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ORIGINAL STUDY

How accurate are orthopaedic surgeons in visually estimating lower limb alignment ?

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This study aimed to determine the accuracy and reliability of visual estimation of limb alignment and knee flexion by orthopaedic surgeons when compared to recordings done by computed navigation. Orthopaedic surgeons attending a national conference were asked to place a lower limb synthetic bone model in 6 positions of the knee in the coronal and sagittal planes. These were simultaneously quantified and recorded by a computer navigation system. In the sagittal plane, 44% , 54% and 60% of the surgeons deviated by more than 5° when positioning the knee in 0° flexion, 10° flexion and 90° flexion respectively. In the coronal plane, 15%, 12% and 8% of the surgeons deviated by more than 5° when positioning the knee in 0° varus/valgus, 5° varus and 5° valgus respectively. Only 25% of the surgeons could position the knee both within 3° of neutral varus/valgus and within 5° of neutral flexion. Accuracy of visual estimation was not different when surgeons were compared based on time since residency, experience with TKA and experience with computer-assisted TKA. Visual estimation of knee alignment in both the sagittal and coronal plane is prone to error and may lead to inaccurate limb alignment during procedures such as TKA.

Keywords : computer navigation ; total knee arthroplasty ; alignment ; knee.

INTRODUCTION

Intraoperative assesment of limb alignment in the coronal and sagittal plane is an important part of many surgical procedures in orthopaedic surgery such as corrective osteotomies, high tibial osteotomy and total knee arthroplasty. Restoration of a neutral mechanical axis is a well known factor for long term implant survival and function after total knee arthroplasty (TKA). Limb malalignment of more than 3° has been associated with poor implant survival (*3,10,12,13*). Range of motion after TKA is an important functional measure of this procedure and leaving the knee in residual flexion or hyperextension may result in suboptimal function postoperatively (*6,11*).

Conventionally, coronal alignment of the limb after implantation during TKA has been judged either using an alignment rod or by visual estimation by the surgeon. However, use of an alignment rod requires that the centre of the hip and ankle is estimated accurately. This may be challenging

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in patients especially in the presence of overlying drapes or excessive soft-tissue as in the obese. Estimation of flexion or extension at the knee intra-operatively is commonly done visually or using a goniometer. However, goniometric measurement may not be precise and reproducible and has been reported to underestimate true flexion (*1,5,14*).

Several studies have validated the accuracy and consistency of computer-assisted navigation and have reported significant improvement in component orientation and limb alignment in TKA with the use of computer navigation (*2,4,7,8*). Computer navigation offers an alternative method to estimate the amount of coronal alignment of the limb and knee flexion during TKA. Austin *et al* (*1*) have reported that the goniometric method underestimated flexion measurements as compared to navigation, especially in patients with high body mass index and that navigation is a reliable tool for performing *in vivo* assessment of knee range of motion. There are no studies in the literature which have assessed the accuracy of the orthopaedic surgeon in visually estimating limb alignment. The current *in vitro* study is the first of its kind which aimed to assess the accuracy of visual estimation of limb alignment and knee flexion. We therefore asked how accurate was limb alignment and knee flexion estimated visually by orthopaedic surgeons when compared to recordings done by a computer using navigation technology.

MATERIALS AND METHODS

The study was conducted during a conference where orthopaedic surgeons were tested for accuracy of their visual estimation of limb alignment and knee flexion using a synthetic bone model of the entire lower limb. The inclusion criterion was orthopaedic surgeons who have completed their residency in orthopaedic surgery. The target population were orthopaedic surgeons attending a 2-day national orthopaedic conference. The study was announced using posters placed throughout the conference venue and surgeons were invited to voluntarily participate in it. The participating surgeons were asked to fill in a questionnaire with personal details including name, age, institution, designation, years since completion of residency, and details of their practice such as number of total knee arthroplasties (TKAs) performed per year and experience with performing computer-navigated TKA. Surgeons who performed at least 50 TKAs per year were termed as joint replacement surgeons.

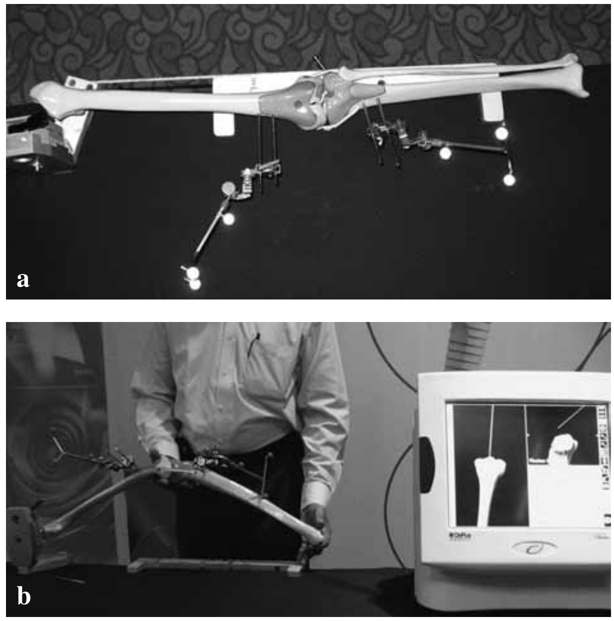

Fig. 1. — (a) Photograph showing the setup of the synthetic limb model with the attached navigation arrays. The head of the femur is clearly visible and is attached to a holder ; (b) : Photograph showing the study participant holding the knee in a position of flexion. The computer screen is hidden from the participant and is facing the investigator.

A synthetic bone model (Sawbones® Inc. Vashon Island, WA) of the entire lower limb consisting of the femur and tibia with the exposed femoral head attached to a holder was used for the study (Fig. 1). The tibia and femur were attached to each other with elastic bands representing the medial and lateral collaterals and the cruciate ligaments. The computer navigation arrays were attached to the distal part of the femur and the proximal part of the tibia using two pins. We used the image-free Ci navigation system with its software (BrainLab, Munich, Germany) and registration was performed in the standard fashion by one of the authors. The study planned to test the accuracy of visual estimation of the surgeons when placing the knee in 3 positions in the coronal plane and 3 positions in the sagittal plane. To verify the recordings of the computer navigation, the investigators simultaneously confirmed the knee position in the coronal and sagittal plane using a goniometer before the start of the study.

During the study the participant was asked to place the knee in 3 different positions in the coronal and sagittal planes each. Before the start of positioning of the knee and recording, the surgeons were informed that for estimating the coronal plane position, the mechanical axis was defined as the line joining the center of the femoral head and the centre of the distal tibial end and for estimating the sagittal plane position the posterior surface of the femur and tibia should be referenced. In the coronal plane, the knee was asked to be placed in 0° varus/valgus, 5° varus and 5° valgus position with respect to the mechanical axis of the limb and in the sagittal plane, the knee was asked to be placed in 0° flexion, 10° flexion and 90° flexion. The participant was asked to position the knee twice in a sequence starting with the coronal plane position followed by the sagittal plane positions. The computer screen and the readings as recorded by the computer were hidden from the participant. Each reading was noted and recorded by one of the authors.

For data analysis, the mean of two readings for each test condition was taken. Comparison of the amount of deviation from the actual designated test position of limb in both coronal and sagittal plane among subgroups based on time since residency, experience with total knee arthroplasty and experience with computer-assisted TKAs was performed. Data between groups were compared using unpaired t-test and Fisher's exact test and a p value of < 0.05 was taken to be statistically significant. Intra- and interobserver correlation coefficient was calculated from a two-way random effects model for consistent agreement using the SPSS 16.0 statistical software.

RESULTS

Out of the 400 delegates who attended the conference, 52 (13%) participated in the study. The mean age was 40 ± 9.7 years (range : 30-65 years) and the mean time period since completion of residency was 10.8 ± 9 years (range : 1-29 years). There were 27 surgeons (52%) who were < 10 years from the time of completion of their residency and 25 surgeons (48%) were ≥ 10 years. Thirty-one surgeons (59%) claimed to be performing at least 50 total knee arthroplasties (TKAs) per year in their practice and 10 surgeons (19%) claimed to be performing computer-assisted TKAs.

The amount of deviation from the actual designated test position of the knee in both coronal and sagittal plane in each study subgroup is summarised in Table I. In the sagittal plane, 44% of the surgeons deviated by more than 5° and 5.7% of the surgeons deviated by more than 10° when positioning the knee in 0° flexion. Similarly, 54% of the surgeons deviated by more than 5° and 21% of the surgeons deviated by more than 10° when positioning the knee in 10° flexion. Finally, 60% of the surgeons deviated by more than 5° and 25% of the surgeons deviated by more than 10° when positioning the knee in 90° flexion. In the coronal plane, 15% of the surgeons deviated by more than 5° when positioning the knee in 0° varus/valgus ; 12% of the surgeons deviated by more than 5° when positioning the knee in 5° varus and 8% of the surgeons deviated by more than 5° when positioning the knee in 5° valgus. Overall, 57% of the surgeons could position the knee within 3° of varus or valgus in the coronal plane, 55% the surgeons could position the knee within 5° of flexion in the sagittal plane and only 25% of the surgeons could position the knee both within 3° of varus or valgus and within 5° of flexion.

Comparison of the amount of deviation from the actual designated test position of the knee in both coronal and sagittal plane among various subgroups is summarised in Table II. The difference in the amount of deviation in knee position in both the coronal and sagittal plane when different subgroups were compared based on time since residency, experience with total knee arthroplasty and experience with computer-assisted TKAs was not significant. Intra and interobserver correlation coefficient (ICC) showed poor intra and interobserver agreement for 5° valgus and all 3 sagittal positions of the knee whereas it was good for 0° varus / valgus and 5° varus position (Table III).

DISCUSSION

Accurate evaluation of knee position intraoperatively during total knee arthroplasty (TKA) is crucial and has an effect on the final position and alignment of the limb in both coronal and sagittal planes. Leaving the knee after TKA in excessive varus or valgus or in flexion or hyperextension may have a detrimental effect on functional outcome (*6,11*). The results of the current study show that

Table I. — Deviation from the actual designated test position of the knee in both coronal and sagittal plane in each study subgroup

Group	Age (years)	n	Years post-residency	Sagittal plane deviation			Coronal plane deviation		
				From 0° flexion	From 10° flexion	From 90° flexion	From 0° varus/valgus	From 5° varus	From 5° valgus
All	40 ± 9.7	52	10.8 ± 9	4.6° ± 3.3° (3.6°-5.5°)	7.3° ± 5.9° (5.6°-8.9°)	7.5° ± 6.3° (5.7°-9.2°)	2.8° ± 1.9° (2.2°-3.3°)	2.5° ± 2.2° (1.8°-3.1°)	2.7° ± 1.8° (2.1°-3.2°)
< 10 years post-residency	32.3 ± 2.3	27	3.4 ± 2.1	4.1° ± 3.3° (2.7°-5.4°)	7° ± 5.6° (4.7°-9.2°)	6.1° ± 4.1° (4.4°-7.7°)	2.7° ± 1.6° (2.0°-3.3°)	2.6° ± 2.2° (1.7°-3.4°)	2.5° ± 1.5° (1.9°-3.0°)
≥ 10 years post-residency	48.2 ± 7.7	25	18.8 ± 6.2	5.2° ± 3.2° (3.8°-6.5°)	7.6° ± 6.4° (4.9°-10.2°)	9° ± 7.8° (5.7°-12.2°)	2.8° ± 2.2° (1.8°-3.7°)	2.5° ± 2.3° (1.5°-3.4°)	2.9° ± 2° (2.0°-3.7°)
JRS	45.3 ± 9.1	31	16.1 ± 7.7	4.8° ± 3.2° (3.6°-5.9°)	7.7° ± 5.8° (5.5°-9.8°)	7.7° ± 7.5° (4.9°-10.4°)	2.9° ± 2° (2.1°-3.6°)	2.6° ± 2.3° (1.7°-3.4°)	2.6° ± 1.9° (1.9°-3.2°)
Non-JRS	32.1 ± 2.7	21	2.9 ± 2.4	4.3° ± 3.5° (2.7°-5.8°)	6.7° ± 6.1° (3.9°-9.4°)	7.2° ± 4.1° (5.3°-9.0°)	2.5° ± 1.7° (1.7°-3.2°)	2.4° ± 2.2° (1.3°-3.4°)	2.7° ± 1.6° (1.9°-3.4°)
CAS JRS	42.5 ± 7.1	10	14.9 ± 7.5	3.9° ± 2.4° (2.1°-5.6°)	7.2° ± 3.6° (4.6°-9.7°)	8.6° ± 5.5° (4.6°-12.5°)	3.2° ± 2.2° (1.6°-4.7°)	3.3° ± 2.3° (1.6°-4.9°)	2.2° ± 1.3° (1.2°-3.1°)
Non-CAS JRS	46.6 ± 9.8	21	16.7 ± 7.9	5.2° ± 3.5° (3.6°-6.7°)	7.9° ± 6.7° (4.8°-10.9°)	7.3° ± 6.4° (4.3°-10.2°)	2.8° ± 1.9° (1.9°-3.6°)	2.3° ± 2.2° (1.2°-3.3°)	2.9° ± 2.1° (1.9°-3.8°)

All deviation values given as mean ± standard deviation (95% confidence interval).
n – number of participants ; JRS – joint replacement surgeons ; CAS JRS – computer-assisted joint replacement surgeons.

Table II. — Comparison of the amount of deviation from the actual designated test position of the knee in both coronal and sagittal plane among various subgroups (p values)

	< 10 years *vs* ≥ 10 years	JRS *vs* Non-JRS	CAS JRS *vs* Non-CAS JRS
Deviation from 0° flexion	0.22	0.59	0.29
Deviation from 10° flexion	0.72	0.55	0.76
Deviation from 90° flexion	0.09	0.78	0.58
Deviation from 0° varus/valgus	0.85	0.45	0.6
Deviation from 5° varus	0.87	0.75	0.25
Deviation from 5° valgus	0.41	0.84	0.34

p value of < 0.05 is significant ; JRS – joint replacement surgeons ; CAS JRS – computer-assisted joint replacement surgeons.

relying on clinical judgement and visual estimation for assessing the position of the knee in the coronal and sagittal plane may lead to inaccuracies (Fig. 2). Out of the 52 surgeons, only 25% were able to position the knee within both 3° of varus or valgus and 5° of flexion. The inaccuracy was more pronounced in the sagittal plane where 44% of the surgeons deviated by more than 5° and 5.7% deviated by more than 10° when positioning the knee in 0° flexion compared to the coronal plane where 15% of the surgeons deviated by more than 5° when positioning the knee in 0° varus or valgus. The amount of error considering the experience of an orthopaedic surgeon was no different when surgeons who were < 10 years from of time of completion of their residency were compared with surgeons ≥ 10 years from the time of completion of their residency. Similarly the error was similar when orthopaedic surgeons who had experience with TKA were compared with those surgeons who had no experience with TKA and when joint replacement surgeons who had experience with computer-assisted TKA were compared with those who had no experience with computer-assisted TKA. This implies that the reliability of visual estimation is equally poor irrespective of the experience of the surgeon.

In the coronal plane, knee alignment is usually estimated intraoperatively using alignment rods

Table III. — Intra and Interobserver Variability in estimating the 6 knee positions

PARAMETER	INTRAOBSERVER VARIABILITY COEFFICIENT	INTEROBSERVER VARIABILITY COEFFICIENT
0° Flexion	0.35	0.34
10° Flexion	0.31	0.31
90° Flexion	0.34	0.34
0° Varus/Valgus	0.77	0.77
5° Varus	0.82	0.81
5° Valgus	0.60	0.57

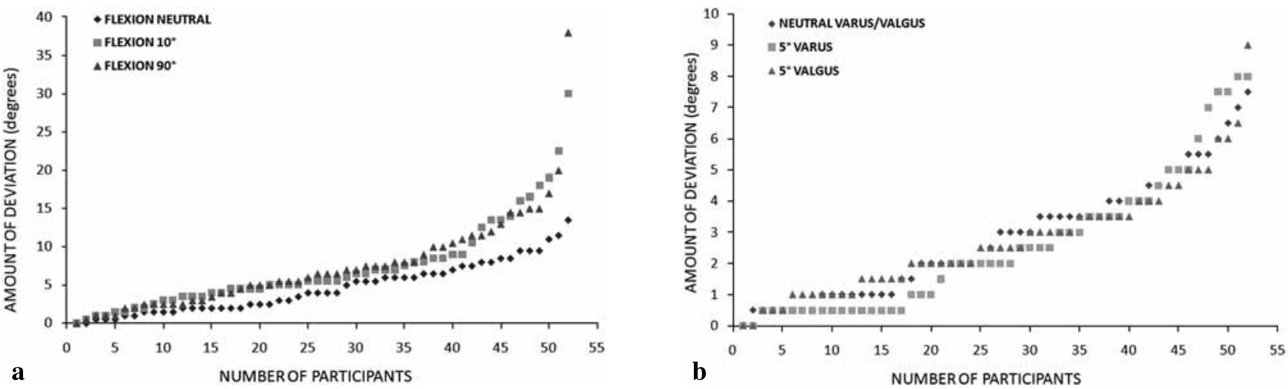

Fig. 2. — (a) Amount of deviation among surgeons for the 3 sagittal knee positions ; (b) : Amount of deviation among surgeons for the 3 coronal knee positions.

which take the center of the hip, knee and ankle as references. However, the center of the hip is a difficult landmark to acquire during surgery, especially in the presence of drapes and in the obese. In the current study the limb model had an exposed prosthetic hip joint whose center was easily identified. Despite this, 15% of the surgeons deviated by more than 5° when positioning the knee in 0° varus/valgus and only 33% of surgeons could place the limbs within 3° of varus or valgus. Similarly in the sagittal plane, determining the amount of knee flexion or extension could be challenging in the presence of drapes and in the obese where excessive fat may obscure any visible landmarks. The error in visual estimation of knee position in the sagittal plane in the current study was more pronounced.

Computer-assisted TKA has been reported to increase the precision of implant positioning and limb alignment ; it relies on determination of the functional rotational center of the femoral head, centre of the knee joint and the centre of the ankle to calculate the mechanical axis of the limb. Intraoperative navigation during TKA can generate precise, accurate, and reproducible alignment measurements with a reported accuracy to within 1° and can function as an effective tool for assessing limb alignment (*9*). However, factors such as error during registration of anatomic landmarks, error during measurement process by the computer based on data acquired from the registration process and intraoperative changes in the navigation environment such as pin loosening may cause subtle error to be inadvertently introduced during surgery (*15*).

There are a few drawbacks to this study. The number of surgeons is small in this study and hence its findings need to be verified using a much larger cohort. However, the surgeons were conference attendees who volunteered to take part in the study and could only participate during the limited time period when the scientific sessions were not in progress. Besides, the surgeons got enrolled in the study at random, showed good variation in terms of experience, age and practice background and hence the influence of selection bias was minimal. In performing this study in a synthetic bone model the authors wanted the surgeons to have the full advantage of a fully exposed limb where the centre of the femoral head, knee and ankle can be clearly visualised. Performing this study on cadaveric limbs may have given a much realistic estimation of the error possible when visual estimation is used to determine knee position. However this may be logistically challenging when it needs to be used during a conference. Based on the result of the current study which showed inaccuracies of visual estimation even when all bony landmarks were clearly seen it can be safely concluded that the amount of error will be greater when visual estimation is used in an actual limb with its soft-tissue cover. In conclusion, visual estimation of knee alignment in both the sagittal and coronal plane is prone to error and may lead to inaccurate limb alignment during procedures such as TKA.

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