Does computer-assisted surgical navigation total knee arthroplasty reduce venous thromboembolism compared with conventional total knee arthroplasty?

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ABSTRACT

Introduction: The study aims to show that total knee arthroplasty using computer-assisted surgical navigation without intramedullary rodding is safer than conventional intramedullary techniques in preventing venous thromboembolism.

Methods: 30 patients were grouped into groups of 10. Groups A and B had conventional intramedullary rodding of the femur and/or tibia. Group C had no rodding of the femur and tibia using computer-assisted surgical navigation. The degree, duration and size of the embolic shower were captured by a transoesophageal echocardiography probe. The echogenic emboli were graded according to the Mayo Clinic score. Haemodynamic parameters such as pulse oximetry oxygen saturation, end-tidal carbon dioxide, heart rate and mean arterial pressure were also recorded.

Results: There was a significant difference in the size of the emboli and the Mayo Clinic score when comparing the groups with intramedullary rodding and those without. There was also a significant difference in the pulse oximetry oxygen saturation and heart rate when the group without intramedullary rodding was compared with groups with rodding.

Conclusion: Surgical navigation total knee arthroplasty may be safer than conventional total knee replacement with intramedullary rodding in preventing venous thromboembolism.

Keywords: intramedullary rodding, surgical navigation, pulmonary embolism, total knee arthroplasty, venous thromboembolism

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INTRODUCTION

The rise of venous thromboembolism (VTE) is worrying with an eight-fold increase within a decade in our local setting.[1] Orthopaedic patients form the largest group of patients with this condition. The development of VTE is reported to be as high as 57% in one series, even with some form of prophylaxis.[2] The major concern is the propagation of the VTE into a fatal pulmonary embolism (PE). Published incidences of nonfatal PE range from 0% to 40% and of fatal PE from 0% to 7%.[3] Total knee arthroplasty (TKA) is a common elective procedure in our centre with more than 900 performed per year. Although fatal PE is a rare occurrence, the observation is that VTE is more common than previously thought.[1] Nevertheless, it is our endeavour to make TKA a safer procedure. The use of a computer-assisted surgical navigation system (BrainLAB, Feldkirchen, Germany) has enabled the surgeon to make accurate femoral and tibial osteotomies without the use of intramedullary guides. This recent advance in surgical technique may prevent the development of VTE.

It is understood that violation of the medullary cavity with instruments is associated with a higher risk of embolic events. Indeed, several authors have attributed larger and significant amounts of embolic particles in the right atrium detected by transoesaphageal echocardiography whenever the medullary cavity was violated by an intramedullary instrument.[4,5] Moreover, undesirable haematological changes have been shown to occur in the mean pulmonary arterial pressure, heart rate, arterial oxygen saturation and end-tidal carbon dioxide with conventional intramedullary-assisted TKA.[4,6,7] Computer-assisted TKA using the surgical navigation system provides accurate cuts of the distal femur and proximal tibia without the need for intramedullary instrumentation. All cuts were made with instruments that allowed accuracy within one degree of alignment and 1 mm of cut depth to be performed.[8] The aim of the study is to show that an accurate and safe method of TKA can be performed without intramedullary instrumentation.

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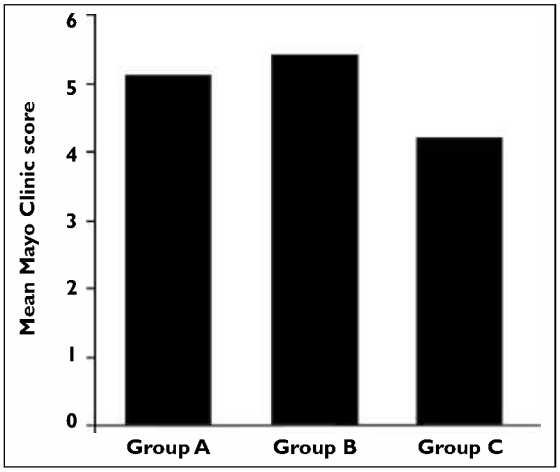

Fig. 1. Bar chart shows mean Mayo Clinic score.

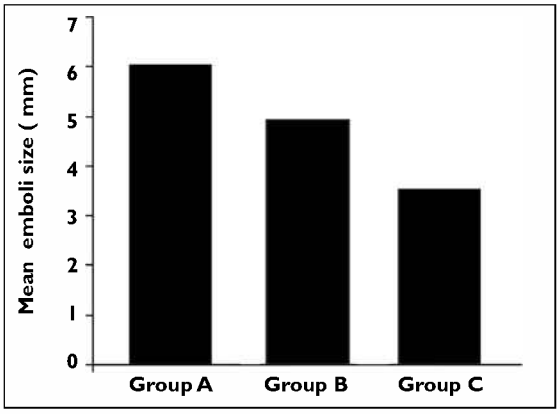

Fig. 2. Bar chart shows mean size of emboli.

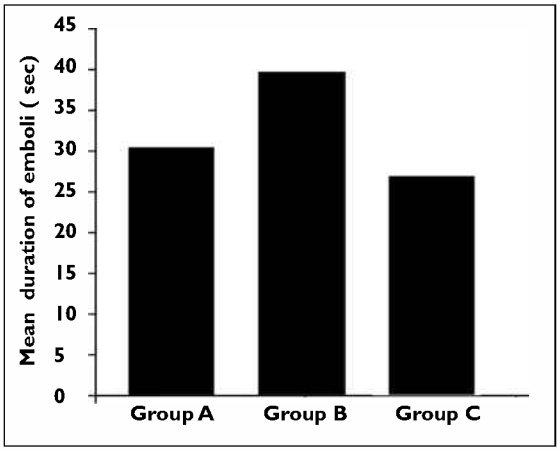

Fig. 3. Bar chart shows mean duration of emboli.

Table I. Surgical techniques employed.

Group	No. patients	Femur	Tibia
A	10	IM	EM
B	10	IM	IM
C	10	SN	SN

IM: intramedullary alignment guide used; EM: extramedullary alignment guide used; SN: BrainLAB surgical navigation system used

Table II. Modified Mayo Clinic grading system for echogenic emboli.

Score	Amount*	Duration**	Size (mm)***
0	None	None	None
1	< 1/2	< 30	< 5
2	> 1/2	30–45	5–10
3	Complete	> 45	> 10

* Amount of right atrium filled by echogenic particles
** Duration of echogenesis during one minute video segments looking at time to peak intensity
*** Diameter of largest echogenic particle

Table III. Summary of demographic data.

	Group A	Group B	Group C
Mean age (years)	67.0	64.6	66.8
Gender (male:female)	2:8	2:8	5:5
Mean operative time (min)	108.3	102.5	122.8
Mean tourniquet time (min)	74.3	72.6	92.4

METHODS

30 patients were recruited for the study during the study period. The study was approved by the ethics committee of our institution. The patients were randomised into three groups. The first group (Group A) underwent TKA with an intramedullary femur guide and an extramedullary tibia guide. The second group (Group B) underwent TKA using intramedullary guides for both the femur and tibia. The third group (Group C) underwent TKA using the computer-assisted BrainLAB technique with no medullary cavity instrumentation of the femur or tibia. The distribution of the patients and techniques utilised are shown in Table I. Exclusion criteria included history of previous VTE or PE, those on prophylaxis or treatment for VTE, and previous procedure of the oesophagus.

All patients underwent general anaesthesia. The two senior authors (SJY, NNL) performed the procedures. For each operation, the limb was exsanguinated with elevation after which a tourniquet was inflated to 350 mmHg. The prosthesis implanted was the Press-fit Condylar (PFC) Sigma TKA prosthesis (DePuy, Johnson & Johnson, Leeds, UK). When an intramedullary system was used, the marrow contents were sucked out prior to insertion of guides. All tibial and femoral canals were irrigated with jet lavage before insertion of cement. All implants were cemented with the standard techniques. At the end of the surgical procedure, a 5-MHz, single-plane, transoesophageal echocardiography probe (Hewlett-Packard, Palo Alto, CA, USA) was inserted to image the right atrium and right ventricle. The tourniquet was then released and recordings of the transoesophageal echocardiography images were recorded. The images were recorded until little or no embolic material was seen.

The images were read and graded independently by two cardiologists (DZP, AL) using the modified Mayo Clinic grading system for echogenic emboli (Table II).[9] The cardiologists were blinded to all information

Table IV. Data of haemodynamic variables expressed as mean and standard deviation.

Group	Oxygen saturation (%)	Heart rate (bpm)	End-tidal CO_2 (mmHg)	Mean arterial pressure (mmHg)
A	93.33 ± 1.51	82 ± 16	37.83 ± 3.66	125 ± 19
B	94.13 ± 1.81	75 ± 7	40.25 ± 7.42	102 ± 16
C	96.22 ± 1.86	67 ± 9	37.44 ± 5.29	110 ± 21

regarding the patients' demographics, type of procedure and intraoperative events. Each image was assigned a score of 0, 1, 2 or 3 points for the amount of filling of the right atrium, the duration of echogenesis and the diameter of the largest particle. The possible scores ranged from 0 to 9. In addition to assessing for emboli, the pulse oximetry oxygen saturation, end-tidal carbon dioxide, heart rate and mean arterial pressure were recorded. These haemodynamic variables were recorded after release of the tourniquet.

In anticipation that the variables were non-normal, multivariate robust regression based on iterative reweighted least squares was applied to ascertain if there were significant differences in size, duration, oxygen saturation, heart rate, end-tidal carbon dioxide, mean arterial pressure and Mayo Clinic score among the three groups while adjusting for confounding variables such as operative and tourniquet times. The data was analysed with Stata 9.0 (Stata Corp, Texas, USA). All statistical tests were carried out at 5% level of significance. A p-value of less than 0.05 was considered significant.

The conventional arthroplasty technique for Groups A and B employed the standard PFC Sigma instrumentation of TKA. We used the intramedullary femur guide in all the cases. For the tibia, the patients in Group A had the proximal tibial resection using the extramedullary guides. In Group B, an intramedullary tibial guide was used. In Group C, surgical navigation is a visualisation system that gives positional information about surgical tools or implants relative to the femur and tibia on a computer display.[10] This method made use of kinetic information about joints or morphometric information about the target bones obtained intraoperatively. A virtual reality display allowed the surgeon to visualise the actual movements of implants and instruments in real-time during the surgery. By guiding the surgeon through the individual steps of the procedure, the navigation system brought high surgical accuracy.[11] The perceived advantage was that all the bone cuts were made without the need to pass intramedullary guide rods into the femur and tibia.

RESULTS

There were nine male and 21 female patients. The mean age of the patients in all groups was 66.1 years. There was no significant difference between groups A, B and C, with respect to their age or the American Society of Anesthesiologists score. The patients' demographic and operative data are summarised in Table III. There was a significant difference in the Mayo Clinic score when Group C was compared with Group A or B ($p = 0.02$ and 0.04, respectively). The mean Mayo Clinic scores showed a downward trend, when the medullary canals of the femur and tibia were less violated (Fig. 1). Group B has a mean score of 5.4, as compared to scores of 5.1 and 4.2 for groups A and C, respectively. Similarly, the duration of the echogenic emboli showed the same downward trend with less violation of the medullary cavities (Fig. 3). The mean size of the emboli was smaller in Group C, compared to Groups A and B (Fig. 2). Only the Group C showed a significant difference to that of Group A with respect to the size of the emboli recorded on transoesophageal echocardiography ($p = 0.03$).

In general, the degree of embolic shower appeared more intense in patients undergoing arthroplasty using intramedullary guides. The surgical navigation group exhibited embolic showers that peaked early and began to wane shortly with time. However, group B showed the longest duration of embolic shower of 120 seconds and the largest embolic particle that measured 18 mm. Operative and tourniquet times had no effect on the Mayo Clinic score, the size, duration or amount of the emboli formed. There was a significant difference in the pulse oximetry oxygen saturation ($p = 0.03$) and heart rate ($p = 0.03$), when group C was compared with group A. There was no significant effect on the end-tidal carbon dioxide and mean arterial pressure during the comparisons between the groups. Similarly, there was no significance between the tourniquet and operative times with the haemodynamic variables measured. The data of the haemodynamic variables are shown in Table IV. All patients recovered well from the procedure and there were no adverse events in our series.

DISCUSSION

The study focused on whether we can make TKA a safer procedure with the use of a computer-assisted surgical navigation system that allowed accurate cuts to be made without the need for intramedullary guides. Most

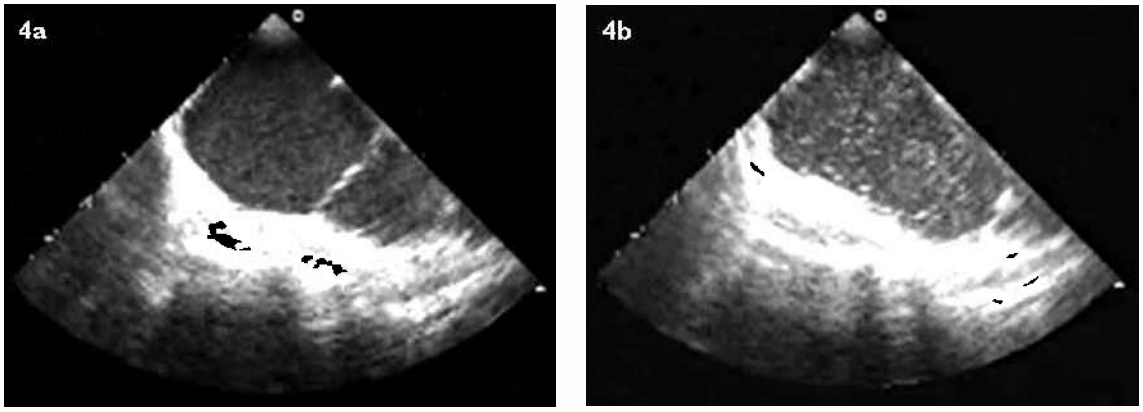

Fig. 4 US images show (a) the right atrium before the deflation of the tourniquet; and (b) the embolic shower filling the whole of the right atrium as depicted by the white speckled dots that arise after the deflation of the tourniquet. The images were taken from a patient from Group B.

conventional extramedullary systems are less accurate than intramedullary systems.[12] With the surgical navigation system, an even higher degree of accuracy can be achieved, when compared with conventional techniques.[8] The added benefit of the surgical navigation system is the avoidance of introducing intramedullary guides into the femur or tibia to make the bone cuts. The belief is that intramedullary instrumentation triggers a response that leads to VTE. However, the true nature of the emboli is uncertain with fat, platelet clumps, fresh thrombus, marrow contents and polymethylmethacrylate cement considered in the past.[6,13-16]

The danger of VTE is the passage of the embolic material into the pulmonary circulation. In most instances, there will be minor but detectable changes in the haemodynamic variables of the patients with no serious adverse outcome.[7,17] However, the development of large emboli could trigger a massive pulmonary embolic event that can lead to fatal PE.[3,15,18] The use of a transoesophageal probe to detect pulmonary emboli has been attempted previously.[4-6,9,13] The procedure has been deemed safe to evaluate emboli in the right atrium during general anaesthesia.[19] We used the Mayo Clinic grading system for venous embolism detected by transoesophageal echocardiography as described by Ereth et al.[9] Previous studies have used this grading system, but the main difference between our study and the other studies is that we attempted to compare conventional TKA techniques with one in which the medullary canals were not violated.

When comparing the groups, there was a significant difference in the Mayo Clinic score between the conventional groups (Groups A and B) and the surgical navigation group (Group C). The Mayo Clinic score is an aggregate score for the degree of emboli formation and it appears that violation of the medullary canal with a rod does lead to changes that provoke more emboli formation. Higher mean scores were noted when the medullary canals were breached (Fig. 1). Similarly, we were able to show a significant decrease in the duration, size and amount of emboli in the right atrium with the surgical navigation technique. Our study mirrors that of Berman et al's and Giachino et al's.[6,14] Most of the emboli appeared 15 seconds after the tourniquet was deflated, and peaked at around 30 seconds. There were a few patients where the embolic shower lasted beyond two minutes. The appearance of large emboli occurred in three of our patients (8.6, 10 and 18 mm). The mean size of emboli was 4.46 mm. In Giachino et al's series of 66 patients, seven patients (10%) had emboli greater than 5 mm.[14] There was also no association between tourniquet time on the amount, size and duration of emboli formed.

The effect of tourniquet and operative times on VTE is unclear. Venous stasis caused by the tourniquet is thought to be a factor in the development of VTE. However, there is a disagreement between those who believe it does[20,21] and those who do not.[6,17] Our experience with the BrainLAB system is relatively new. The slightly longer time taken to perform TKA using this new system is due to the calibration of the markers for navigation. It takes approximately 20 minutes longer with the BrainLAB system (Table III). As the effect of tourniquet time is at present indeterminate, it may prove to be a confounding variable. With better experience and familiarity with the surgical navigation system and as the tourniquet time approaches that of conventional TKA procedures, this variable can be eliminated as it may prove to be an important factor in the pathogenesis of VTE.

The change in the haemodynamic variables is known to occur after the release of the tourniquet.[4,7,13,17] The change is seen in the heart rate, arterial oxygen saturation, end-tidal CO_2 tension, mean arterial pressure, pulmonary

vascular resistance, pulmonary artery pressure. This change in haemodynamic parameters frequently proves to be transient and uneventful, and the patient recovers well. Occasionally, a sustained and drastic change occurs which heralds the development of a massive PE. In the clinical situation, the use of the transoesophageal echocardiography probe will facilitate the diagnosis of PE if the suspicion is high.[18] In our study, only the heart rate and arterial oxygen saturation were noted to change significantly when comparing the surgical navigation group with the intramedullary groups. It is difficult to ascertain if this difference is purely through the effect of intramedullary rodding or the patient's inherent predispositon to VTE due to venous stasis because either situation obeys the laws of Virchow's triad of VTE.

In a similar study comparing conventional arthroplasty with computer-assisted arthroplasty, other workers have shown that cerebral emboli is significantly reduced with less intramedullary rodding.[22] The effect is thought to be due to the transpulmonary shunting of embolic material. In these studies and in our study, a potential benefit of surgical navigation may be seen in simultaneous bilateral TKA, where the higher incidence of VTE and other embolic phenomena may be related to intramedullary instrumentation of both femora and tibiae. Hence, the study has shown that computer-assisted surgical navigation systems without the need for intramedullary instrumentation may perhaps become a safer alternative for TKA in the future.

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