



## Do thigh tourniquets contribute to the formation of intra-operative venous emboli ?

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The authors undertook a randomised prospective study to investigate the contribution of thigh tourniquets to the formation of intra-operative venous emboli during lower limb surgery. Patients were randomised to have a thigh tourniquet or no tourniquet and transoesophageal echocardiography was used to detect embolic signals in the right heart during and after knee arthroscopy. Three physicians blinded to patient demographics and tourniquet status separately assessed videotapes of the echocardiograms for evidence of emboli.

Of the 32 patients randomised, 18 underwent knee arthroscopy with and 14 without tourniquet. Emboli were seen in 72% (95% CI 55 to 84) of patients, in 14 patients with tourniquet and in 9 patients without tourniquet. There was an estimated 13% greater incidence of emboli in the tourniquet group compared to the non-tourniquet group, a difference which was not statistically significant (Fisher's Exact Test,  $p = 0.45$ ). No patients suffered symptoms or signs attributable to a pulmonary embolus.

### INTRODUCTION

During lower limb surgery, clinical pulmonary embolism is a potentially fatal but rare complication. Previous reports document fatal peri-operative pulmonary embolus (PE) associated with lower limb arthroplasty (8,13,15) as well as in less extensive operations such as fracture fixation (2,19). Using transoesophageal echocardiography (TOE) venous emboli have been demonstrated during many lower limb procedures (3,4,11,12,16,17, 18,19,22) although few patients experience cardiorespiratory symptoms and signs.

Published studies investigating intra-operative embolism have explored the incidence of embolism, embolic content, cardiopulmonary response to emboli and possible prediction of symptomatic embolism. Use of a thigh tourniquet has been suggested as a cause of intra-operative venous embolus production (17) but no studies have investigated this area. The current study was constructed to investigate the effect of using a thigh tourniquet during lower limb surgery upon venous embolus formation.

### PATIENTS AND METHODS

A randomised prospective longitudinal study was conducted to investigate the association of the

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occurrence of venous emboli with the application of a thigh tourniquet and to investigate the incidence of emboli in knee arthroscopy.

The study was approved by the regional Ethics of Research Committee. Patients were recruited from the senior author's (IKR) elective waiting list. Informed consent was obtained from each patient and his General Practitioner. Several groups of patients were excluded from the study (table I).

To reduce confounding variables a single type of operation was undertaken. Knee arthroscopy was adopted as the operation of choice because it is easy to perform with or without a tourniquet, the intra-medullary cavity is not instrumented and the procedures are relatively similar. All procedures were performed in the same operating theatre by the same surgeon (IKR) using the same equipment. Patients were randomised to have a tourniquet or not have a tourniquet using a random number table. To avoid bias pre-operatively, a patient's tourniquet group was not identified to staff until the patient was under general anaesthesia in the operating theatre. After induction a TOE probe was inserted and a four-chamber view of the heart (fig 1) was visualised peri-operatively using a 5Mhz Acuson ultrasound probe, an Acuson 128XP/10c ultrasound machine (Mountain View, California, U.S.A) and recorded on super VHS video.

The heart was initially imaged before handling of the lower limb, during application of the tourniquet, exsanguination and preparation of the lower limb until both arthroscopy portals had been inserted or for a minimum of five minutes. Imaging was then performed for alternate minutes during the



Fig. 1. – Normal right side of heart.

procedure and then finally from before bandaging of the knee (and tourniquet release) until two minutes following completion of bandaging. The timing of imaging for the patients in the tourniquet and the non-tourniquet groups was identical. Continuous imaging for the entire procedure was not performed as prolonged use of the ultrasound probe produced heat and the equipment was designed to automatically shut off upon reaching 40°C to avoid oesophageal injury. Thus the maximal continuous recording time was approximately 10 minutes.

In the tourniquet group a pneumatic tourniquet was placed around the upper thigh and inflated to a pressure of 250 mmHg after the limb had been exsanguinated using a Rhys-Davies pneumatic exsanguinator (Woodville Polymer Engineering, Derby, UK). Exsanguination was not carried out in the non-tourniquet patients. The arthroscopies were performed using anterolateral and anteromedial portals and irrigation carried out with normal saline fed by gravity. No pressurisation or vasoconstrictor agents were used in the irrigation system. No patients in the study underwent arthroscopic ligamentous reconstructive surgery or arthroscopic washout for septic arthritis. Patients were admitted on the day of surgery and no thromboprophylaxis was used.

All patients underwent general anaesthesia. The choice of anaesthetic agents was at the discretion of the attending Consultant Anaesthetist. Standard intra-operative monitoring for our institution was used including continuous electrocardiography, transcutaneous oxygen saturation monitoring and expiratory capnography. No invasive monitoring

Table I. – Patient Exclusion Criteria

<b>Unable to consent</b>	- age under 16 years - reduced mental capacity
<b>Tourniquet contraindicated due to thromboembolic risk</b>	- previous deep venous thrombosis - previous pulmonary embolus - malignant disease - immobile patient - obesity
<b>Transesophageal ultrasound contraindicated</b>	- pharyngeal pathology - oesophageal pathology - dysphagia

devices such as arterial cannulae, central venous cannulae or Swan Ganz catheters were used.

Three physicians trained in TOE interpretation independently assessed the recorded TOEs. The assessing physicians were blinded to the patients' identities, demographics and operative details including tourniquet status. Embolic signals in the right heart (fig 2) were evaluated and the TOE for each patient was classified as showing emboli or no emboli and when present, the size and timing of emboli during the procedure were noted. All three assessors classified the videotapes of the TOEs identically in the majority of the cases. In the event of an inter-observer difference of classification, the opinion of the majority was used.

## RESULTS

Thirty-two patients were randomised to treatment (25 males and 7 females). Eighteen patients were randomised to the thigh tourniquet group and 14 to the non-tourniquet group. Seventeen patients underwent arthroscopy with partial meniscectomy, 13 diagnostic arthroscopy and 2 patients had arthroscopic loose body removal. There were no differences in gender or operation type between the group who had a tourniquet and the group who did not (table II). The mean operation time was 21.8 minutes (20.2 minutes with tourniquet, 23.9 minutes without tourniquet) and the mean tourniquet time was 17.1 minutes.

Table II. – Summary of baseline variables

	Tourniquet	No tourniquet
Number of patients	18	14
Male patients	14 (78%)	11 (79%)
Diagnostic arthroscopy	8 (44%)	5 (36%)
Partial meniscectomy	9 (50%)	8 (57%)
Removal of loose body	1 (6%)	1 (7%)

Emboli were seen in 72% (23 out of 32) of the patients ; the 95% confidence interval for this estimate was 55% to 84% (23). The incidence of emboli was 78% (14 out of 18) in the tourniquet group and 64% (9 out of 14) in the non-tourniquet group (table III). Thus the incidence of emboli was 14% greater amongst those who had a tourniquet applied

Table III. – Summary of outcome variables

	Tourniquet	No Tourniquet
Number of patients	18	14
Operation time – mean (sd)	20.2 (5.4)	23.9 (10.9)
Emboli seen in TOE	14 (78%)	9 (64%)
Small emboli only	13 (93%)	9 (100%)
Large emboli also	1 (7%)	0
Emboli timing		
Start	11 (61%)	5 (55%)
Middle	8 (44%)	6 (67%)
End	5 (28%)	2 (14%)

Operation time — from start of preparation of limb until finish of bandaging of knee (minutes).

Emboli timing — 'start' is initial TOE recording period, 'middle' is during rest of procedure, 'end' is final TOE recording period.



Fig. 2. – Multiple small emboli in the right side of heart.

compared to those who had no tourniquet. The difference in the incidence of emboli was not statistically significant (Fisher's Exact Test,  $p = 0.45$ ). The 95% confidence interval for the estimated 13% difference in incidence is -17% to 42% (14).

Only in one patient, in the tourniquet group, were the emboli greater than 5 mm. Seven patients with tourniquet had emboli at the end of the operation compared with three of those who had not had tourniquet, a difference which is not statistically significant.

Emboli varied in size, echogenicity and frequency, with some patients having no detectable signals, and others with several hundreds detected during the TOE. In one patient, two individual very large approximately 30 mm long snake-like emboli were seen at separate times during the middle of the pro-



Fig. 3. – Large “snake-like” embolus transversing tricuspid valve.

cedure with the tourniquet inflated (fig 3). In two other patients, one a tourniquet patient and one a non-tourniquet patient, showers of massive numbers of small emboli lasting for over 20 seconds called ‘snowstorms’ were visualised at the end of the procedure.

No patient experienced symptoms or signs of pulmonary embolism peri-operatively and intra-operative monitoring revealed no abnormalities suggestive of significant pulmonary embolism. In particular when the large emboli and the snowstorms were visualized there was no reduction in oxygen saturation, change in expiratory carbon dioxide level or systemic hypotension.

Temporary intra-operative intra-articular bleeding occurred in one patient in the non-tourniquet group with a resulting increase in operative time. This patient experienced no postoperative symptoms of haemarthrosis or bleeding from portal sites. No other patient experienced complication and at follow-up no patient had suffered from a clinical deep venous thrombosis (DVT).

## DISCUSSION

Post-operative pulmonary embolism is a significant cause of morbidity and mortality among lower limb surgery patients. Orthopaedic surgeons are very aware of the risk of postoperative PE following major lower limb surgery and considerable resources are committed to prophylaxis against DVT and subsequent PE. Surgeons may however be less aware of intra-operative venous embolism as, despite their high frequency, symptomatic intra-operative emboli are rare in procedures of interme-

diante size such as knee arthroscopy although they are more common in major procedures such as bilateral knee arthroplasties (6).

Thigh tourniquets are also considered to have the potential to contribute to the production of intra-operative emboli (17), which is potentially important as the use of thigh tourniquets in lower limb orthopaedic surgery is extremely common (10). Also the incidence of DVT post-arthroscopy demonstrated by venography is as high as 18% and the duration of tourniquet use increases the risk of postoperative DVT development (5). Thus in light of the facts that during lower limb surgery the potential for venous embolism appears high, tourniquet use is common and tourniquets may contribute to embolus production, the current study was undertaken to investigate the contribution made by tourniquets to intra-operative venous embolus formation.

There are variations in the reported incidence of intra-operative embolus formation during lower limb procedures in previous studies (1,3,4,6,7,11,12,17,18,19,22). However, procedures during which the cortex is breached and the intramedullary canal instrumented appear to produce emboli in the majority of or in all patients (3,4,11,16,17,18,19,22). We wished to study the contribution of the tourniquet to embolus formation and therefore studying procedures in which all patients would produce large numbers of emboli on TOE would have prevented assessment of subtle differences in embolus rate. Knee arthroscopy had previously been demonstrated to produce lower rates of embolus production (12) and thus this procedure was chosen to allow differences in embolus production to be detected with greater sensitivity.

Venous emboli were detected in 72% of patients in our study. We had anticipated a lower incidence of embolus production as the only relevant previously published study by McGrath *et al* (12) documented an incidence of 30% intra-operative embolus production demonstrated by TOE during knee arthroscopy. However the embolism rate for total knee arthroplasty in this previous study was 33% which contrasts with the embolism rate of nearly 100% seen in the majority of studies investigating emboli in knee arthroplasty (3,16,17,18) and thus it

seems that current methods of detecting emboli are more sensitive than those employed by McGrath. A Medline search did not identify any previously published data relating to embolus production during knee arthroscopy without tourniquet and we believe this study was able to estimate for the first time the incidence of emboli in knee arthroscopy without tourniquet.

Current ultrasound machines can reliably demonstrate small emboli but the sensitivity of this technique depends on the composition of embolic material. The detection of emboli is based on a difference in echogenicity between the embolic particle and the background signal reflected by blood. Gas bubbles cause very intense echogenic signals whereas thrombus signals will be less intense and potentially more difficult to detect. It is difficult therefore to determine the composition of an embolus by TOE. Embolus composition has been explored by means of aspiration through large pulmonary artery and femoral vein catheters during total knee arthroplasty and some investigators have identified thrombus (18), others identified thrombus plus marrow (22) and post-mortem examinations of patients with fatal intra-operative PE have demonstrated numerous fat emboli (8,13,15,19,20). There was no breaching of the bony cortex in the patients of the current study, and thus we believe that the emboli seen during the TOEs were either thrombus or gas particles. The large snake like particles however had the typical appearance of large thrombi. Emboli were visualised in the tourniquet group during the middle of the procedures with the tourniquet inflated and we presume these emboli originate from the femoral vein proximal to the tourniquet where stagnation occurs due to absence of distal flow.

The current study was designed to investigate the association between the incidence of emboli in patients with or without tourniquet during knee arthroscopy. There was a higher incidence of emboli in the group who had a tourniquet than in the group who did not (78% vs 64%). The difference between the tourniquet and non-tourniquet groups is not statistically significant, indicating that there is insufficient evidence in this study to suggest that the application of tourniquets is asso-

ciated with an increase in the incidence of emboli. If the estimated 13% excess incidence in the tourniquet group had been statistically significant we believe this would have represented a clinical significant finding suggesting that in 'at risk patients' tourniquets should be avoided. However, the width of the confidence interval for this estimate (-17% to 42%) indicates that a larger study is needed to give a more reliable estimate and a greater power to detect a difference in the incidence of emboli with the application of a tourniquet, if it exists.

In this study no patient displayed symptoms or signs on routine monitoring consistent with a PE. This correlates with previous studies in total hip and knee joint arthroplasty where large embolic loads passed into the pulmonary circulation but few patients demonstrated symptoms of PE (4,11,12). It seems probable that the pulmonary circulation is tolerant to receiving embolic material and sieves embolic material removing it from the circulation. Symptoms and frank signs of PE occur only when the capacity of the pulmonary circulation to contend with emboli is overwhelmed by the amount or size of embolic particles (21). It is possible that small venous emboli are a common physiological event during life and that the lungs are readily able to clear small numbers of small emboli. However, no work has been undertaken to look at this question as it is not possible to undertake accurate surveillance for small emboli during everyday activity using current imaging technology.

Upon tourniquet deflation a transient small reduction in blood oxygen saturation or blood pressure is frequently observed after major lower limb procedures. It is commonly considered that these cardiorespiratory changes are as a result of the increased metabolic load of the venous blood entering the general circulation from the limb. However, it is quite possible that a proportion of these cardiorespiratory signs result from venous emboli.

In some situations venous emboli may be of increased significance. When the embolic load delivered to the pulmonary circulation is high, the risk of clinically apparent PE increases as seen in bilateral knee arthroplasty where the incidence of symptomatic embolism may be up to 12% (6). In addition, patients with patent foramen ovale (PFO)

are at increased risk of peripheral embolic complications due to paradoxical embolism of thrombus from the right to the left side of the circulation, especially if pulmonary hypertension develops as the result of emboli entering the pulmonary circulation (4,11,19,20). Therefore despite the low incidence of symptoms of embolism during lower limb surgery, intra-operative embolism must be considered should cardiorespiratory difficulties develop during lower limb surgery especially during major procedures or in patients known to have a septal defect. The foramen ovale is patent in up to 25% of the normal population although defects large enough to allow clinically significant paradoxical embolism are probably present in only around 2% of the population (9).

In summary, the current study is to our knowledge the first randomised prospective investigation of the contribution of thigh tourniquets to intra-operative venous embolus production during surgery of the lower limb. Venous embolism during lower limb surgery is common with 72% of patients in this study demonstrating emboli intra-operatively using TOE. Emboli were seen in 78% of the tourniquet patients and 64% of the non-tourniquet patients although the difference in the incidence of emboli was not statistically significant. Emboli seen during each patient's TOE varied from the more common isolated small number of small emboli, to 'snowstorms' of emboli or the large 'snake like' emboli seen in one patient. Despite the high incidence of emboli there were no symptoms or signs consistent with PE in the patients of this study.

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