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KNEE ARTHROPLASTY

Computer-assisted total knee arthroplasty: impact of the surgeon's experience on the component placement

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Abstract
Introduction Accuracy of implant positioning in total knee arthroplasty (TKA) has a major impact on postoperative outcomes. We investigate the accuracy of positioning of multiples values simultaneously in TKA navigated, even among novice users.
Method The "novice" group included the first 91 knees operated on by 10 operators new to navigation and the "experienced" group 174 knees by an experienced navigator. Deviations from the preoperative planning were graded as optimal (≤3°), acceptable (4°–5°) or non-acceptable (≥5°). Moreover, the percentage of the three values fulfilling simultaneously the objective was calculated.
Results No significant difference in the number of non-acceptable results was found. The common objective for these three values was achieved within 5° in 96 % in the novice group and 98 % in the experienced one.
Conclusion The satisfactory HKA alignment was not the result of reversed errors between the tibia and the femur, since it correlated the successful simultaneous results of alpha and beta angles.

Keywords Total knee arthroplasty · Navigation · Computer-assisted surgery · Learning curve

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Introduction

Optimal restoration of lower limb alignment [1–6] within three degrees of the neutral mechanical axis [7–11] is the main factor for good long-term survivorship in total knee arthroplasty (TKA). Accurate implant positioning leads to improved function and health-related quality of life [12, 13].

Conventional implantation techniques (using intra- or extra-medullary alignment guides) achieve satisfactory lower limb alignment in only 60–80 % of the cases [1, 11, 14], whereas navigation leads to an improved execution of planned axis relations in 90 % [15–17]. These results are further confirmed through meta-analyses [7, 18–20] which demonstrate the superiority of navigated knee replacement surgery in achieving accurate component orientation and reducing scattering compared with conventional techniques. Surgical techniques along with materials and implant designs have evolved. The overall survival rate of total knee prostheses is 85–95 % at 15 years [14, 21, 22]. As demonstrated by Parratte et al. [14], the mechanical axis of the lower limb is not the only goal in the establishment of a TKA. Improvement in implant survivorship and function requires the utmost surgical accuracy. The value of the lower limb mechanical angle is not the only criteria to consider, and achievement of a neutral lower limb mechanical axis should not be defined as a strict dogma for all patients [14]. Optimal mechanical axis of the tibial and femoral epiphysis, soft-tissue balancing, joint line restoration and rotational alignment of the components are further key factors for success in TKA. However, whatever the chosen implantation philosophy, bone cuts should be meticulously planned and free-hand implantation avoided, since it may lack accuracy.

Reticence exists regarding conversion to this new technology by fear of navigation-related technical difficulties and lack of immediate benefits. So far, only few studies have been published on the learning curve with navigated TKA. As demonstrated in some studies, the accuracy of alignment is not modified when skilled surgeons with no previous experience in navigated TKA perform surgery. However, the operating time is increased by 15 % during the learning curve of 20–30 procedures [23, 24]. These studies are based on different methodologies.

Our hypothesis was that navigation prevents the occurrence of non-acceptable results not only for the value of the mechanical axis, but also to control multiple values simultaneously. The purpose of the present study was to assess the accuracy of implant positioning in computer-assisted TKA in experienced navigators and to show its benefices even among novice ones.

Materials and methods

Population

A continuous series of patients was prospectively included in two groups. The “novice” cohort included 91 patients operated in two different medical centres by 9 surgeons new to navigated TKA from a University Hospital Centre (UHC) and one surgeon from a private clinic. The surgeons from UHC were not novices in the field of conventional TKR. The first 30 procedures of navigated TKA in the practice of the operator from the clinic were included in the novice cohort. The “experienced” cohort included 174 patients operated in the clinic by a single operator with systematic use of navigation in his current practice. This surgeon performs approximately 100 procedures per year.

Navigation system and implants

All patients from the series were implanted the DePuy LCS total knee prosthesis. Surgery was performed using the Praxim and BrainLAB navigation systems in the “novice” group, whereas the experienced operator used the BrainLAB system. Both were image-free passive optical tracking systems.

Radiographic data

Preoperative planning included standard A/P and lateral radiographs of the operated knee, a 30° femoro-patellar view and a long-leg weight-bearing radiograph of both lower limbs. An identical radiographic assessment was performed on the first postoperative visit at 45 days. An independent observer, orthopedic surgeon, measured the following pre- and postoperative data: lower limb mechanical angle (HKA), alpha angle (distal femoral mechanical angle in the coronal plane) and beta angle (proximal tibial mechanical angle in the coronal plane). Measurements were made as defined by the Knee Society [25]. These values constituted the main criteria for analysis.

Postoperative values of the HKA angle were first classified according to Konermann et al. and Clemens U et al. [26] and graded as optimal within 3° from the objective, acceptable within 4°–5° and non-acceptable over 5° from the neutral axis. The alpha and beta angles were classified as optimal within 2° of error, acceptable between 3° and 4° and non-acceptable over 4°. Then, each of the three measurements (HKA, alpha and beta) had to match target values on a common basis.

Statistical methods

Statistical analyses were performed using the SPSS 17.0.1 software (SPSS Inc., Chicago, IL, USA). The normality of distribution for quantitative values was assessed using the Stewness and Kurtosis coefficients and the Shapiro-Wil test. The parametric Student’s t test for independent samples was used. The Chi-square test was used for qualitative values. The statistical significance was set at $p \leq 0.05$ for all tests. Bilaterally operated patients were considered as two distinct subjects for statistical analysis.

Results

Overall epidemiologic data

The “novice” cohort included 91 knees operated from August 2004 to October 2008 and the “experienced” cohort included 174 knees operated on from January 2005 to September 2007. Patients from the “novice” group were operated by 10 different surgeons and were continuously selected as their first navigated TKA cases. A female predominance was observed among the 265 patients included in the series as classically reported: 163 females (61.5 %) and 102 males (38.5 %). The features of both groups are reported in Table 1. The mean age at surgery was 71.7 ± 8.2 years, that is 47 years for the youngest

Table 1 Comparison of the studied population

	Novice	Experimented	p
Females/males	2.8/1	1.4/1	0.003
Mean age (mean, minimum, maximum)	69.8 (47–86)	72.3 (49–95)	0.02
Right/left side	1.3/1	1/1	NA
Arthritis	81 %	98 %	<0.001

patient and 95 years for the oldest. The right knee was involved in 137 cases (51.7 %) and the left knee in 128 (48.3 %). 9 patients underwent bilateral TKA. One patient was excluded from the study ("novice" group) since the navigation tracker pins had moved during surgery thus requiring conversion to conventional technique.

Medical data

The most predominant etiology was arthritis in 245 patients (92.5 %). Moreover, 6 cases of rheumatoid polyarthritis (2.3 %), 10 cases of necrosis (3.7 %), 2 cases of chondrocalcinosis (0.8 %) and 2 etiologies classified as "others" (loosening of unicompartmental knee prosthesis and chronic sagittal laxity) (0.8 %) were reported. 193 patients had no previous local history (72.8 %), 61 patients (23 %) had already undergo knee surgery and 11 patients had been operated more than once (4.2 %). No fixation pin-related complications could be observed (fracture, infection and pain). Fractures were secondary to bone metastases in one case and a fall in another case. In the "novice" group, one case of fracture of the anterior tibial tubercle, one case of persistent patellar pain and one case of polyethylene dislocation requiring revision surgery were reported.

Surgical data

The operative time showed a difference between the two groups with the novice having a median of 120 min and the experienced a median of 50 min ($p < 0.001$). A pneumatic tourniquet was systematically applied to the patient's thigh. In the experienced cohort, a medial surgical approach was used in 262 cases and a lateral approach in 4 cases with preoperative valgus (4°, 10°, 11° and 17°). Anterior tibial tubercle elevation was required in six cases (one case of patella baja in the novice group). A ligament release was performed in 21 cases (16 medial and 5 lateral compartments always related to the initial deformity).

Radiographic data

Preoperative data

70.3 % of genu varum and 26.8 % of genu valgum were identified on long-leg coronal plane radiographs. Thirty-five percent of the patients had a deformity ≥10°, of which 26.4 % in varus and 8.5 % in valgus (Table 1). No significant difference could be detected between groups. The percents did not reach 100 % because some cases had a neutral alignment.

Postoperative data

Values of the HKA, alpha and beta angles are reported in Table 2 for each group in relative and absolute deviation. No significant difference could be detected between these groups except for the alpha angle. The standard deviations decreased between the "novice" and "experienced" groups for each measurement. The values followed a normally distributed pattern with about 95 % of the values falling within 2 standard deviations of the mean; 4.6° in the "novice" group and 4° in the "experienced" group (Fig. 1). The results were qualitatively classified in Table 3. There was no significant increase in the non-acceptable results. Then, the percentage rate of HKA, alpha and beta angle values matching the pre-defined targets was noted (Table 4).

Table 2 Values of the HKA alpha and beta angles

	Novice		Experienced		p
	Mean (Minimum–maximum)	Standard deviation	Mean	Standard deviation	
Angulation					
HKA	179.5° (173–187)	2.3°	179.7° (172–185)	2.0°	NA
Alpha	89.8° (84–95)	1.8°	90° (84–94)	1.5°	NA
Beta	89.7° (86–95)	1.9°	89.7° (84–94)	1.7°	NA
Absolute angulation (from neutral position)					
HKA	1.7° (0–7)	1.6°	1.4° (0–8)	1.5°	NA
Alpha	1.3° (0–6)	1.2°	1° (0–6)	1.1°	0.04
Beta	1.4° (0–5)	1.3°	1° (0–6)	1.4°	NA

Mean (minimum maximum) and standard deviation. Relative and absolute angulations

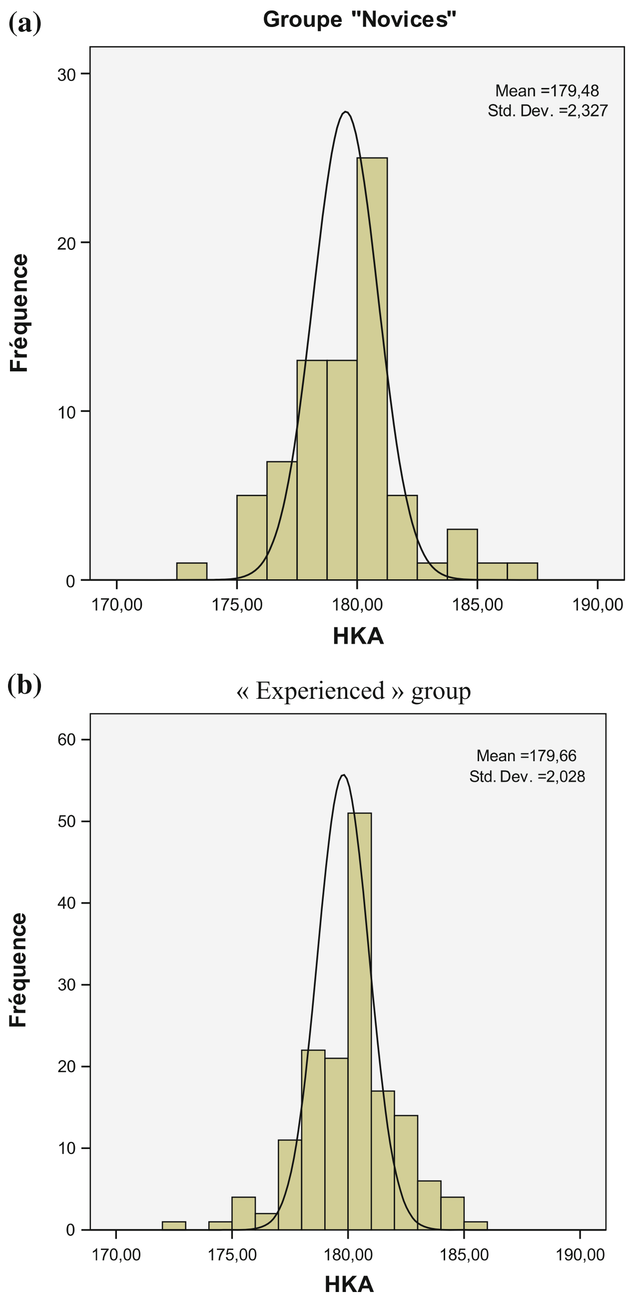

Fig. 1 Gaussian curve representing the distribution of the HKA angle values in the "novice" (**a**) and "experimented" (**b**) groups

Table 3 Classification of the postoperative radiographic results in both groups according to the HKA (a) alpha (b) and beta (c) angles

	Novice	Experimented	*p*
(a)			
Mechanical axis coronal plane : HKA			
Optimal	81.33 %	91.61 %	0.02
Acceptable	16.00 %	7.10 %	0.04
Non-acceptable	2.67 %	1.28 %	0.5
(b)			
Femoral component, coronal plane : alpha			
Optimal	82.67 %	91.67 %	0.04
Acceptable	14.67 %	7.05 %	0.07
Non-acceptable	2.67 %	1.28 %	0.5
(c)			
Tibial component, coronal plane : beta			
Optimal	80.26 %	85.81 %	0.3
Acceptable	18.42 %	11.61 %	0.2
Non-acceptable	1.32 %	2.58 %	0.5

Table 4 Percentage rate of HKA, alpha and beta values simultaneously fulfilling the objective according to the admitted error criteria

Common objective achieved	Novice	Experimented
1°	32 %	48 %
2°	47 %	65 %
3°	**76 %**	**88 %**
4°	88 %	94 %
5°	**96 %**	**98 %**
6°	97 %	99 %
7°	100 %	99 %
8°		100 %

Bold values indicate success rate of the all three values within 3 or 5°

Discussion

According to this original study, computer-assisted TKA was not associated with an increased rate of non-acceptable results when performed by novice navigators compared with experienced ones. Navigation prevents the augmentation of non-acceptable results, even in novice surgeon in total knee arthroplasty.

The HKA angle was within 3° of the pre-determined objective in 81 and 92 % of the cases in the "novice" and "experienced" group, respectively. In the "novice" group, the results followed a normally distributed pattern with 95 % of the values falling within 2 standard deviations of the mean that is 4.6°. Despite significant differences regarding optimal results, such results were displaced for the benefit of acceptable results in the "novice" group, and no statistically significant difference in the number of non-acceptable results was reported between the two groups (Fig. 1). This finding was the main interest of navigated TKA for novice navigators. The use of conventional instrumentation induced more than 30 % of outliers beyond 3° of the mechanical axis regarding the HKA angle, and 10 % beyond 8° [27, 28] which was not reported with navigated systems. The results achieved by the experienced operator correlated those reported in the literature [15–17, 23, 29]. As noted in our "experienced" group, Bové [29] described a further increased accuracy and a lower dispersion of angular values through higher navigation experience. Non-navigated instrumentation reported 30 % of outliers exceeding 3° of deviation from the neutral HKA axis [1, 11, 27, 30]. Poor results were attributed to the instrumentation that could not provide the expected accuracy.

The secondary analysis combining simultaneously the results of the three obtained values (HKA, alpha and beta angles) revealed that the obtained results were within 3° of neutral alignment in 76 and 88 % of the cases, respectively. These results were lower than those reported by Maniar [24] (94 % at the beginning of the surgeon's learning curve and 100 % after experience), but similar to those achieved by Jenny [23] in a multicenter study with 72 and 73 % of cumulated optimal values in a group of navigated TKA novice surgeons and a group of experienced surgeons, respectively. The successful values of isolated HKA angle correlated the simultaneous successful values of HKA, alpha and beta angles in the novice (81 and 76 %) and experienced (92 and 88 %) groups. The use of conventional instrumentation decreased to 82 % the success rate of values within ±3° of neutral alignment for isolated HKA angle and to 66 % the simultaneous successes of the three angular values [24]. Our results confirmed this interpretation: the use of conventional TKA induced poorer results regarding the HKA angle, and the good results could be the consequence of reversed errors between the femur and tibia. The similarity of our results confirmed that accurate alignment in navigated TKA was due to the success of simultaneous alignment of femur and tibia. This could be considered as another major advantage of navigated surgery. The achievement of the HKA angle objective could not be the sum of reversed errors between the femur and the tibia since each parameter had been independently controlled. According to Parratte et al. [14] a postoperative mechanical axis of 0° + −3° did not improve implant survival at the time of the fifteen-year follow-up since the ideal alignment is influenced by the individual patient's dynamic gait pattern. The criteria of the simultaneously achieved values would have been interesting to analyze to establish a correlation with survivorship. The high range between extreme values reported by Parratte et al. (range of 19° for HKA angle, 19° for alpha angle and 17° for beta angle) suggests that such errors might have occurred. Moreover, the anatomical [31] and radiographic studies [32, 33] of healthy knees did not report inter-individual variations which required to exceed 3° from neutral mechanical axis (mean lower limb mechanical axis of 1.1° of varus on the left side and 1.5° on the right side [32]). There was a 3° varus of the proximal tibial epiphysis mechanical angle [32], and a corresponding 3° valgus of the distal femoral epiphysis mechanical angle compensating for the 3° inclination of the lower limb mechanical axis relative to the vertical line to restore a horizontal joint line. The tibial varus and femoral valgus were not taken into account by conventional instrumentation due to the risk of cumulated bone cutting errors in the same direction induced by the inaccuracy and greater dispersion of values and the related risk of joint line malposition. This can be possible thanks to the navigation. Navigation is a measuring instrument accurate and reliable, and the surgeon can change at each stage its indications and objectives.

A significant difference was found in the operating time between the "novice" and "experienced" groups (120 min vs. 50 min). The selected method was different between the two groups (UHC and clinic). Navigated TKA requires a longer operating time when comparing surgeons with comparable experience. The operating time was increased by 11–18 min at the beginning of the navigation learning experience [23, 24, 29], that is about 15 % of conventional TKA overall operating time and was only prolonged by 8 min when comparing conventional and navigated surgeries performed by surgeons with similar experience [24] that is <10 % of the overall operating time. This was the only significant difference reported in the literature regarding the learning curve which took approximately 20 [34] to 30 [23, 35] procedures.

There were no navigation tracker pin-related complications reported in these publications (fracture and bone infection). A higher number of navigation-related technical difficulties could be observed in some cases (hip centre acquisition and tracker detection): seven versus two in Jenny's study [23] (among 368 patients), four in the Smith and Picard study [34]. These operative difficulties were considered subjective data and were not based on rigorous criteria. In our series, only one navigated TKA was abandoned since the navigation tracker pins had moved. Surgery was easily completed after conversion to conventional instrumentation.

Previous published studies having observed a relationship between the learning curve and the operative time showed that this experience curve was approximately 20 [34] to 30 [23, 35] procedures. Therefore, the first 30 patients of the operator were included in the novice cohort. Maniar [24] had included the first 100 navigated TKA procedures in his "novice" group. Although the experienced group contains only one operator, the results were similar to results reported in the literature. The same surgeons of the novices group should have been re-evaluated after they gained sufficient experience. This would allow the comparison of the results of the same surgeon. But the realization of such study would be difficult. We also have compared our results for the group "novice" to the results of the literature [15–17, 23, 29]. The sub-groups of navigations systems results have not been investigated in this study because it was not our purpose.

Conclusion

Our original study has shown the prevention of occurrence of non-acceptable results by the control of navigation, not only for the value of the mechanical axis, but also to control multiple values simultaneously, even among novice operators. Navigated TKA performed by surgeons new to this technique provides more reliable results in terms of axis alignment and values distribution than those reported in the literature using conventional techniques even when performed by experienced surgeons. Navigated TKA is also a valuable educational tool for surgeons undergoing training in knee arthroplasty. Efforts to more consistently achieve accurate mechanical axis alignment in TKA should be made to substantially improve implant survivorship. Enhanced accuracy and reproducibility will require the use of a computer-assisted system whether in the per or preoperative period.

Conflict of interest None.

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