle formed by a line drawn tangential to the base plate (surface in contact with bone) of the respective component and the anterior femoral cortex and tibial mechanical axis, respectively. The desired prosthesis alignment for each parameter was determined prior to the study as a fFC angle of 90° , fTC angle of 90° , HKA angle of 180° , femoral slope of 90° and tibial slope of 87° . The total number of outliers for all five radiological parameters were determined for each group and compared. An outlier was defined as a postoperative

malalignment of any parameter greater than 3° of the target value.

Statistical analysis of the results was performed and the three groups were compared. Because of an abnormal data distribution, non-parametric testing (Kruskal-Wallis test) was adopted using Statistica 7.0 software (StatSoft Inc., Tulsa, OK, USA) for analysis. Statistical significance was set at $p \leq 0.05$.

Results

Analysis of the demographic data for all three groups showed no statistically significant differences in preoperative flexion, body mass index and preoperative deformity (Table 1).

No significant differences were seen for the distal femoral cut in the coronal plane with standard deviations of 0.89° , 0.87° and 0.95° for groups A, B, and C, respectively (Table 2). The standard deviations of the distal femoral cut in the sagittal plane were 0.77° , 0.78° and 0.98° for groups A, B and C, respectively. A statistically significant inferior result was seen for the patients operated on by the general orthopaedic surgeon for the distal femoral cut in the sagittal plane compared to the other two surgeon groups ($p = 0.05$). For the proximal tibial cut in the coronal plane there were standard deviations of 0.91° , 1.31° and 1.28° for groups A, B and C, respectively. The differences were not statistically significant. In the sagittal plane the standard deviations of the proximal tibial cut were 0.79° , 0.83° and 1.04° for group A, B and C, respectively. A statistically significant difference ($p = 0.007$) was seen for the proximal tibial cut in the sagittal plane between the patients operated up on by the surgeon experienced in computer-guided and knee replacement surgery and the general orthopaedic surgeon. There was a correlation between the level of experience both in computer navigation and knee replacement surgery and the number of re-cuts. Four re-cuts were seen in group A, eight in group B

Table 1 Patient demographic data for the three groups

Demographic	Group A			Group B			Group C			<i>p</i>
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	
Body mass index	31.36	± 2.78	26–35	31.72	± 2.44	26–35	31.20	± 2.86	26–35	0.79
Preoperative flexion ($^\circ$)	105.4	± 9.67	90–120	109.8	± 10.25	90–120	107.6	± 8.43	95–120	0.23
Preoperative HKA angle ($^\circ$)	170.84	± 5.04	165–183	171.96	± 5.26	172–180	174.4	± 4.79	166–183	0.38
Postoperative flexion ($^\circ$)	113.6	± 9.18	95–130	113.8	± 8.20	100–125	144.0	± 8.41	100–130	0.70
Postoperative HKA angle ($^\circ$)	179.28	± 1.06	177–181	178.94	± 1.50	177–182	178.12	± 1.50	176–183	0.005

SD standard deviation, HKA hip–knee–ankle

Twenty-five patients in each group

Table 2 Intraoperative cutting errors and re-cuts for the three groups

Cutting angle	Group A				Group B				Group C			
	Mean	SD	Range	Re-cuts	Mean	SD	Range	Re-cuts	Mean	SD	Range	Re-cuts
fFC angle (°)	1.04	±0.89	0–3	2	1.20	±0.87	0–3	2	1.32	±0.95	0–3	3
fTC angle (°)	0.80	±0.91	0–3	1	0.96	±1.31	0–5	4	1.28	±1.28	0–4	5
FS angle (°)	0.52	±0.77	0–3	1	0.76	±0.78	0–3	1	1.04	±0.98	0–3	2
TS angle (°)	0.72	±0.79	0–2	0	0.88	±0.83	0–3	1	1.08	±1.04	0–3	3

SD standard deviation, *fFC* frontal–femoral-component, *fTC* frontal–tibial-component, *FS* femoral slope, *TS* tibial slope

and 13 in group C. A statistically significant difference was seen between groups A and C ($p=0.02$). This difference suggested an inverse relationship between the surgeon's experience and the number of re-cuts.

The postoperative fFC angle was 89.04° (range 86–92°) in group A, 88.88° (range 86–93°) in group B and 88.68° (range 86–93°) in group C (Table 3 and Fig. 6). The postoperative fTC angle was 89.04° (range 86–91°), 88.82° (range 85–91°) and 88.52° (range 85–91°) in groups A, B and C, respectively. There were no significant statistical differences for these two radiographic parameters across the three patient groups. The slope of the femoral component was 90.36° (range 87–94°), 89.92° (range 88–95°) and 90.68° (range 88–94°) in groups A, B and C, respectively. A statistically significant difference ($p=0.05$) was seen for femoral component slope between the patients operated on by the experienced TKR surgeons and the general orthopaedic surgeon. The slope of the tibial component in group A was 86.72° (range 84–91°), in group B 87.44° (range 84–92°) and in group C 88.24° (range 84–91°). A statistically significant difference ($p=0.007$) was shown between groups A and C. The HKA angle was 179.28° (range 177–181°), 178.94° (range 177–182°) and 178.12° (range 176–183°) for groups A, B and C, respectively. The patients undergoing TKR performed by the surgeon

experienced in both computer-guided and knee replacement surgery achieved a statistically significant better aligned mechanical axis compared to the patients from groups B ($p=0.030$) and C ($p=0.0006$) (Fig. 7). Despite these findings, no statistically significant difference was seen between the three patient groups in the total number of outliers for all five radiographic parameters.

A statistically significant increase in surgical time was shown for patients in groups B (a mean of 10.4 minutes longer) and C (a mean of 20.32 minutes longer) who underwent TKR with surgeons lacking experience in computer-assisted techniques. No complications were seen in the three groups.

Discussion

Malalignment of a TKR has been shown to adversely influence implant survivorship. Malalignment in the sagittal plane in excess of 3° can increase implant failure rates and result in poorer clinical outcomes [15, 19]. The final postoperative alignment of a TKR is subject to a number of pitfalls. Using traditional intramedullary alignment systems, deviations of up to 8° can occur in the femoral axis, depending on the size and length of the intramedullary

Table 3 Postoperative results for the three groups

Criteria measured	Group A			Group B			Group C		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Surgical time (minutes)	78.72	±4.57	70–88	89.20	±7.84	78–107	99.04	±7.87	88–114
fFC angle (°)	89.04	±1.62	86–92	88.88	±1.69	86–93	88.68	±1.88	86–93
fTC angle (°)	89.04	±1.37	86–91	88.82	±1.59	85–91	88.52	±1.63	85–91
FS angle (°)	90.36	±1.89	87–94	89.92	±1.78	88–95	90.68	±1.75	88–94
TS angle (°)	86.72	±1.84	84–91	87.44	±2.18	84–92	88.24	±2.00	84–91
HKA angle (°)	179.28	±1.06	177–181	178.94	±1.50	177–182	178.12	±1.50	176–183

SD standard deviation, *fFC* frontal–femoral-component, *fTC* frontal–tibial-component, *FS* femoral slope, *TS* tibial slope, *HKA* hip–knee–ankle

Fig. 6 Postoperative angles (fFC, fTC, FS and TS) for the three groups. Data reported as mean value $\pm$ standard deviation (SD). *fFC* frontal–femoral-component, *fTC* frontal–tibial-component, *FS* femoral slope, *TS* tibial slope

guide [17]. Unstable cutting blocks and saw deviation during osteotomy have been shown to result in cutting errors [1, 17]. In 2001, Mahaluxmivala et al. showed that TKR alignment is improved with surgical experience [14]. A strict correlation has been demonstrated between surgical experience with TKR and implant survivorship [14, 15, 19].

Computer-assisted surgery provides the surgeon with continuous intraoperative feedback on implant alignment and cutting errors during all phases of TKR [1]. A reduction in cutting errors has been shown when a navigation system is used for TKR surgery [17]. Use of a computer navigation system reduces the influence of cutting block stability and saw blade movement on the final result [17]. Recent studies have demonstrated that computer navigation may play a role in reducing the learning curve in joint replacement surgery [9, 20]. Superior alignment and clinical results have been shown with computer-guided TKR when compared to traditional techniques even in experienced hands [9, 13, 20, 22]. In 2008, Sampath et al., using a computer-assisted TKR, reported that tourniquet time is increased with larger preoperative deformities and

high body mass index and decreased with surgical experience [20].

The advantages of computer-guided TKR have not been as clearly demonstrated in low volume surgical centres. Yau et al., in a retrospective study, could not show any improvement in postoperative TKR alignment with use of a navigation system in a low volume practice [25]. The authors stated that the severity of the preoperative deformity affected postoperative overall alignment. Slover et al., using a Markov decision model, demonstrated that computer navigation is less likely to be a cost-effective investment in healthcare improvement in centres with a low volume of joint replacements [23].

The aim of our prospective controlled trial was to assess the influence of different levels of experience both in computer-assisted surgery and reconstructive surgery on the alignment in TKR. The strengths of this study include the use of a standardised surgical protocol in a single orthopaedic department and application of strict inclusion criteria. Obese patients and those with a major preoperative knee deformity were excluded. As such it is the first paper in the literature to attempt to reduce the influence of patient variables on the final result by minimising these differences preoperatively. A potential weakness of the trial is that the series magnitude was not confirmed by a preliminary power study.

This study shows that experience with computer navigation in TKR results in a lower number of intraoperative cutting errors. The number of re-cuts required was greater in the two groups with no prior experience of computer-assisted TKR. A statistically significant increase in the number of re-cuts was seen for TKRs performed by the general orthopaedic surgeon compared with the surgeon experienced in computer-guided surgery.

Jeffery et al. stated that an error of rotation of the limb of up to 20° during radiography could introduce a projectional error of less than 2° in the tibio-femoral angle, provided

Fig. 7 Postoperative angles (fFC, fTC, FS, TS and HKA) for the three groups. Data reported as mean value $\pm$ standard deviation (SD). * Statistically significant difference. *fFC* frontal–femoral-component,

fTC frontal–tibial-component, *FS* femoral slope, *TS* tibial slope, *HKA* hip–knee–ankle

that the knee is fully extended, but a combination of rotation and knee flexion may introduce much larger errors [8]. Likewise, in our study, for all three groups we adopted a rigid standardised protocol with painstakingly educated radiographers.

The postoperative mechanical axis of the knee was significantly better when performed by the surgeon experienced in computer-assisted TKR (179.28° compared to 178.94° and 178.12°). Other postoperative radiological parameters in the coronal plane were similar in all three groups. The accuracy of the tibial and femoral slope cuts was affected by the experience of the surgeon. A statistically significant inferior result was obtained when the TKR was performed by the general orthopaedic surgeon in this study for both these parameters. A possible explanation for this difference, based on the author's previous experience with computer-assisted TKR, is that in the sagittal plane, saw inclination is not completely controlled by the cutting block. As a result, experience in knee replacement surgery may play an extremely important role in the determination of the tibial and femoral slopes in particular. Despite this the overall postoperative TKR alignment was similar for all three surgeons. Each surgeon had a similar number of total outliers for all five radiological parameters with no statistically significant difference in the number of patients with malalignment exceeding 3° of the target value (8 outliers for group A, 10 for group B, and 9 for group C).

Previous studies [9, 15, 20, 25] have shown a significant difference in surgical time, measured between skin incision and tourniquet release, when comparing those familiar with computer navigation and inexperienced surgeons. Our study also demonstrates a significant reduction in surgical time with no specific complication in all three groups.

In this study the authors demonstrated that, despite different levels in surgical experience, TKR performed with computer navigation produces similar postoperative overall alignment with no statistical significant difference in the total number of outliers. Likewise, recovery of mechanical axis was statistically better achieved when surgery had been performed by a surgeon experienced in computer-assisted TKR. Furthermore, experience in knee replacement surgery resulted in statistically superior tibial and femoral slope. The surgical time was directly influenced by the experience with computer-assisted alignment techniques—the more experienced the surgeon, the shorter the surgical time.

In conclusion, computer navigation appears to be a useful tool to train inexpert surgeons in knee replacement surgery in a dedicated clinical centre. Longer follow-up will be needed to determine whether better postoperative alignment will result in superior clinical outcomes and compensate for higher costs and longer surgical time.

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