Thoracic Ultrasound Demonstrates Variable Location of the Intercostal Artery

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Key Words
Doppler ultrasonography • Intercostal artery • Intercostal catheter • Pleural effusion • Thoracocentesis

Abstract
Background: Ultrasound (US) guidance is advocated to reduce complications from thoracocentesis or intercostal catheter (ICC) insertion. Although imaging of the intercostal artery (ICA) with Doppler US has been reported, current thoracic guidelines do not advocate this, and bleeding from a lacerated ICA continues to be a rare but serious complication of thoracocentesis or ICC insertion. Objectives: It was the aim of this study to describe a method to visualise the ICA at routine US-guided thoracocentesis and map its course across the posterior chest wall. Method: The ICA was imaged in 22 patients undergoing US-guided thoracocentesis, at 4 positions across the back to the axilla. Its location, relative to the overlying rib, was calculated as the fraction of the intercostal space (ICS) below the inferior border of that rib. Results: An ICA was identified in 74 of 88 positions examined. The ICA migrated from a central ‘vulnerable’ location within the ICS near the spine (0.28, range 0.21–0.38; p < 0.001) towards the overlying rib (0.08, range 0.05–0.11; p < 0.001) in the axilla. Conclusions: The ICA can be visualised with US and is more exposed centrally within the ICS in more posterior positions; however, there is a marked variation between individuals, such that the ICA may lie exposed in the ICS even as far lateral as the axilla. Future studies need to identify which patients are at risk for a ‘low-lying’ ICA to further define the role of US imaging of the ICA during thoracocentesis or ICC insertion.

Introduction
Thoracocentesis or intercostal catheter (ICC) insertion are frequently performed as an initial diagnostic and/or therapeutic procedure for patients with pleural effusion [1, 2]. Potential complications include pneumothorax, damage to the viscera, skin or pleural space infection or bleeding due to laceration of the intercostal artery (ICA) [3]. The optimal site for thoracocentesis is within the ‘triangle of safety’ [4th to 6th intercostal space (ICS) mid-axillary line] as this minimises the inadvertent injury of anatomical structures [4]. However, in clinical practice, loculations, body habitus and other factors frequently mandate thoracocentesis through the posterior chest wall [4], which increases the risk of ICA laceration [5]. Use of ultrasound (US) to guide pleural procedures is associated with a reduced rate of adverse events [6], and its routine use has recently been advocated for all thoracocenteses and ICC insertions [4]. Doppler US has been

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extensively used to examine the vascular supply of pulmonary and chest wall tumours [7–9], and its ability to specifically image the ICA has been established [10, 11]. However, acknowledgement of this has not been widespread in the international community, as evidenced by its absence in a number of recent reviews [12–14]. Indeed, some international guidelines have published statements refuting the ability of thoracic US to image the intercostal vessels [4]. As such, bleeding from a lacerated ICA or ICA pseudoaneurysm continues to be a rare but serious complication [15–18].

This study aims to describe a method to identify the ICA while performing routine US-guided thoracocentesis and to document the variation in position of the ICA, relative to the ICS, across the posterior chest wall to the mid-axillary line. We hypothesise that there will be considerable variation in the location of the ICA between individuals. It may be that in a subset of individuals, with increased bleeding risk due to an underlying coagulopathy or a posteriorly placed effusion, screening for a low-lying ICA should be performed with US prior to thoracocentesis.

Materials and Methods

Study Design

The primary aim of this study was to prove the feasibility of visualising the ICA at routine US-guided thoracocentesis. Twenty-two consecutive patients undergoing US-guided thoracocentesis between November 2010 and January 2011, for any medical reason, were recruited. The study was approved by the institution ethics committee, and written informed consent was obtained from all participants.

Methods

Thoracic US was performed using a standard commercially available machine (Zonare z.one ultra or Philips ATL HDI 5000) with a linear probe (4–7, 5–10 or 7–12 MHz) held flat to the skin and perpendicular to the line of the ribs. The investigators performing the US examination were a radiologist and a respiratory physician, neither with specialist thoracic ultrasonographer-level experience. An ICA was defined as a pulsatile tubular structure within the ICS on colour flow Doppler imaging, in accordance with the vascular access algorithm described by Kumar and Chuan [19]. The ICA was identified within the first complete ICS inferior to the angle of the scapula, at 3 positions across one side of the back and in the 4th, 5th or 6th ICS in the mid-axillary line on the ipsilateral side (fig. 1). These positions were chosen as they represented common sites used for thoracocentesis and were easily identifiable during thoracic US, assuring standardisation of the positions examined across the study population. They did not necessarily correlate with the actual site used for thoracocentesis in each subject. Initially, a 7- to 12-MHz linear probe was used; however, in some patients with a large amount of subcutaneous tissue, a lower frequency probe (5–10 or even 4–7 MHz) gave better views of the ICS. Care was taken to keep the probe flat to the skin and perpendicular to the line of the ribs. In the majority of cases, the ICA was identifiable with colour Doppler imaging as a round, pulsatile structure within the ICS inferior to the overlying rib. Where it was not clearly visible, a number of sequential steps were taken: (1) adjust the pulse repetition frequency of the US beam; (2) subtle side-to-side and heel-toe movements of the probe to adjust the direction of the US signal; (3) ask the patient to hold breath; (4) analyse the signal with power Doppler [20], and (5) try a different frequency probe. If a structure resembling the ICA was seen, but was not clearly pulsatile, spectral Doppler analysis was used to confirm arterial flow [21].

Measurement of the distance between the inferior border of the overlying rib and the inferior border of the ICA on colour Doppler imaging as well as the width of the ICS was made as shown in figure 2. These points were chosen as the intervening distance represents the minimum clearance below the superior rib required to guarantee that no damage is done to the ICA when performing thoracocentesis.

Analysis

Statistical analysis was performed with SAS software version 9.2 (SAS Institute, Cary, N.C., USA). Data were examined for normality and found to be well approximated by a normal distribu-
tion after log transformation. Repeated measures analysis of variance (ANOVA) was used to assess the statistical significance of variation in the ICA position, relative to the ICS, in different locations across the chest wall. The effects of age were assessed by including this as a covariate in the model. Results from the repeated measures ANOVA model were presented as geometric means with 95% confidence intervals. Statistical significance was set at a two-sided p value of 0.05.

**Results**

Characteristics of the study population are shown in table 1. Age ranged from 16 to 92 years, and 11 of 22 subjects were females. Five subjects had suspected or proven malignant effusions, of which none had pleural or chest wall malignant disease at the site of US examination of the ICA.

Out of the 88 positions examined, an ICA was visualised in 74 positions with colour Doppler. No additional vessels were found with the use of power Doppler. A typical colour Doppler appearance of the ICA is shown in figure 3 and a spectral Doppler trace confirming arterial blood flow in figure 4. The ICA could not be visualised on 14 occasions (1 at position 2, 5 at position 3, and 8 at position 4), and this did not correlate significantly with age or body mass index. The location of the ICA, at each position across the back, is expressed as the ratio of the distance of the ICA below the superior rib to the width of the ICS (fig. 2) and is displayed graphically in figure 5. As can be clearly seen, there is a steady migration of the ICA superiorly towards the overlying rib at positions progressively lateral. This was significant at the p < 0.001 level, confirming that this migration is a reliable finding. However, the range in position of the ICA at any given point, between any 2 subjects, is quite large, as documented by the 95% confidence intervals. This did not correlate with age. Even as far lateral as the mid-axillary line, the ICA was up to 0.2 of the ICS below the superior rib.

**Discussion**

This is the first description, to our knowledge, of a method to visualise the ICA during routine US-guided thoracocentesis. Similar to previous studies, the report confirms the general trend of the ICA to migrate towards the overlying rib in more lateral positions. However, it also highlights that there is considerable variation in this trend between individuals, such that in a small percentage of people, the ICA remains exposed in the ICS and vulnerable to injury, even as far lateral as the axilla.

Traditionally, the intercostal neurovascular bundle has been thought to run in the sub-costal groove behind the inferior border of each rib [22]. Thus, ‘safe’ insertion of a needle through the ICS by passing just above the superior border of the inferior rib has been recommended [4, 23]. However, the relationship between ICA and sub-costal groove is probably less reliable than previously thought. Wraith et al. [24] documented the position of the neurovascular bundle, relative to the supe-
rior rib, within ICS 4–6 in the mid-axillary line of 38 cadavers. The position of the ICA was highly variable, ranging from 50% of the ICS above to 43% of the ICS below the inferior border of the superior rib. A recently published study of CT angiograms showed a steady migration of the ICA towards the overlying rib in locations progressively lateral [5]. This meant that the ICA was effectively ‘protected’ by the superior rib in locations >6–8 cm from the costovertebral junction. However, it is of note that only the mean results of ICA locations for the

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BMI = Body mass index; NSCLC = non-small cell lung cancer; CABGS = coronary artery bypass graft surgery; CLD = chronic liver disease; ILD = interstitial lung disease; ESRF = end-stage renal failure.

Fig. 3. Colour flow Doppler image of an ICA inferior to a rib shadow.

Fig. 4. Spectral Doppler trace of an ICA demonstrating arterial flow.
study population were presented. No information on the variance within the population was reported. Thus, the position of the ICA at any given location, for any given individual, may not have been as predictable as it is for the population at large. Another factor impacting on the location of the ICA within the ICS is the tortuosity of its course. A study of thoracic aortograms showed that the degree of tortuosity of the ICA increased with age, especially in those >60 years old where its appearance could be almost sinusoidal. Finally, an additional vessel located in the inferior region of the ICS, the collateral artery, has been reported in cadaveric dissection studies. In all cases, a collateral artery arose from the ICA between the corresponding vertebra and angle of the rib, and could be as large as the ICA. These findings have led some authors to suggest that the 'safe zone' for thoracocentesis should be located 50–70% down into an ICS, rather than immediately superior to the lower rib as traditionally taught. However, in our experience, due to body habitus, poor co-operation or medical instability, it is often not possible to be this accurate with needle placement.

In our study, there is a predictable migration of the ICA upwards towards the overlying rib as one moves progressively lateral across the back. That is, the ICA is more exposed in the centre of the interspace in positions more posterior. This is consistent with recently published findings. However, our data have also shown that the actual position of the ICA within the ICS (whether protected by the rib above or exposed) at any given position, in any given individual, is variable. Even as far lateral as the mid-axillary line, the ICA may lie 20% of the way down into the ICS. This has been shown in previous dissection studies and has serious implications for safety when performing procedures through the ICS.

The technique adopted in this study used standard US equipment routinely employed to guide thoracocentesis and ICC insertion. In the cases where no ICA could be seen, there are two possible explanations. Either the ICA was 'hiding' behind the rib at the position inspected or the ICA was within the ICS, but for a variety of possible reasons, we were just unable to see it. There are a number of factors which may have made imaging of the ICA more difficult in this study. The US probe was held perpendicular to the line of the ribs (and thus the overall line of the ICA), with the ICA viewed in cross-section. This is not the optimum to detect flow with Doppler US and probably reduced the sensitivity of US to identify the ICA. In a previous description of Doppler US imaging of the ICA, the probe was held more transversely, in the line of the ribs, such that the ICA was visualised along its course. This allowed accurate beam steering in the direction of blood flow, and thus, maximised the chances of visualising the ICA. This was important in this previous study as Doppler US was used quantitatively to calculate flow velocity and impedance indices within the ICA. However, the primary aim in our study was to document the position of the ICA relative to the overlying rib using Doppler US in a qualitative manner only. This could not be done accurately without viewing the entire ICS in cross-section, and so, we feel our method is valid for this more limited objective. Another factor influencing successful imaging of the ICA in our study was the body habitus of the subjects. In obese patients, an increased thickness of the chest wall degraded signal quality making the ICA harder to visualise. Use of a lower frequency probe with better penetration was useful in these cases.
closer to the spine were easier, possibly because the ICA tends to lie lower in the ICS, and thus, there is less chance of the superior rib impairing views. Patient clinical state, including their ability to maintain posture, and an increased respiratory rate which enhances movement artefact, also had a marked influence. A number of manoeuvres and use of US imaging techniques as outlined in Materials and Methods proved useful in some difficult cases. As mentioned, colour Doppler will not detect flow if the angle of movement is perpendicular to the line of the US beam. Small side-side movements of the probe may optimise the angle of incidence between US beam and blood flow, improving the Doppler image. It is also possible that in some cases, an absence of tortuosity meant the course of the ICA reliably followed the line of the rib and was thus invisible to a Doppler beam directed perpendicularly down from the skin. According to previous studies, this should be more common in younger patients [5, 25], which was not found in our study, possibly due to a small sample size. The use of power Doppler analysis, which is not angle dependent [20], should theoretically overcome this problem.

There were a number of limitations to this study. Low subject number potentially reduces the applicability of our results to the population at large. However, the high statistical significance, despite these low numbers, suggests results are robust. Due to the distance between the US probe on the skin where images were acquired, and the ICS where distances were calculated, it is possible that parallax errors were generated in measurements. However, we feel these are unlikely to be significant, as ensuring that the US probe remained perpendicular to the skin and line of the ribs proved relatively simple, and the geometry employed for measurements (fig. 2) was not complicated. Not all images of the ICA were confirmed to have arterial flow with spectral Doppler analysis. Even though images not analysed with spectral Doppler had clearly pulsatile signals consistent with arterial flow [19], it is possible that some of the recorded images were of venous rather than arterial structures. When imaged in cross-section, US is also unable to map the tortuosity of vessels. It may be that inter-subject variability in the location of the ICA is due to capturing the ICA at differing points of its tortuous course, rather than a shift in position of the entire artery. Although consistent with previous studies [5], the apparent ‘lower-lying’ location of the ICA closer to the spine may possibly reflect greater tortuosity of the ICA as one moves progressively posteriorly. As mentioned earlier in the discussion, the presence of a collateral artery which typically runs in the lower part of the ICS has been reported. This vessel was not specifically looked for in this study, and it is possible that some of the images of a ‘low-lying’ ICA actually represented a collateral artery. Finally, procedure time was not recorded in this study. The feasibility of incorporating screening for the ICA with US before thoracocentesis or ICC insertion into clinical practice depends largely on the extra time this would add to the procedure. We anticipate vascular imaging would only be necessary in a subset of patients, for example those with small posteriorly placed effusions or patients with coagulopathy.

Despite its deficiencies, this study has demonstrated the feasibility of visualising the ICA at standard US-guided thoracocentesis. It has defined a number of relevant questions to be addressed in future studies and has implications for thoracocentesis and ICC insertion. Although the trend for the ICA to migrate under the superior rib as one moves laterally is reliable, the actual position of the ICA in any individual at any given position across the back is highly variable and may be well down into the middle of the ICS. This is particularly true in older patients and closer to the spine. Screening for an artery within the ICS, utilising thoracic US, may reduce the incidence of its inadvertent laceration during thoracocentesis or ICC placement. Future studies need to define populations ‘at risk’ for having a vulnerable ‘low-lying’ intercostal or collateral artery within the ICS, and the additional screening time for such an artery with US would add to the procedure. They also need to clarify the sensitivity of thoracic US for identifying the position of the ICA relative to the overlying rib. If no ICA is seen on US, is it because the artery is behind a rib (and thus protected from injury during thoracocentesis) or simply that US was unable to visualise it on that occasion, due to factors related to the patient, imaging technique or operator experience. This question could be resolved by correlating US findings with an alternative imaging modality such as CT angiography.

Financial Disclosure and Conflicts of Interest

The authors declare that there are no conflicts of interest.
References


