RELATIONSHIP BETWEEN CUTTING ERRORS AND LEARNING CURVE IN COMPUTER ASSISTED TOTAL KNEE REPLACEMENT

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Abstract

Computer assisted total knee replacement (TKR) has been shown to improve radiographic alignments. Continuous feedback from the navigation system allows accurate adjustment of the bone cuts, 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 intra-operative 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 intra-operatively. The complications and mean surgical time were collected for each group. The post-operative 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. However the total number of outliers was similar with no statistically significant differences among the 3 surgeons. Experience with navigation did significantly reduce the surgical time.

Key Words: Computer, total knee replacement, learning curve, cutting errors

Introduction

Mal-alignment can adversely effect the longevity of the knee prostheses with early wear and implant loosening, both linked to sub-optimal implant position [9, 11, 18]. 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 [7,10,18]. 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, 13, 15, 16, 20]. 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 5 and 8 years compared with those performed in the highest volume hospitals (>200 procedures/year) [14].

Total knee replacement performed with computer-aided alignment appears to produce superior radiological results compared with hand-guided techniques. These computer-assisted systems have been shown to improve both mechanical alignment and to reduce outliers. 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 post-operative alignment using a computer-assisted technique in a low volume knee practice [24]. In 2005, Daubresse et al. hypothesized 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 of 75 selected patients undergoing computer-assisted TKR divided into 3 equal groups. Group A had their surgery performed by a surgeon experienced in both knee replacement (more than 70 TKRs/year) and computer navigated (more than 250 CAS-TKRs implanted) surgery. 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 TKR. 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 surgeries of the other two.

A standardized operative approach was taken for all TKRs. In all cases the midline patellar skin incision was pre-drawn to a length ranging from between 13.5cm and 15.5cm. 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 post-operative rehabilitation protocols were used in all the 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 4 measurements. According to a pre-determined 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.

Standing radiographs were obtained 6 months post-operatively 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 20x40 cm. The radiographs were taken with a standardized protocol and magnification. If mal-rotation was detected the radiographs were repeated. An independent radiologist assessed all radiographs.

The frontal-femoral-component angle (fFC), the frontal-tibial-component angle (fTC), the hip-knee-ankle angle (HKA) and the sagittal orientation of components (slopes) were all measured. These parameters were utilized to evaluate the quality of the 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 femoral (FS) and tibial (TS) 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 post-operative malalignment of any parameter greater than 3° of the target value.

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

Results

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

No significant difference was seen for the distal femoral cut in the coronal plane with a standard deviation of 0.89°, 0.87° and 0.95° for groups A, B, and C respectively (Table II). The standard deviation of the distal femoral cut in the sagittal plane was 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 was a standard deviation 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 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, 8 re-cuts in group B and 13 re-cuts in group C. A statistically significant difference was seen between group A and C (p=0.02). This difference suggested an inverse relationship between the surgeon's experience and the number of re-cuts.

The post-operative fFC angle was 89.04° (range: 86°-92°) in the group A, 88.88° (range: 86°-93°) in group B and 88.68° (range: 86-93°) in group C (Table III and Figure 1). The post-operative 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 was no significant statistical difference 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 had a statistically significant improvement in mechanical axis when compared to the patients from groups B (p=0.030) and C (p=0.0006) (Figure 2). 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 and C 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 [14, 18]. The final post-operative alignment of a TKR is subject to a number of pitfalls.

Using traditional intra-medullary alignment systems, deviations of up to 8° can occur in the femoral axis, depending on the size and length of the intra-medullary guide [17]. Unstable cutting blocks and saw deviation during osteotomy have been shown to result in cutting errors [1, 16]. Mahaluxmivala et al in 2001 showed that TKR alignment is improved with surgical experience [13]. A strict correlation has been demonstrated between surgical experience with TKR and implant survivorship [13, 14, 18].

Computer-assisted surgery provides the surgeon with continuous intra-operative feedback on implant alignment and cutting errors during all the phases of TKR [1]. A reduction in cutting errors has been shown when a navigation system is used for TKR surgery [16]. Use of a computer navigation system reduces the influence of cutting block stability and saw blade movement on the final result [16]. Recent studies have demonstrated that computer navigation may play a role in reducing the learning curve in joint replacement surgery [8, 19]. Superior alignment and clinical results have been shown with computer guided TKR when compared to traditional techniques even in experienced hands [8, 12, 19, 21]. Sampath et al in 2008, using a computer assisted TKR, reported that tourniquet time is increased with larger pre-operative deformities and high body mass index and decreased with surgical experience [19].

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 post-operative TKR alignment with use of a navigation system in a low volume practice [24]. The authors stated that the severity of the pre-operative deformity effected post-operative 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 [22].

The aim of the current prospective controlled trial was to assess the influence of computer navigation simultaneously on the learning curve and the frequency of intra-operative cutting errors in TKR. The strengths of this study include the use of a standardized surgical protocol in a single orthopaedic department and application of strict inclusion criteria. Obese patients and those with a major pre-operative 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 pre-operatively. 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 intra-operative cutting errors. The number of re-cuts required was greater in the 2 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. The post-operative mechanical axis of the knee was significantly better when performed by the surgeon experienced in computer assisted TKR. Other post-operative radiological parameters in the coronal plane were similar in all three groups. The accuracy of the tibial and femoral slope cut was effected 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 slope in particular. Despite this the overall post-operative TKR alignment was similar for all three surgeons. Each surgeon had a similar number of total outliers with no statistically significant difference in the number of patients with malalignment exceeding 3° degree of the target value.

Previous studies [8, 14, 19, 24] 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. The current study also demonstrates a significant reduction in surgical time with experience in navigation but no difference in intra-operative complication rate.

The authors demonstrated in this study that TKR performed with computer navigation produces similar post-operative overall alignment, despite variations in surgical experience. Recovery of mechanical axis is statistically better achieved when surgery is performed by a surgeon experienced in computer assisted TKR. Experience in knee replacement surgery in general, results in statistically superior tibial and femoral slope when computer navigation is used. Experience with computer assisted alignment techniques decreases surgical time.

In conclusion, computer navigation appears to be a useful tool in knee replacement surgery, independent of surgical experience achieving the same grade of outliners. Longer follow-up will be needed to determine whether better post-operative alignment will result in superior clinical outcomes and compensate for higher costs and longer surgical time.

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Table I

	Group A	**Group B**	**Group C**	***P***
Body Mass Index	31.36 *S.D.* ±2.78 *Range*: 26-35	31.72 *S.D.* ±2.44 *Range*: 26-35	31.20 *S.D.* ±2.86 *Range* : 26-35	0.79
Pre-operative flexion (°)	105.4 *S.D.* ±9.67 *Range*: 90-120	109.8 *S.D.* ±10.25 *Range*: 90-120	107.6 *S.D.* ±8.43 *Range*: 95-120	0.23
Pre-operative HKA angle (°)	170.84 *S.D.* ±5.04 *Range*: 165-183	171.96 *S.D.* ±5.26 R: 172-180	174.4 *S.D.* ±4.79 *Range*: 166-183	0.38

Table II

	Group A	**Group B**	**Group C**
fFC angle (°)	1.04 *S.D.* ±0.89 *Range*: 0-3 *# Recuts*: 2	1.20 *S.D.* ±0.87 *Range*: 0-3 *# Recuts*: 2	1.32 *S.D.* ±0.95 *Range*: 0-3 *# Recuts*: 3
fTC angle (°)	0.80 *S.D.* ±0.91 *Range*: 0-3 *# Recuts*: 1	0.96 *S.D.* ±1.31 *Range*: 0-5 *# Recuts*: 4	1.28 *S.D.* ±1.28 *Range*: 0-4 *# Recuts*: 5
FS angle (°)	0.52 *S.D.* ±0.77 *Range*: 0-3 *# Recuts*: 1	0.76 *S.D.* ±0.78 *Range*: 0-3 *# Recuts*: 1	1.04 *S.D.* ±0.98 *Range*: 0-3 *# Recuts*: 2
TS angle (°)	0.72 *S.D.* ±0.79 *Range*: 0-2 *# Recuts*: 0	0.88 *S.D.* ±0.83 *Range*: 0-3 *# Recuts*: 1	1.08 *S.D.* ±1.04 *Range*: 0-3 *# Recuts*: 3

Table III

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

Figure 1

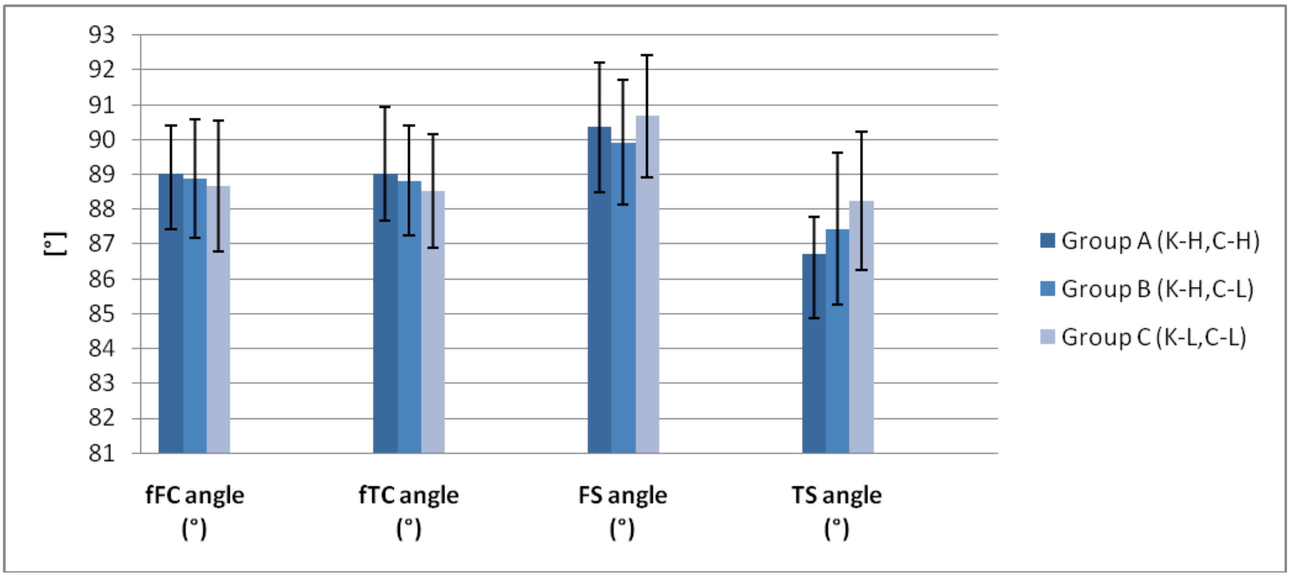
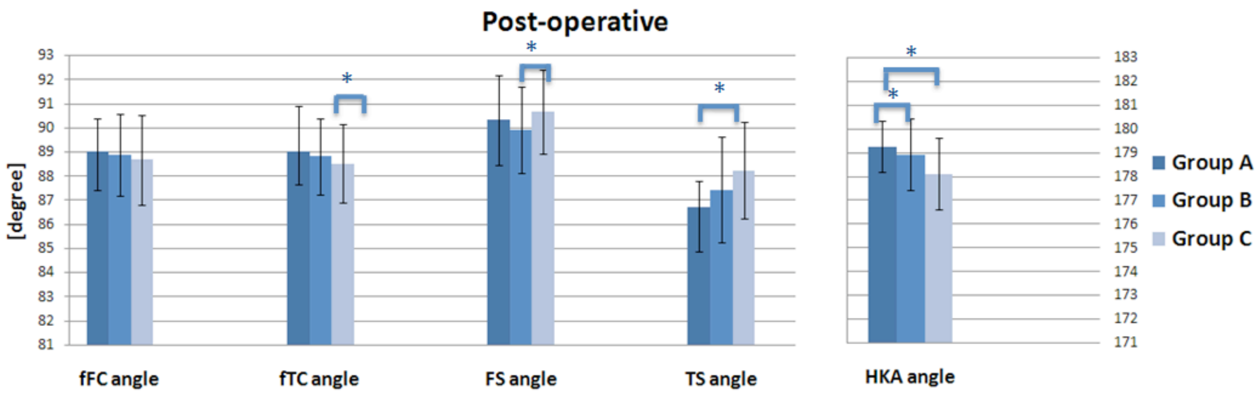


Figure 2



Legends

Table I. Patient demographic data for the three groups.Twenty-five patients in each group. Data reported as mean value, standard deviation (S.D.) and range (Range).

Table II. Intra-operative cutting errors and recuts for the three groups. Data reported as mean value, standard deviation (S.D.), range (Range) and number of recuts (# recuts).

Table III. Post-operative results for the three groups. Data reported as mean value, standard deviation (S.D.) and range (Range).

Fig 1: Post-operative angles (fFC, fTC, FS and TS) for the three groups. Data reported as mean value ± standard deviation (S.D.)

Fig 2: Post-operative angles (fFC, fTC, FS, TS and HKA) for the three groups. Data reported as mean value ± standard deviation (S.D.). * = statistically significant difference.