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The effect of increased hip flexion using stirrups on lower extremity venous flow: a prospective observational study

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Abstract

Background—Patient positioning during operations for colorectal cancer may represent an unrecognized risk factor for deep venous thrombosis.

Methods—Twelve healthy control patients were positioned supine with knee flexion at 90°. Duplex ultrasound examined common femoral vein (CFV) and proximal femoral vein (PFV) diameter, peak systolic velocity, and volume-flow with hip flexion at 0°, 30°, 60°, and 90°. Data were analyzed using the paired t-test.

Results—In the CFV, hip flexion to 90° was associated with significant increase in mean volume-flow when compared to hip flexion at 0° (0.59 L/min vs. 0.36 L/min, $p=0.05$) and 30° (0.59 L/min vs. 0.35 L/min, $p=0.038$). In both the CFV and PFV, increased hip flexion was associated with significantly reduced vessel diameter and increased peak systolic velocity.

Conclusions—Intra-operative positioning of the lower extremities represents a modifiable risk factor for deep venous thrombosis. When stirrups are used, hip flexion of 90° maximizes venous drainage from the legs.

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Keywords

Venous stasis; operative positioning; deep venous thrombosis; venous thromboembolism; colorectal cancer; stirrup

Introduction

Venous thromboembolism (VTE) is a disorder with short-term mortality and long-term morbidity^{1,2}. Risk-adjusted models have shown that VTE is a significant predictor of death in colorectal cancer patients. 52% of colorectal cancer patients who develop VTE will die within two years, compared to 35% of those who do not develop VTE³. Patients who present for colorectal cancer surgery have inherent risk factors for VTE including age, obesity, malignancy-associated hypercoagulability, and need for surgery under general anesthesia⁴⁻⁶. These inherent risk factors often cannot be modified prior to surgery.

Venous stasis is a recognized risk factor for deep venous thrombosis (DVT). Several intra- and post-operative factors are known to affect lower extremity venous flow and are potentially modifiable. For example, induction of pneumoperitoneum, as commonly performed for laparoscopic surgery, significantly increases intra-abdominal pressure. This results in lower extremity venous stasis, venous dilation, and intimal microtears in the vein wall, which are all recognized DVT risk factors⁷⁻¹¹. Similarly, post-operative compression garments and abdominal wall binders are known to impede lower extremity venous drainage¹².

Patient positioning is a potential risk factor for DVT which can easily be modified. The American College of Chest Physicians VTE prophylaxis guidelines note that the reverse Trendelenberg position is associated with lower extremity venous stasis⁶. VTE prophylaxis guidelines in plastic surgery^{13,14} recommend knee flexion at 5 degrees to maximize flow through the popliteal vein. Additionally, studies in total hip arthroplasty (THA) patients demonstrate that intra-operative manipulation of the lower extremity, including flexion, adduction, and internal rotation at the hip, can kink and occlude the femoral vein¹⁵⁻¹⁷.

Intra-operative positioning using stirrups, as is commonly performed for colorectal cancer surgery, routinely flexes and abducts the hip, which could impede or obstruct lower extremity venous drainage. We hypothesize that 1) increased hip flexion may narrow or occlude the femoral vein and, as a result, 2) hip flexion may impede lower extremity venous drainage, causing venous stasis. Thus, operative positioning using stirrups may represent an unrecognized, easily modifiable risk factor for lower extremity DVT after colorectal cancer surgery. To examine our hypotheses, we performed a prospective, observational study to examine the effect of increasing hip flexion on femoral vein diameter, peak systolic velocity, and volume-flow in a group of healthy control patients.

Methods

This study was approved by the University of Michigan Institutional Review Board. All patients signed informed consent prior to participation.

Healthy control patients with minor hand lacerations, fractures, or infections were recruited from the University of Michigan plastic surgery clinic. Study inclusion criteria included male gender, age 20–50, and the ability to provide informed consent. Obesity has been shown to significantly alter common femoral vein (CFV) diameter and peak systolic velocity¹⁸ in addition to making studies technically difficult. Thus, patients with body mass

index ≥ 35 were excluded. Patients who were scheduled for surgery under general anesthesia, or who had general anesthesia within the past two months, were excluded. All patients received a physical examination to rule out clinical evidence of venous insufficiency, such as lower extremity edema, varicosities, or hemosiderin deposits. We also excluded any patient with a history of lower extremity varicosities, edema, lymphedema, amputation, significant trauma, or prior surgical intervention which could impede lower extremity venous drainage. Finally, patients with prior major abdominal surgery or a personal or family history of VTE were excluded.

Duplex ultrasound measurements for all enrolled patients were performed by the same two registered vascular technologists (SMS and SLB) using the Antares ultrasound system (Siemens, Mountain View, CA). All studies were interpreted by a board-certified vascular surgeon. Positions in which measurements were taken are summarized in Table I. A pictorial representation of these positions is shown in Figure 1.

Patients were laid supine on the operating room table for baseline analyses. A supine lower extremity duplex ultrasound demonstrated absence of DVT prior to the study protocol being initiated. The legs were then placed in Yellofin stirrups (Allen Medical Systems, Acton, MA). Measurements for the CFV were obtained immediately distal to the inguinal ligament in all patients. The proximal femoral vein (PFV) was identified as just distal to the bifurcation of the CFV into the femoral and profunda veins and measurements were taken within 1 cm of this location.

Baseline analysis of the patient's CFV and PFV cross-sectional diameter, peak systolic velocity, and volume-flow were obtained with the knee in 90° of flexion and the hip abducted to 20° . The hip was then flexed to 30° while knee flexion and hip abduction remained unchanged. CFV and PFV measurements as above were then repeated. This sequence was repeated with the hip in 60° and 90° of flexion while keeping knee flexion and hip abduction stable. After each change in hip flexion, the patient was left in position for five minutes to allow for equilibration before additional measurements were taken. The range of hip flexion (0° to 90°) was chosen as it reflects the positions most commonly used during an operation. Bilateral CFV and PFV measurements were obtained.

Prior work has demonstrated that left common iliac vein compression is a common anatomic variant among asymptomatic women (41% compared to the contralateral side)¹⁹. A two-tailed t-test was used to compare baseline measurements for mean vessel diameter, mean peak systolic velocity, and mean volume-flow for the right vs. left CFV and right vs. left PFV prior to pooling data for right and left sides.

Data analysis was performed using the Stata11 statistical package (StataCorp LP, College Station, TX). All measured variables, including vessel diameter, peak systolic velocity, and volume-flow, are continuous and were measured in the same patient. The paired t-test (two-tailed) was used to examine changes in CFV and PFV diameter, peak systolic velocity, and volume-flow in response to graded increase in hip flexion. A p value of ≤ 0.05 was considered significant.

Results

Twelve healthy controls who met inclusion criteria were recruited. Mean age was 32 and mean BMI was 27.6. All patients were male. No patient demonstrated clinical evidence of venous insufficiency, such as lower extremity edema, varicosities, or hemosiderin deposits. No patient had an asymptomatic DVT demonstrated by duplex ultrasound.

No significant differences were present among baseline measurement for mean vessel diameter, mean peak systolic velocity, or mean volume-flow for the right vs. left CFV or right vs. left PFV. Data were pooled and analyzed as a group of 24 limbs.

In the CFV, hip flexion to 90° was associated with significant increase in mean volume-flow when compared to hip flexion at 0° (0.59 L/min vs. 0.36 L/min, $p=0.05$) and 30° (0.59 L/min vs. 0.35 L/min, $p=0.038$). Similar trends were seen in the PFV, although the differences were not significant. Of note, PFV measurements showed high inter-subject variability, as indicated by large standard deviations around the mean (Table II).

Mean vessel diameter in the CFV was higher with hip flexion of 30° vs. 0° (1.24cm vs. 1.17cm, $p=0.121$) and 60° vs. 0° (1.24cm vs. 1.17cm, $p=0.236$). These differences were not statistically significant. CFV measurements showed that hip flexion to 90° was associated with significant decrease in mean vessel diameter when compared to hip flexion at 30° (1.11cm vs. 1.24cm, $p=0.002$) and 60° (1.11cm vs. 1.24cm, $p=0.005$) (Table III). An inverse relationship was demonstrated between mean vessel diameter and mean peak systolic velocity. In both the CFV and PFV, significant reduction in mean vessel diameter was associated with significant increase in mean peak systolic velocity (Table IV).

Discussion

The principles of venous hemodynamics, the Bernoulli equation, and the Poiseuille equation have been described elsewhere^{20, 21} and are central to understanding our results. Bernoulli's equation considers the two potential sources of pressure on fluid: those relating to change in velocity and those related to the action of gravity (weight of the fluid column). The venous system is low-velocity. As a result, pressure differences, not kinetic energy, drive the majority of flow. Our data demonstrate that increased hip flexion causes a decrease in CFV diameter and concomitant increased peak systolic velocity. With increased hip flexion, the focal constriction should decrease the pressure gradient along the vein and create venous stasis. However, despite the focal venous constriction, volume-flow was significantly increased. Thus, the increased fluid column weight (increased hydrostatic pressure) from hip flexion appears to overcome the focal venous constriction with a resultant augmentation in volume-flow (Figure 2).

Prior to undertaking this study, our null hypotheses were that 1) increased hip flexion will not decrease CFV or PFV diameter and 2) increased hip flexion will not alter lower extremity drainage. Our data demonstrate that increased hip flexion is associated with significantly decreased CFV and PFV diameter. Our data also show that increased hip flexion is associated with significant increase in CFV volume-flow. The findings of this study refute both of our null hypotheses. In our study, the optimal hip position to maximize lower extremity venous drainage, measured by mean volume-flow, was 90° of hip flexion.

Previous studies have examined the effect of intra-operative factors on lower extremity venous hemodynamics. Studies in general surgery patients have demonstrated that abdominal insufflation with resultant increase in intra-abdominal pressure can impede lower extremity venous drainage and cause vein wall damage⁷⁻¹¹. Additionally, insertion of a hip prosthesis, which requires flexion, adduction, and internal rotation of the distal femur segment, can kink the femoral vein¹⁵⁻¹⁷. Although these maneuvers may increase risk for DVT, they are also essential if the operation is to be appropriately performed. In stark contrast, hip position is not a mandated or standardized portion of colorectal cancer operations. Hip position thus represents a modifiable risk factor for VTE in the colorectal cancer population. Our study provides objective evidence to support that when stirrups are

required, the hips should be placed in 90° of flexion to maximize venous outflow from the lower extremities.

Venous thromboembolism has been identified as a major patient safety issue by physicians, policymakers, and third-party payers^{22–25}. The Surgical Care Improvement Project (SCIP), a national partnership whose goal is to improve the quality of surgical care through reduction in post-operative complications, has identified VTE prevention as a measure of quality care²⁶. The Centers for Medicare and Medicaid Services (CMS) has considered all VTE events for addition to their list of “never events”: those post-operative complications deemed potentially preventable for which CMS will not pay if acquired in-hospital. At present, only VTE after major orthopaedic procedures are considered a “never event”²⁷.

Colorectal surgery patients are known to be at disproportionately increased risk for VTE^{4, 28, 29}. At baseline, patients with colorectal cancer have multiple intrinsic risk factors for VTE, including increased age, obesity, malignancy-associated hypercoagulability, and multiple medical comorbidities. Length of operation is believed to independently increase VTE risk^{5, 6, 29, 30}. Those patients with complicated post-operative courses may develop additional, in-hospital risk factors, which include central venous catheter placement, multiple operations, myocardial infarction, or sepsis^{5, 6}.

Multiple randomized controlled trials have shown that extended-duration low-molecular weight heparin (LMWH) can prevent VTE after abdominal and pelvic cancer surgery^{31–34}. However, even with appropriate provision of extended-duration LMWH, the incidence of post-operative symptomatic and asymptomatic VTE is approximately 5%. VTE may never be totally eradicated, even when appropriate prophylaxis is provided³⁵. A non-zero rate of VTE when best-practice prophylaxis is rigorously provided indicates that room for improvement still exists. Optimization of patient positioning during an operation may help to further decrease observed rates of VTE.

Limitations

Increased hydrostatic pressure may be the driving force by which external CFV compression is overcome. However, the observed decrease in CFV diameter seen with increased hip flexion may also be explained by increased hydrostatic pressure (and thus increased venous outflow) alone. Thus, the observed decrease in vessel diameter might be secondary to decreased venous pooling in the extremity and not to external compression. Although the end result is clear, the complete mechanism by which increased hip flexion augments lower extremity venous outflow remains unclear, based on this study.

Operating room availability, as well as patient and staff availability, required that each patient examination be limited to 90 minutes. Thus, our protocol allowed for five minutes of equilibration time after each positional change. This time period may have been insufficient to demonstrate the true extent of venous congestion, if present, especially as colorectal cancer operations commonly last several hours. Additionally, both elastic compression stockings and sequential compression devices (SCDs) are commonly used as non-pharmacologic methods of VTE prophylaxis. Future studies could utilize a similar protocol to ours to examine how use of stockings or SCDs may affect lower extremity venous drainage with the legs in stirrups. We have provided means and standard deviations for all measurements in Tables II, III, and IV to assist others with sample size calculations for future studies.

Patients with obesity have been shown to have abnormal venous hemodynamics¹⁸, and obesity is a recognized risk factor for VTE. Thus, obese patients were excluded from this study. Further work should examine the applicability of our findings to the obese population.

Conclusion

Intra-operative positioning of the lower extremities represents a modifiable risk factor for DVT. When stirrups are used, hip flexion of 90° maximizes venous drainage from the legs. Future work should examine the effect of compression stockings and/or sequential compression devices on these findings.

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Figure 1.
Positions in which study measurements were obtained.

Figure 2.
Proposed mechanism for increased lower extremity venous drainage with increased hip flexion.

Table I

Summary of measurements performed in each position.

	Hip flexion	Hip abduction	Knee flexion	Measurements
Baseline	0°	20°	0°	Bilateral lower extremity duplex ultrasound
Baseline	0°	20°	90°	Bilateral CFV and PFV diameter, peak systolic velocity, volume-flow
Variant 1	30°	20°	90°	Bilateral CFV and PFV diameter, peak systolic velocity, volume-flow
Variant 2	60°	20°	90°	Bilateral CFV and PFV diameter, peak systolic velocity, volume-flow
Variant 3	90°	20°	90°	Bilateral CFV and PFV diameter, peak systolic velocity, volume-flow

Table II

Comparison of volume-flow at varying degrees of hip flexion.

Degree of hip flexion	Mean $\pm$ SD, L/min	p value
Common femoral vein		
0° vs. 30°	0.37 $\pm$ 0.16 vs. 0.39 $\pm$ 0.25	0.75
0° vs. 60°	0.37 $\pm$ 0.16 vs. 0.46 $\pm$ 0.23	0.147
0° vs. 90°	0.36 $\pm$ 0.15 vs. 0.59 $\pm$ 0.51	0.05
30° vs. 60°	0.39 $\pm$ 0.25 vs. 0.46 $\pm$ 0.23	0.278
30° vs. 90°	0.35 $\pm$ 0.15 vs. 0.59 $\pm$ 0.51	0.038
60° vs. 90°	0.46 $\pm$ 0.23 vs. 0.59 $\pm$ 0.51	0.238
Proximal femoral vein		
0° vs. 30°	0.18 $\pm$ 0.14 vs. 0.21 $\pm$ 0.21	0.498
0° vs. 60°	0.18 $\pm$ 0.14 vs. 0.25 $\pm$ 0.32	0.248
0° vs. 90°	0.18 $\pm$ 0.14 vs. 0.30 $\pm$ 0.32	0.094
30° vs. 60°	0.21 $\pm$ 0.21 vs. 0.25 $\pm$ 0.32	0.405
30° vs. 90°	0.21 $\pm$ 0.21 vs. 0.30 $\pm$ 0.32	0.179
60° vs. 90°	0.25 $\pm$ 0.32 vs. 0.30 $\pm$ 0.32	0.40

Table III

Comparison of vessel diameters at varying degrees of hip flexion.

Degree of hip flexion	Mean $\pm$ SD, cm	p value
Common femoral vein		
0° vs. 30°	1.17 $\pm$ 0.22 vs. 1.24 $\pm$ 0.20	0.121
0° vs. 60°	1.17 $\pm$ 0.22 vs. 1.24 $\pm$ 0.28	0.236
0° vs. 90°	1.17 $\pm$ 0.22 vs. 1.11 $\pm$ 0.28	0.267
30° vs. 60°	1.24 $\pm$ 0.20 vs. 1.24 $\pm$ 0.28	0.938
30° vs. 90°	1.24 $\pm$ 0.20 vs. 1.11 $\pm$ 0.28	0.002
60° vs. 90°	1.24 $\pm$ 0.28 vs. 1.11 $\pm$ 0.28	0.005
Proximal femoral vein		
0° vs. 30°	0.75 $\pm$ 0.17 vs. 0.78 $\pm$ 0.17	0.487
0° vs. 60°	0.75 $\pm$ 0.17 vs. 0.67 $\pm$ 0.18	0.015
0° vs. 90°	0.75 $\pm$ 0.17 vs. 0.63 $\pm$ 0.18	0.002
30° vs. 60°	0.78 $\pm$ 0.17 vs. 0.67 $\pm$ 0.18	0.008
30° vs. 90°	0.78 $\pm$ 0.17 vs. 0.63 $\pm$ 0.18	<0.001
60° vs. 90°	0.67 $\pm$ 0.18 vs. 0.63 $\pm$ 0.18	0.220

Table IV

Comparison of peak systolic velocity at varying degrees of hip flexion.

Degree of hip flexion	Mean $\pm$ SD, cm/sec	p value
Common femoral vein		
0° vs. 30°	25.4 $\pm$ 15.7 vs. 23.3 $\pm$ 12.6	0.132
0° vs. 60°	25.4 $\pm$ 15.7 vs. 24.4 $\pm$ 12.6	0.657
0° vs. 90°	24.8 $\pm$ 15.9 vs. 38.4 $\pm$ 22.2	<0.001
30° vs. 60°	23.3 $\pm$ 12.6 vs. 24.4 $\pm$ 12.6	0.487
30° vs. 90°	22.6 $\pm$ 12.3 vs. 38.4 $\pm$ 22.2	<0.001
60° vs. 90°	24.1 $\pm$ 12.8 vs. 38.4 $\pm$ 22.2	<0.001
Proximal femoral vein		
0° vs. 30°	17.8 $\pm$ 10.3 vs. 18.0 $\pm$ 10.6	0.876
0° vs. 60°	17.8 $\pm$ 10.3 vs. 23.5 $\pm$ 14.6	0.035
0° vs. 90°	17.8 $\pm$ 10.3 vs. 25.6 $\pm$ 17.1	0.028
30° vs. 60°	18.0 $\pm$ 10.6 vs. 23.5 $\pm$ 14.6	0.061
30° vs. 90°	18.0 $\pm$ 10.6 vs. 25.6 $\pm$ 17.1	0.037
60° vs. 90°	23.5 $\pm$ 14.6 vs. 25.6 $\pm$ 17.1	0.471