Perioperative lower limb venous haemodynamics in patients under general anaesthesia†

A. L. Knaggs1*, K. T. Delis3, P. Mason2 and K. Macleod1

Departments of 1Anaesthesia and 2Gynaecology, St Mary’s Hospital, London, UK. 3Mayo Clinic, Rochester, Minnesota, USA. 4Faculty of Medicine, Imperial College, London, UK.

*Corresponding author: Department of Anaesthesia, 4th Floor QEQM Wing, St Mary’s Hospital, Paddington, Praed Street, London W2 1NY, UK. E-mail: akotow@aol.com

Background. This study prospectively determined the haemodynamic changes in the lower limb venous circulation during and shortly after elective abdominal surgery, performed under general anaesthesia.

Methods. Ten females, aged 36–65 yr, ASA I or II, undergoing total abdominal hysterectomy had their peak, mean and minimum velocities, diameter, volume flow and venous pulsatility (peak−minimum/mean velocity) measured in the left popliteal vein on recumbency with duplex at: (i) baseline, (ii) 15 min after induction, (iii) during surgery, and (iv) in recovery 30 min after extubation. Anaesthesia was induced with fentanyl and propofol, paralysis with vecuronium, maintenance with isoflurane in nitrous oxide 66%, and analgesia with morphine. Results are presented as percentage difference from baseline mean value. The Friedman and Wilcoxon[corrected*] tests were applied.

Results. Mean velocity decreased by 23.6% during surgery and by 34.6% in recovery (P<0.05*). Minimum velocity was decreased by 56% during surgery and by 78% in recovery (P<0.05). The volume flow decreased by 26% during surgery, and by 54.4% in recovery (P<0.001). Diameter and peak velocity changed little at surgery and recovery (P>0.2). In contrast, the pulsatility increased by 30% on induction, 83% on surgery and 109% in recovery (P<0.05). Compared with baseline, haemodynamic changes on induction were small (P>0.1*).

Conclusions. A significant decrease in the volume flow, mean and minimum velocities was noted during and immediately after elective total abdominal hysterectomy under general anaesthesia in ASA I and II patients. Flow changes in early recovery mirrored or enhanced those noted intraoperatively. Despite venous flow attenuation, haemodynamic readjustments produced a significant and progressive enhancement of venous flow pulsatility during the course of the procedure.


Keywords: anaesthesia, general; measurement techniques, duplex ultrasound; surgery, abdominal; veins, lower limb venous haemodynamics

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Elective abdominal surgery, in the absence of appropriate prophylaxis, is associated with a 25% documented risk of deep venous thrombosis (DVT),1 and an estimated 1–2% risk of pulmonary embolism.1 2 Recognition of the clinical and financial repercussions of deep venous thromboembolic sequelae has lead to the development of stringent prophylaxis protocols before, during and after abdominal surgery.13 Elastic compression hosiery, unfractionated or fractionated heparins, dextran, and intermittent pneumatic compression constitute currently well-documented measures of DVT prophylaxis and their use can be adjusted to the individual patient’s need.1 3 However, DVT develops in 5–15% of patients undergoing elective abdominal surgery despite prophylaxis.1

Stasis, hypercoagulability and endothelial damage, the factors comprising Virchow’s triad, are instrumental in the pathogenesis of DVT.1 The mechanisms of hypercoagulability1 and endothelial damage in peripheral venous circulation intraoperatively4 are reasonably well described but there is limited information on the haemodynamics of stasis

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during general anaesthesia (GA), which holds such a pivotal role in thrombosis.

We hypothesized that lower limb venous flow velocities are markedly reduced during and early after abdominal surgery performed under GA. The aim of this prospective study was to evaluate the venous haemodynamics of the lower limb, using duplex ultrasound, before, during and immediately after GA in ASA I or II subjects undergoing elective total abdominal hysterectomy.

Methods

After ethics committee approval, written informed consent was obtained from all subjects. The haemodynamic status of peripheral venous circulation before, during and after elective total abdominal hysterectomy, performed under GA for benign disease via a Pfannensteil incision, was determined in 10 females selected randomly. Exclusion criteria included: peripheral vascular disease, detected by abnormal peripheral pulses, duplex velocity spectra, and ankle brachial pressure index (ABPI) at rest <1.0; clinical signs of chronic venous disease associated with abnormal venous reflux (>0.5 s) on duplex; obesity (BMI >30); previous abdominal or lower limb surgery; ASA status >II; and lymphoedema.

The investigation protocol entailed: (i) history, (ii) examination, (iii) review of the case notes, (iv) duplex scanning of peripheral arteries and veins, (v) measurement of the resting ABPIs, and (vi) determination of the venous haemodynamics at the popliteal vein in the horizontal position using a duplex ultrasound fitted with a 7.5/5.5 MHz linear array scan head; gated Doppler sonography superimposed on real-time B mode imaging under standardized duplex settings (gain, contrast, rejection), enabled an optimized evaluation of the venous haemodynamics. Dedicated software provided enveloping of the spectral waveforms with automated estimation of its peak, mean and minimum velocities. Estimations of these parameters were obtained consecutively over time periods of 6 s. Popliteal vein diameter was measured by placing the B-mode callipers over the proximal and distal intimal-luminal interphases. Volume flow was estimated from the cross-sectional area (π × diameter²/4) multiplied by the mean velocity. The venous pulsatility was determined by the formula: (peak–minimum)/mean velocities. At least four readings were obtained per parameter per time point and then averaged. To ensure comparability the popliteal vein was duplex scanned level to the proximal and distal intimal-luminal interphases. Volume flow in recovery was conducted with analysis of variance (Friedman’s test); P values next to ‘overall’ (implying ≥3 time points) are based on the Friedman’s test. The exact significance of paired differences between two time points was assessed using the Wilcoxon test, with a Bonferroni correction (*) when appropriate. The data distribution was checked for normality with the K-S test. Data are presented as mean (sd) [range]. P value <0.05 was considered to be significant.

Results

Ten patients, median age 51 yr (interquartile range 36–65) years were studied. No significant changes in the peak velocity were documented (overall P>0.2; Table 1). The mean velocity was similar at baseline and induction, but decreased by 23.6% during surgery and by 34.6% in recovery (P<0.05*; overall P<0.01). Minimum velocity was highest at baseline and induction, but decreased by 56% during surgery and by 78% in recovery (P<0.05). Minimum velocity in recovery was significantly lower (P=0.049) than at baseline (overall P<0.05; Table 1).

The diameter of the popliteal vein (Table 1) changed very little from baseline through to surgery, with a small decrease in recovery (overall P>0.2). Volume flow (Table 1) was highest at baseline and induction but decreased by 26% during surgery, and by 54.4% in recovery (overall P<0.001). Volume flow in recovery was
significantly lower compared with both baseline and induction ($P<0.014^\ast$).

Venous pulsatility (Table 1) was lowest at baseline, increasing by 30% on induction, 83% on surgery, and 109% in recovery (overall $P<0.05$). Venous pulsatility in recovery was significantly higher than that at baseline ($P=0.04$).

The procedure lasted a median 80 min (interquartile range 54–91), with a median blood loss of 450 ml (interquartile range 35–725). The mean arterial pressure was similar throughout the four time points of lower limb haemodynamic assessment (overall $P>0.5$).

**Discussion**

A decrease in femoral venous flow during surgery under GA was described over 30 yr ago, using radioisotopes and basic sonography. The increased propensity of DVT in the soleal veins has been linked to a prolonged stasis in the large venous sinuses of inactivated calf muscles. The current study evaluated the venous flow dynamics in the lower limb at three stages of GA administered for elective total abdominal hysterectomy (post-induction, intraoperatively, and post tracheal extubation), in comparison to resting venous flow before induction. Stringent criteria enabled selection of ASA I or II subjects without peripheral arterial, venous or lymphatic disease.

The study showed that, relative to baseline, the mean and minimum velocities and volume flow were unchanged 15 min after GA induction, before surgery, but all decreased significantly at the subsequent stages. During surgery the minimum velocity [mean] decreased by 56% and the mean velocity [mean] by 23.6%, associated with a volume flow reduction of 26.3%. The trend of increasing flow attenuation continued into recovery, 30 min after tracheal extubation, when the mean and minimum velocities [mean] and volume flow [mean] all came to their lowest levels (34.6%, 78%, and 54.4%, respectively). These changes at the four time-points of flow evaluation occurred in the absence of significant alterations in the mean arterial blood pressure.

Compared with the significant overall decrease in peripheral venous flow during and immediately after elective total abdominal hysterectomy, the impact of GA alone as viewed by the changes sustained after induction and before the surgical insult, was insignificant. Venous flow reduction became apparent at the stage of surgery, when GA and abdominal surgery exerted their effects concurrently. Yet, the highest level of flow reduction was recorded at early recovery, when the patients’ tracheas had been extubated and the direct effects of GA and artificial ventilation had been withdrawn. The presence of small haemodynamic changes on induction, and the manifestation of maximal flow attenuation on recovery, indicate that the isolated direct effects of GA are probably limited and overtly outweighed by those of surgery.

Similar to the ebb phase in response to injury, stress response causes mobilization of energy reserves perioperatively and cardiovascular reflex activity changes attributable to sympathetic overflow. Plasma catecholamine elevation, linked to hormonal secretion from the pituitary and the adrenal medulla, results in peripheral vasoconstriction.

The significant lower limb venous haemodynamic impairment on recovery also reflects the arterial limb inflow attenuation reported upon completion of the surgical intervention. The mean arterial leg blood flow in patients undergoing transurethral resection of the prostate under GA was only 28% of control at 1 h after surgery, rising to 66% of control by 2 h on occlusion plethysmography. This arterial leg inflow compromise has been linked to a higher rate of early postoperative graft failure in infrainguinal arterial bypass surgery, in GA patients compared with bypass grafting performed under epidural anaesthesia, which abolishes the peripheral vascular sympathetic activity. The occurrence of pathophysiological changes in the venous circulation perioperatively is supported by the current study’s findings.

By disrupting laminar flow in the venous circulation, stasis brings platelets into contact with the endothelium, prevents dilution of activated clotting factors by fresh flowing blood, retards the inflow of clotting factor inhibitors, permits the build-up of thrombi and promotes the activation of endothelial cells. The release of kinins into the systemic circulation from tissues disrupted by surgery may further promote endothelial cell activation, setting in a vicious circle of hypercoagulability.

### Table 1 Haemodynamic parameters and popliteal vein diameter of the study patients at baseline, induction of general anaesthesia (15 min after tracheal intubation), surgery (upon resection of uterus), and recovery (30 min after tracheal extubation). Data are expressed as mean (SD) [range]. The Friedman test refers to all four time-points of assessment. The Bonferroni-corrected Wilcoxon test highlights the presence of significant difference ($P<0.05$) between the baseline and the marked time point (*), when significance was achieved. The data distribution was checked for normality (K-S test)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Induction</th>
<th>Surgery</th>
<th>Recovery</th>
<th>Friedman test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak velocity (cm s$^{-1}$)</td>
<td>8.4 (2.5) [4.5–12]</td>
<td>9.5 (4.7) [4.1–19]</td>
<td>9.4 (2.9) [4.8–13.6]</td>
<td>9.3 (4.6) [3.6–14.9]</td>
<td>$P&gt;0.2$</td>
</tr>
<tr>
<td>Mean velocity (cm s$^{-1}$)</td>
<td>5.3 (2.2) [3.1–8.2]</td>
<td>5.5 (2.9) [2.1–10.2]</td>
<td>4.2 (1.9) [1.8–5.4]*</td>
<td>3.6 (1.2) [1.7–5.2]*</td>
<td>$P&lt;0.01$</td>
</tr>
<tr>
<td>Minimum velocity (cm s$^{-1}$)</td>
<td>3.6 (2.7) [0–8]</td>
<td>3 (2.8) [0–8.4]</td>
<td>1.6 (3.6) [−4.5–8.9]</td>
<td>0.8 (4.1) [−6.2–5.8]*</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Pulsatility</td>
<td>1.15 (1) [0.3–1.6]</td>
<td>1.5 (1.5) [0.3–1.37]</td>
<td>2.1 (1.2) [0.61–4.82]</td>
<td>2.4 (1.9) [0.33–6.09]*</td>
<td>$P&lt;0.05$</td>
</tr>
<tr>
<td>Diameter (cm)</td>
<td>0.64 (0.13) [0.43–0.82]</td>
<td>0.63 (0.09) [0.50–0.77]</td>
<td>0.62 (0.12) [0.45–0.79]</td>
<td>0.55 (0.15) [0.36–0.72]*</td>
<td>$P=0.2$</td>
</tr>
<tr>
<td>Volume flow (ml min$^{-1}$)</td>
<td>114 (79) [39–254]</td>
<td>112 (82) [34–268]</td>
<td>84 (59) [26–138]</td>
<td>52 (28) [10–112]*</td>
<td>$P&lt;0.001$</td>
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</table>
The relatively unaltered peak venous velocity perioperatively indicates that the peak shear stress forces in lower limb veins remain unchanged. This resulted in a significant step-up increase in the venous pulsatility in the later part of the study. The relative pulsatility of venous flow increased by 30.4% on induction, 82.6% during surgery, and by 108.7% after extubation. Similar to the arterial pulsatility index, reflecting the level of outflow resistance,\textsuperscript{16} the gradual pulsatility enhancement in the popliteal vein with time may reflect a sequential increase in resistance to venous return. This could be attributable to a number of factors including: the manipulation of the abdominal organs during surgery; an increase in abdominal pressure caused by surgical oedema,\textsuperscript{16} increased abdominal muscle contraction after tracheal extubation;\textsuperscript{17} the use of mechanical ventilation and the temporary abolition of the beneficial effect of negative mediastinal pressure on venous return, and the loading of central circulation with fluids infused i.v., particularly in view of sympathetic overflow causing peripheral vasocstriction. The increasing venous pulsatility and unaltered peak velocity could be viewed as haemodynamic alterations counteracting the decreasing venous flow.

Venodilatation, reported during GA for total hip replacement exceeding 3 h duration, and its magnitude have been linked with the perioperative development of DVT. Venous dilatation was not significant in the current study, although a 14% decrease in the popliteal vein diameter [mean] was noted in recovery, exceeding the reproducibility of our measurements reported at 1.4–4.9% in the horizontal position.\textsuperscript{5} This is probably attributable to the lack of consistency in the diameter changes recorded and the relatively brief operative time in the current study (median 80 min), which involved only otherwise healthy subjects.

In conclusion, elective total abdominal hysterectomy under GA in females ASA I or II was associated with a marked decrease in the volume flow, and the mean and minimum velocities of the proximal venous circulation of the leg during surgery, but not after induction of anaesthesia, with a further decrease in recovery. An increase in venous pulsatility, reflecting a higher pulsatility of venous flow and outflow resistance, was noted during surgery, rising further on recovery. These findings suggest that, in response to venous flow reduction, haemodynamic alterations may occur enhancing flow pulsatility. In the absence of venous flow changes after GA induction, before the onset of surgery, the occurrence of maximal haemodynamic attenuation at the phase of early recovery points more at the surgical insult as a cause rather than the implementation of GA.

References