Title: The REBOA window – a cadaveric study delineating the optimum site for austere cannulation of the femoral artery for resuscitative endovascular balloon occlusion of the aorta.

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Key words: REBOA, arterial access, common femoral artery, profunda femoris, pre-hospital care

Original research: The REBOA window – a cadaveric study delineating the optimum site for austere cannulation of the femoral artery for resuscitative endovascular balloon occlusion of the aorta.

Abstract:

Introduction: Haemorrhage is the major cause of early mortality following traumatic injury. Patients suffering non-compressible torso haemorrhage (NCTH) are more likely to suffer early death. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) can be effective in initial resuscitation, however establishing swift arterial access is challenging, particularly in a severe shock. This is made more difficult by anatomical variability of the femoral vessels.

Methods: The femoral vessels were characterised in 81 cadaveric lower limbs, measuring specifically the distance from the inferior border of the inguinal ligament to the distal part of the origin of the profunda femoris artery, and from the distal part of the origin of the profunda femoris artery to where the femoral vein lies posterior to and is completely overlapped by the femoral artery.

Results: The femoral vein lay deep to the femoral artery at a mean distance of 105mm from the inferior border of the inguinal ligament. The profunda femoris artery arose from the femoral artery at a mean distance of 51.1mm from the inguinal ligament. From the results it is predicted that the profunda femoris artery originates from the common femoral artery approximately 24mm from the inguinal ligament, and the femoral vein is completely overlapped by the femoral artery by 67.7mm distal from the inguinal ligament, in 95% of subjects.

Conclusions: Based on the results proposed is an ‘optimal access window’ of up to 24mm inferior to the inguinal ligament for common femoral arterial catheterisation for pre-hospital REBOA, or more simply within one finger breadth.

Key words: REBOA, arterial access, common femoral artery, profunda femoris, pre-hospital care

Key points:

1) There is considerable variation in the configuration of the femoral vessels, which can complicate emergency cauterisation of the common femoral artery for REBOA.

2) Particularly in austere conditions where ultrasound is not as reliable, or where there is no femoral pulse, use of anatomical landmarks may be better.

3) The safe area for catheterisation of the femoral artery, without injury to the femoral vein or profunda femoris artery, is 24mm inferior to the inguinal ligament.

4) Practically speaking this equates to within one finger breadth from the inguinal ligament, this teaching could be incorporated into REBOA courses.

Main paper:

Introduction

Haemorrhage is a major cause of mortality following traumatic injury in both the civilian and military setting.[1,2] Haemorrhage from an injured limb can usually be controlled through the use of a combination of therapies such as direct pressure, application of a tourniquet, or use of a haemostatic dressing. These interventions provide a window of opportunity during which definitive surgical treatment can be arranged. However, haemorrhagic torso injuries continue to pose a challenge, particularly on the battlefield where such injuries constitute the leading cause of mortality, as well as in the civilian context whereby nearly fifty percent of such patients die prior to arrival to the Emergency Department.[3,4]

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) has been shown to be effective in the initial resuscitative management of non-compressible torso haemorrhage (NCTH) and yields favourable outcomes when compared to resuscitative thoracotomy.[5] The aim of REBOA is to restore aortic blood pressure by temporary balloon occlusion of the descending aorta using an endovascular approach through the femoral artery.[6] Having shown promise with animal models of NCTH the evidence of favourable outcomes in humans at present is mostly derived from trauma centres with access to significant endovascular expertise and radiological guidance.[7-9] The need to reduce mortality for those that suffer life-threatening NCTH and do not survive the pre-hospital phase remains unmet. However, the evidence that REBOA can be applied safely and efficaciously in the pre-hospital setting is emerging.[10,11]

In the context of the austere battlefield, the problem of establishing adequate percutaneous access to the common femoral artery for deployment of the REBOA technique is an additional challenge, further hampered by a lack of imaging guidance such as ultrasound. The challenges of gaining rapid, large-bore arterial access are compounded by the variability of the femoral vessels, in terms of the arrangement of the artery and vein, and the origins of the inferior epigastric and profunda femoris arteries.[12,13] These anatomical variations would generally require image guidance to be performed in order to reduce the likelihood of causing significant vascular complications.[14,15] Knowledge of the optimum location for femoral puncture, as well as the anatomical relationship between the femoral artery and vein is essential. The potential complications from sub-optimal catheterisation include femoral or retroperitoneal bleeding, distal embolism, haematoma, pseudoaneurysm or arteriovenous fistula formation all carry significant morbidity.[16-18] Additionally, the need to gain swift access is a primary concern; any time delay in REBOA delivery in an exsanguinating patient due to an unsuccessful access attempt might adversely impact upon survival.[19] A better anatomical understanding might reduce these delays and contribute to more rapid, safe and effective delivery of REBOA.

The purpose of this anatomical study is to better characterise the variability of the femoral vessels in cadaveric specimens with a view to defining an 'optimum access window' for femoral arterial catheterisation that can be used safely and effectively within the setting of REBOA in the austere pre-hospital environment.

Methods

Eighty-one embalmed cadavers were examined, comprising forty-one females and forty males. All subjects were white Caucasian. The average age of death was 84.8 (range 63 – 100). In accordance with the Human Tissue Act (2004), all donors had expressed consent for anatomical research prior to their bereavement.

For each subject, the right leg was examined. The anterior compartment of the thigh was opened via a single midline skin incision, and the fasciae lata removed to expose the femoral triangle. The femoral sheath was opened to expose the femoral vessels. Measurements were taken as follows (figure 1): (A) the distance from the inferior border of the inguinal ligament to the distal part of the origin of the profunda femoris artery (PFA); (B) the distal part of the origin of the PFA to where the femoral vein lies posteriorly to and is completely overlapped by the femoral artery (B). The distance from the inferior border of the inguinal ligament to the point of complete overlap of the femoral vein by the femoral artery was calculated as the sum of these two measurements (A+B). The data was tested for normality using the Shapiro-Wilk normality test on R. The means, standard deviations, minimum and maximum values were calculated using R. Means were compared between male and female subjects using Students' t-testing, and any anatomical variations were noted.

Results

Examination of the eighty-one subjects revealed that the femoral vein lay medial to the femoral artery in all cases. At a mean distance of 105mm (SD=22.7mm, min=33mm, max=178mm) from the inferior border of the inguinal ligament, the femoral vein lay deep to the femoral artery (figure 2). In 7.4% of cases (n=6) the femoral vein and artery were entirely parallel throughout the femoral triangle. The profunda femoris artery (PFA) arose from the femoral artery at a mean distance of 51.1mm (SD=16.5mm, min=10mm, max=94mm) from the inguinal ligament (figure 3). There were no significant differences observed between male and female subjects, with regard to the distance from the inguinal ligament to the origin of the PFA ($p = 0.51$), or to the point at which the femoral vein lay deep to the femoral artery ($p = 0.83$). In one case, two PFAs arose from the femoral artery (figure 4). In another case, the PFA arose directly from the external iliac artery and ran parallel to the femoral artery below the inguinal ligament (figure 5).

Using the Shapiro-Wilk normality test it is evident that the data collected is normally distributed for both the distance from the inguinal ligament to complete overlap of the femoral vein ($W = 0.992$, $p = 0.912$) and the total distance from the inguinal ligament to the origin of the profunda femoris artery ($W = 0.985$, $p = 0.524$). Thus, with the given data set it is predicted that the profunda femoris artery originates from the common femoral artery at approximately 24mm from the inguinal ligament in 95% of subjects, and that the femoral vein is completely overlapped by the femoral artery by 67.7mm distally from the inguinal ligament in 95% of subjects.

Discussion

The present study confirms the typical arrangement of the femoral artery and vein in the majority of cases, but variability was found with regard to the course of the femoral vein in relation to the artery, and the distance from the inguinal ligament from which the profunda femoris artery originates from the common femoral artery. Despite this variability however, an ‘optimum access window’ is proposed—up to 24mm inferior to the mid-inguinal point. This window would also be safe for the two more variant cases seen in figure 4 and figure 5. This should help ensure successful catheterisation of the common femoral artery whilst avoiding accidental injury to the profunda femoris artery, or potential arteriovenous fistula formation by inadvertent puncture of the femoral vein.

The findings are comparable with the current literature. A recent meta-analysis of cadaveric and radiographical studies characterising the profundal femoris artery found that in 282 lower limbs, its pooled mean distance from the mid-inguinal point was approximately 41.2mm (95% CI 32.4—53.7).[13] The variability of the vessels in terms of overlap is less well characterised, however existing studies confirm the tendency of the artery to overlap the vein as the vessels progress distally from the inguinal ligament, and that optimum access to the individual femoral vessels is best achieved more proximally, towards the inguinal ligament.[20-22]

Ultrasound-guided cannulation is superior in terms of accuracy and the prevention of complications, and implementation of an ultrasound-guided approach for femoral arterial cannulation is preferable where resources permit. Active point-of-care ultrasound systems are already in use in the pre-hospital environment in the context of focused assessment with sonography for trauma (FAST), the detection of traumatic pneumothorax, and, more recently, by the London Air Ambulance for common femoral arterial cannulation in REBOA.[23-25] However, there remains a need for a safe and effective method of ‘blind’ cannulation, especially in the context of the austere pre-hospital environment and in a military context at Role 2 treatment facilities; particularly as a bridge to damage control surgery where the patient is peri-arrest, surgery is likely to be delayed, or where a single operating table is occupied by another case.[15,26] Recently published data from the American Association for the Surgery of Trauma registry demonstrated that an anatomy-based approach was being used in 78.3% of recorded REBOA cases (50% with a traditional open ‘cut-down’ approach, and 28.3% with a blind percutaneous approach).[17] Furthermore, a recently published case series reporting on the use of REBOA by the London Air Ambulance in the pre-hospital setting with ultrasound guidance highlighted a failure rate of 32%, with failure to visualise the common femoral artery on ultrasound as the reason for failure in all cases.[25] There is, therefore, a need to refine the anatomical approach to the common femoral artery, either as a means to improve the accuracy of the blind approach or to enhance the initial element of an ultrasound-guided approach.

Several methods to gain access to the common femoral artery without imaging guidance have been described in the literature. The use of the inguinal crease is one such method, but there exists a variable relationship between the cutaneous crease and the underlying inguinal ligament and is therefore unreliable as a method.[27] Detection of the strongest femoral pulse by manual palpation—described to be accurate in a significant majority of patients is less useful in a patient who is peripherally vasoconstricted due to haemorrhagic shock, as likely in the setting of NCTH.[28] A shocked patient is likely to have impalpable femoral pulses which makes establishing common femoral arterial access difficult.[29] This is reflected in a recent large-scale study by DuBose et al.[17] comparing outcomes between open and endovascular aortic occlusion in trauma, whereby endovascular access was achieved via the traditional 'cut-down' method in fifty percent of cases. The cut-down method allows for complete visualisation of the femoral vessels, but takes longer and is associated with groin wound complications as seen following endovascular aortic aneurysm repair, the percutaneous approach for endovascular access is now favoured in most cases.[30-31]

This study is limited by the use of cadaveric specimens which assume a 'fixed' anatomical position after embalming and were free from trauma that would have otherwise distorted the anatomy. It is conceivable that within the context of multisystem trauma whereby injuries are sustained to the trunk and lower limbs simultaneously, a blind landmark-based technique such as the one proposed may be less effective. Additionally, it is acknowledged that whilst the average age of the cadaveric donors was 85 years of age, the average age of military personnel tends to be much lower, and the majority of major trauma patients in the civilian context are under forty years of age. This may have implications on the applicability of the data presented here.

Conclusions

REBOA can achieve aortic occlusion faster than with traditional open thoracotomy once access is obtained, but the 'rate-limiting' step is common femoral arterial access.[32] This study is therefore useful for clinicians who require a quick and reliable method of knowing where to expect to find the common femoral artery for safe and effective REBOA, particularly in the pre-hospital setting where access to imaging is likely to be limited. It is hoped that knowledge of the optimum access site, and variations in the anatomy of the common femoral artery and its branches, can assist with the successful implementation of REBOA in the pre-hospital setting and on the design of emerging formal vascular access training programmes for REBOA.[33] Professionals involved in the deployment of REBOA in austere conditions that are less accustomed to groin puncture in their routine practice, in particular, will require specialised training on its use. This study demonstrates that they should be instructed to attempt access to the common femoral artery 24mm inferior to the inguinal ligament, which more simply equates to within one finger breadth.

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Figure legends:

Figure 1: Measurements taken in the femoral triangle.

Figure 2: Distance from inguinal ligament to complete overlap of femoral vein.

Figure 3: Distance from inguinal ligament to profunda femoris artery.

Figure 4: Cadaveric dissection showing a double Profunda Femoris Artery (PFA), Femoral Artery (FA), Femoral Vein (FV).

Figure 5: Cadaveric dissection showing a high division of Profunda Femoris Artery (PFA) arising from the external iliac artery lateral to the Femoral Artery (FA), Femoral Vein (FV).