ORIGINAL COMMUNICATION

Arterial anatomy of the anterior abdominal wall: Ultrasound evaluation as a real-time guide to percutaneous instrumentation

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Abstract

Introduction: Instrumenting the anterior abdominal wall carries a potential for vascular trauma. We previously assessed the presence, position, and size of the anterior abdominal wall superior and inferior (deep) epigastric arteries with computed tomography (CT). We now present a study using ultrasound (US) assessment of these arteries, to evaluate its use for real time guidance of percutaneous procedures involving the rectus sheath.

Materials and Methods: Twenty-four participants (mean age 67.9 ± 9 years, 15 M:9 F [62:38%]) were assessed with US at three axial planes on the anterior abdominal wall: transpyloric plane (TPP), umbilicus, and anterior superior iliac spine (ASIS).

Results: An artery was visible least frequently at the TPP (62.5 – 45.8%), compared with the umbilicus (95.8–100%) and ASIS (100%), on the left, $\chi^2(2) = 20.571$; $p < .001$, and right, $\chi^2(2) = 27.842$; $p < .001$, with a moderate strength association (Cramer's V = 0.535 [left] and 0.622 [right]). Arteries were most commonly observed within the rectus abdominis muscle at the level of the TPP and umbilicus, but posterior to the muscle at the level of the ASIS (95.8–100%). As with the CT study, the inferior epigastric artery was observed to be larger in diameter, start more laterally, and move medially as it coursed superiorly.

Conclusions: These data corroborate our previous results and suggest that the safest level to instrument the rectus sheath (with respect to vascular anatomy) is at the TPP. Such information may be particularly relevant to anesthetists performing rectus sheath block and surgeons during laparoscopic port insertion.

KEYWORDS
anatomical variation, complications, epigastric artery, rectus sheath block, ultrasound

1 | INTRODUCTION

The anterior abdominal wall is widely instrumented in modern medical practice. It is the gateway to the abdomen for a large proportion of open abdominal surgeries: almost 30,000 patients underwent emergency laparotomy in England and Wales during 2018 alone (NELA Project Team, 2018). Other intervention includes laparoscopic abdominopelvic surgery, as well as plastic, and reconstructive breast surgery. The latter uses blood vessels of this region for deep inferior epigastric perforator flap breast reconstruction after mastectomy (Molina, Jones, Hazari, Francis, & Nduka, 2012). Therefore, knowledge of the vessel position and relations is of importance in this field, as it also is for general and gynecological surgeons to avoid vascular trauma during port site insertion or other invasive procedures of the anterior abdominal wall.

Effective anesthesia includes the management of postoperative pain. In open abdominal surgery, the laparotomy wound itself is a significant source of pain (Toro, John, & Faruqui, 2018). At present, there is a concern regarding the rate of opioid prescription in the United States, which has risen in line with opioid-related deaths (Nobel, Zaveri, Khetan, & Divino, 2019). Local anesthetic-based techniques can mitigate postoperative opioid requirement and related side effects (Rucklidge & Beattie, 2018). Rectus sheath block (RSB) involves needle insertion (and local anesthetic deposition) in the rectus sheath and may be used as part of a multimodal analgesic strategy following laparotomy while avoiding some of the side effects associated with epidural analgesia (Rucklidge & Beattie, 2018). However, RSB is not without complications (Rucklidge & Beattie, 2018; Yarwood & Berrill, 2010). Rectus sheath block and other percutaneous instrumentation of the anterior abdominal wall have resulted in damage to the epigastric arteries, leading to bleeding, rectus sheath hematoma, and arterial pseudoaneurysm (Kawamura, Piemonte, Nesto, & Gossman, 2006; Ko, Choi, Malhotra, & Lee, 2010; Procacciante, Diamantini, Paolelli, & Picozzi, 2009; Splinter & Cook, 2012; Standring, 2008; Yuen & Ng, 2004). As continuous RSB is considered particularly suitable in patients taking antiplatelet agents or anticoagulants, and those with coagulopathy (Rucklidge & Beattie, 2018), avoiding such complications is important. Knowledge of the topography and variation of these vessels is therefore relevant to anesthetists, who typically use ultrasound (US) to guide needle insertion and catheter placement (Rucklidge & Beattie, 2018). This information is also important to surgeons, who may perform the technique under "direct-vision" prior to closing the abdomen: Despite the nomenclature, this technique does not provide good visualization of the blood vessels; therefore, awareness of their likely pattern/presence is particularly important.

Major anatomy texts often describe the anterior abdominal wall vascular supply without detailed comment on the anatomical variation (Moore, Dalley, & Agur, 2017; Sinnatamby, 2011; Standring, 2008). We have previously assessed the topography of the superior and inferior epigastric arteries on computed tomography (CT), with reference to RSB, at readily determined locations in clinical practice (Bowness et al., 2019). These results suggest that the safest level at which RSB could be performed, with reference to vascular trauma, is at the transpyloric plane (TPP; midway between the xiphisternum and umbilicus). The vessels were found here least frequently and were smaller in caliber. However, it is not known whether these results translate into vessels that can be seen (and therefore avoided) using real-time US imaging.

The present study therefore evaluated the deep epigastric vessels with US at the same three axial levels: the TPP, the umbilicus, and the anterior superior iliac spine (ASIS). The primary aims were to determine.

- Is an artery visible on US at the given axial levels.
- What is the coronal relationship of the blood vessel(s) to rectus abdominis (RA).
- What is the sagittal relationship of the blood vessel(s) to RA.

A secondary aim of this study was to assess the size of the blood vessel(s) visualized. An additional aim was to determine whether US data supported the understanding, drawn from CT images (Bowness et al., 2019), that the TPP is the safest axial level at which to perform RSB (with respect to vascular trauma).

2 | MATERIALS AND METHODS

2.1 | Ethical approval

Ethical approval for this study was provided by the university of St Andrews, school of medicine, ethics committee (MD14327).

2.2 | Participant recruitment (including inclusion/exclusion criteria)

Twenty-four participants were recruited from the University of St Andrews, School of Medicine, simulated patient pool. This allowed the subjects to be matched, for mean age and sex, with the previous CT study population (Bowness et al., 2019). The exclusion criteria comprised:

- Any possibility of pregnancy,
- Inability to lie supine for 30 min,
- Known peripheral vascular disease.

2.3 | Ultrasound assessment

Initially, all participants were measured for height and weight, and their body mass index (BMI) was calculated. The abdomen was then exposed, from xiphisternum to symphysis pubis, and a transverse line was marked across the anterior abdominal wall at each level (TPP, umbilicus, ASIS). To do this, the ASIS was palpated and marked on both sides, and then a straight line was drawn between them along the border of a tape measure. In the midline, the distance between
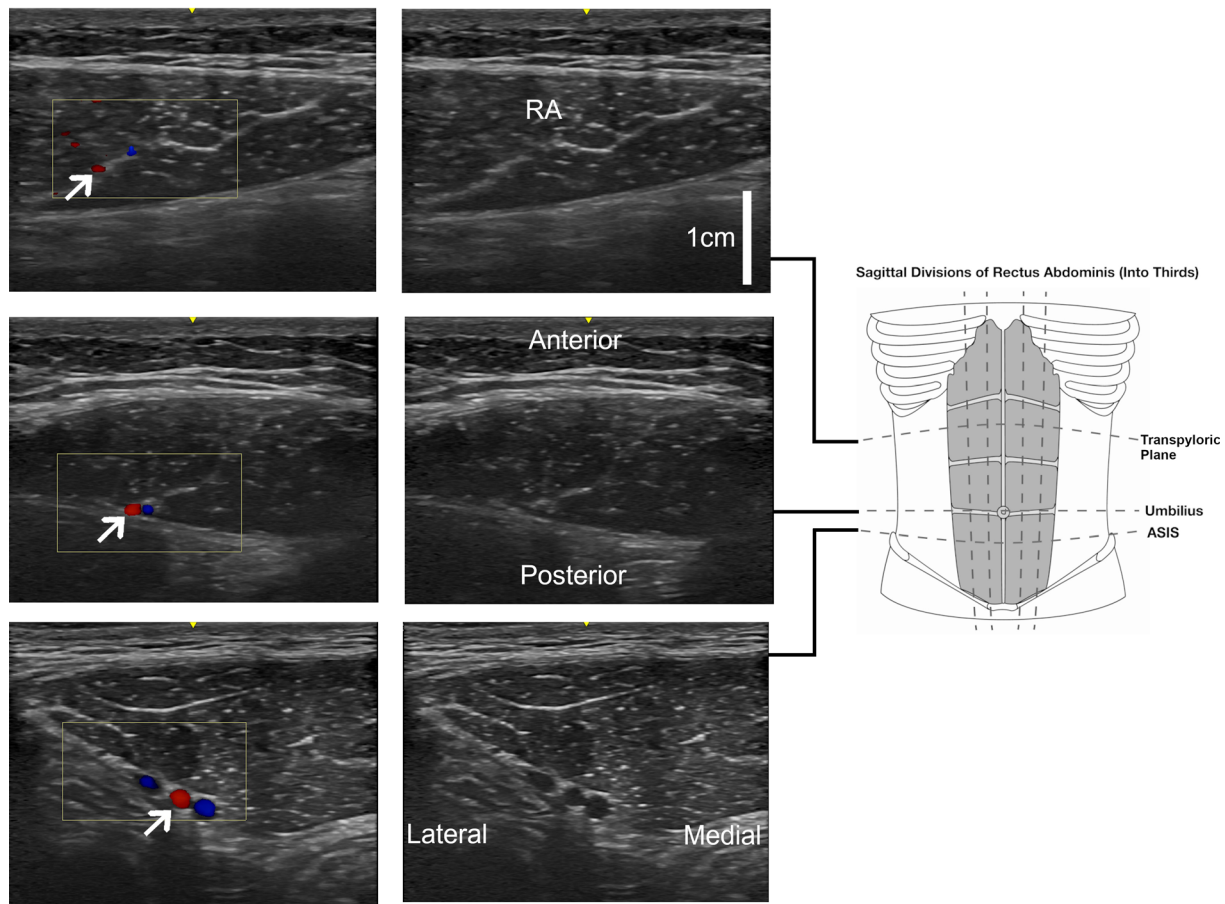
FIGURE 1   (Right) Axial planes assessed on the abdominal wall; the transpyloric plane, level of the umbilicus, and the level of the anterior superior iliac spine. (Left) An example of the vessels visualized with color Doppler: artery in red (highlighted with arrow) and vein(s) in blue [Color figure can be viewed at wileyonlinelibrary.com]

the marked line (at the level of the ASIS) and the umbilicus was measured. This distance was then marked on either side of the midline and the two marks were then joined by a second straight transverse line at the level of the umbilicus (which went through the umbilicus also). Finally, the distance between the xiphisternum and umbilicus was measured, this height was halved and the distance marked on either side of the midline (up from the umbilical level). Again, a transverse line was drawn between these marks. Thus, three axial planes were marked on the anterior abdominal wall and were assessed on each side of the midline (Figure 1).

Each US assessment was performed by two operators, at least one of whom was a senior anesthetist with over 5 years of experience using US in this manner. All anesthetists involved in this study (A.T., C.G., J.B.) have significant experience of performing this block and regularly teach on anatomy, US, and regional anesthesia courses. At each level, on either side of the midline, the plane was assessed using a 6–12 MHz linear array US transducer probe (LOGIQ V2; GE Healthcare, Chicago, IL). The presence of an artery was recorded if a pulsatile (or expansile) anechoic region was noted, which demonstrated pulsatile blood flow on color Doppler. The probe was initially placed in the midline, at the level of the ASIS, to identify the linea alba. The medial border of RA on one side was then identified and

TABLE 1   Axial planes used for the assessment of blood vessels and the position of the blood vessel recorded in relation to rectus abdominis (RA)

Axial level	Coronal plane	Sagittal division of RA
Transpyloric plane (midway between xiphisternum and umbilicus)	Anterior to muscle (within rectus sheath)	Medial third of RA
Umbilicus	Intramuscular (within RA)	Middle third of RA
Level of anterior superior iliac spine (ASIS)	Posterior to muscle (within rectus sheath)	Lateral third of RA

positioned in the center of the probe, where a mark was placed on the skin. The lateral border of RA was marked in the same manner. Subsequently, the plane was scanned from medial to lateral to identify the presence of any vessels within the rectus sheath, and their relationship to RA in the coronal plane (Table 1). For each vessel, the probe was positioned with the vessel in the center and the location again

marked on the skin. The distance of the vessel from the medial border the RA was measured; this distance was then compared with the measured width for the RA at that level to determine which sagittal third of the RA the vessel was related to. Finally, the diameter of each vessel was measured by freezing the US image at the maximum vessel diameter (obtained by minimizing compression and waiting for the maximally expansile point of the artery). On this image, the diameter of the vessel was measured using the distance measurement software on the US machine.

2.4 | Sample size calculation and statistical analysis

A priori calculation for sample size (J.B.), for detection of a statistically significant difference between the TPP and either the umbilicus or the ASIS levels was based on earlier CT data (Bowness et al., 2019). These data identified an arterial vessel at each level with the following frequencies.

- TPP: 5%.
- Umbilicus: 72–79%.
- ASIS: 93–96%.

Using the ClinCalc online software (www.clincalc.com), with an alpha (type I) error of .05 and a power of 80%, a minimum of 14 (TPP: umbilicus) or 8 (TPP:ASIS) US assessments were required. We therefore aimed to recruit a minimum of 20 participants and ultimately assessed 24, thus ensuring adequate power.

Anonymized data were initially recorded in Microsoft Excel (ALSG) and then transferred to SPSS version 25 (IBM Corp, 2017). Analysis was conducted by an independent researcher (OV, not involved in data collection) to eliminate bias. Chi-square test was used to assess for the presence of an association between the three different axial planes (TPP/umbilical/ASIS) and the following parameters.

- Presence of an artery (yes/no).
- Size of the main artery (≤1 or >1 mm).

Data from the left and right sides were analyzed separately. Taking into consideration some of the observed low frequencies, exact p values have been stated to prevent reporting of potentially artificially high values. Cramer's V was used to assess the strength of

association of significant findings from the chi-square test, thus providing a measure for the effect size.

3 | RESULTS

In total, 24 participants were assessed, of whom 15 (62%) were male and 9 (38%) female. The mean age of participants was 67.9 years (SD ± 9; range 53–82; 95% CI: 64.1–71.7). Mean weight was 77.3 kg (SD ± 14.4; range 59–114; 95% CI: 71.3–83.5), with a mean height of 171 cm (SD ± 11.2; range 150–187; 95% CI: 166–176) and a resulting mean BMI of 26.3 (SD ± 3.1; range 21.6–33.1, 95% CI: 25–27.6).

An artery was identified at the TPP in 15/24 (62.5%) on the left and 11/24 (45.8%) on the right (Table 2). At the level of the umbilicus, an artery was identified on 24/24 (100%) on the left and 23/24 (95.8%) on the right, while at the level of the ASIS this rate was 24/24 (100%) on both sides. This association between the presence of an artery and the three different planes was noted to be significant on the left, $\chi^2(2) = 20.571$; $p < .001$, and right $\chi^2(2) = 27.842$; $p < .001$, sides, and was of moderate strength (Cramer's V = 0.535 [left] and 0.622 [right]).

When an artery was present at the TPP, it most commonly lay in the middle-third of the ipsilateral RA muscle on both sides (8/15 on the left, 5/11 on the right). This was also the most frequently observed position at the level of the umbilicus (10/24 on the left and 15/23 on the right). At the level of the ASIS, the artery was most commonly observed in the lateral third of the muscle (21/24 on both sides). For further details, see the supplementary file.

At the TPP, an artery was most commonly observed within the RA muscle (13/15 on the left and 9/11 on the right). At the level of the umbilicus, an artery was observed within the muscle in 16/24 on the left and 18/23 on the right. However, at the level of the ASIS, the artery was observed to lie behind the muscle in all cases on the left (24/24) and in 23/24 on the right (Table 2).

At the TPP, the mean diameter of the artery was 1.02 mm (SD ± 0.077; range 1–1.3; 95% CI: 0.98–1.06) on the left, and 1.17 mm (SD ± 0.241; range 1–1.6; 95% CI: 1.01–1.33) on the right. At the level of the umbilicus, the mean diameter of the artery was 1.14 mm (SD ± 0.22; range 1–1.8; 95% CI: 1.04–1.23) on the left, and 1.11 mm (SD ± 0.169; range 1–1.6; 95% CI: 1.04–1.19) on the right. However, at the level of the ASIS, the mean diameter of the artery was 1.86 mm (SD ± 0.379; range 1–2.5; 95% CI: 1.7–2.02) on the left and right (SD

TABLE 2 Position of the artery (visible on US) in relation to the rectus abdominis muscle within the rectus sheath

	Left (n = 24)				Right (n = 24)			
	Intrarectus (%)	Posterior to rectus (%)	Anterior to rectus (%)	Not seen (%)	Intrarectus (%)	Posterior to rectus (%)	Anterior to rectus (%)	Not seen (%)
Transpyloric	54	4	4	38	38	0	8	54
Umbilicus	67	29	4	0	75	17	4	4
ASIS	0	100	0	0	4	96	0	0

Abbreviations: ASIS, anterior superior iliac spine; US, ultrasound.

± 0.418; range 1.2–2.8; 95% CI: 1.69–2.03). This association between the size of the artery and the three different planes was noted to be significant on the left, $\chi^2(2)$ = 31.208; $p < .001$, and right $\chi^2(2)$ = 19.959; $p < .001$, sides and was of moderate strength (Cramer's V = 0.704 (left) and 0.587 (right)).

4 | DISCUSSION

This study has evaluated the US appearance of blood vessels at three readily-identifiable locations of the anterior abdominal wall. As far as the authors are aware, this is the first such study that provides a direct comparison to similar CT data (albeit in different patient populations). This information may be of great value in providing a real time guide to percutaneous intervention of the anterior abdominal wall, as is performed by anesthetists during RSB and surgeons during laparoscopic abdominopelvic surgery.

We have previously reviewed the topographical descriptions of the deep epigastric arteries (Bowness et al., 2019) and concluded that the descriptions often do not provide detail on the anatomical variation or relative frequencies with which the vessels are present/ absent.

As with our previously published CT data, the deep epigastric arteries were found to be visible (present) less frequently at the TPP and more commonly seen inferiorly (at the level of the ASIS). The inferior epigastric arteries originate more laterally, moving to a more medial position as they course superiorly, and almost always lay posterior to the RA muscle at the level of the ASIS (as opposed to most commonly lying within the RA muscle at the TPP). As before, the artery was of a larger caliber inferiorly.

The relative frequencies with which an artery was seen was higher with US, particularly at the level of the TPP where one was visualized in 62.5% on the left and 45.8% on the right. In contrast, at this level, such an artery was only seen in 5% on CT (bilaterally). As before, it was most commonly found within the muscle at the TPP (rather than in the posterior space of the sheath as is often described). The artery was again of the smallest caliber here compared with that in other axial levels.

The findings of this study reinforce previous data to inform safe practice when deciding on the puncture site least likely to result in arterial injury during instrumentation of the anterior abdominal wall. In contrast to our previous publication, in which we postulated that blood vessels may not always be visible on US, it appears that smaller vessels are more readily apparent with this modality than on CT. This highlights the benefit of US-guided RSB, as is now common practice. For surgeons, who may insert RSB catheters under direct vision, knowledge of the underlying anatomy is important if they are unable to deviate the course of the needle to accommodate for anatomical variation in individual patients.

The authors acknowledge that the two study groups comprised different individuals and therefore direct comparison between the two imaging modalities is not possible. However, the general trend of arterial presence, size, and position is preserved between the two studies. Furthermore, the two study populations were closely matched for age (US: 67.9 ± 9, CT: 69.2 ± 15), and sex. As before, one must take care in extrapolating these results to patients of differing ages, particularly in the pediatric population. Furthermore, it is acknowledged that the US study size was smaller than the CT study. However, a pragmatic approach was required in this study, to determine whether the main CT findings were broadly replicated with US. Thus, the minimum number of assessments required were determined using a priori calculation based on the CT data and a slightly larger number of subjects were assessed. Also, we are aware that US is a subjective and dynamic assessment: measurement of the vessel size on US will naturally be subject to variation with pressure on the vessel and angle of inclination of the US probe. However, steps were taken to minimize these effects, and the consistency of data between the two studies is reassuring.

5 | CONCLUSIONS

This study provides a second description of anatomical variation of the arteries of the anterior abdominal wall, but with a new imaging modality. As on CT evaluation, US assessment found the inferior epigastric artery to be of larger caliber and more frequently encountered at or below the level of the umbilicus. In contrast to the CT study, the artery was most commonly found to lie posterior to the RA muscle at the level of the ASIS (but became intramuscular at the level of the umbilicus and TPP). An artery (visible on CT or US) is least likely to be encountered at the TPP. If one is encountered, it is likely to be smaller at this level. However, importantly, the vessels were observed more commonly in the US cohort, which raises the suggestion that smaller vessels are more readily visualized with careful sonographic assessment. This knowledge may help reinforce practice in regard to instrumentation of the anterior abdominal wall, to minimize risk of inadvertent arterial trauma during RSB and other procedures in this region.

CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

AUTHORS' CONTRIBUTIONS
A.L.S.G.: Project lead, study design, ethical approval, participant recruitment, data collection, manuscript preparation. A.T.: Study design, data collection, manuscript review. O.V.: Study design, ethical approval, data analysis, manuscript review. C.G.: Study design, data collection, manuscript review. E.C.: Local project supervisor, study design, ethical approval, manuscript review. J.B.: Senior project supervisor, study design, ethical approval, data collection, manuscript preparation.

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