Ultrasound in Med. & Biol., Vol. ■■, No. ■■, pp. ■■–■■, 2018

0301-5629/$ - see front matter

ELSEVIER

https://doi.org/10.1016/j.ultrasmedbio.2018.03.007

● *Original Contribution*

SPECTRAL ANALYSIS OF ULTRASOUND RADIOFREQUENCY BACKSCATTER FOR THE DETECTION OF INTERCOSTAL BLOOD VESSELS

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(*Received* 14 *September* 2017; *revised* 23 *February* 2018; *in final form* 12 *March* 2018)

Abstract—Spectral analysis of ultrasound radiofrequency backscatter has the potential to identify intercostal blood vessels during ultrasound-guided placement of paravertebral nerve blocks and intercostal nerve blocks. Autoregressive models were used for spectral estimation, and bandwidth, autoregressive order and region-of-interest size were evaluated. Eight spectral parameters were calculated and used to create random forests. An autoregressive order of 10, bandwidth of 6 dB and region-of-interest size of 1.0 mm resulted in the minimum out-of-bag error. An additional random forest, using these chosen values, was created from 70% of the data and evaluated independently from the remaining 30% of data. The random forest achieved a predictive accuracy of 92% and Youden's index of 0.85. These results suggest that spectral analysis of ultrasound radiofrequency backscatter has the potential to identify intercostal blood vessels. (jokling@siue.edu) © 2018 World Federation for Ultrasound in Medicine and Biology (E-mail: jokling@siue.edu) © 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Intercostal artery, Intercostal vein, Intercostal nerve, Spectral analysis, Tissue characterization, Radiofrequency signals, Ultrasound.**

INTRODUCTION

Regional anesthetic techniques are gaining popularity among practitioners because of their perceived simplicity, effectiveness and low complication rate (Lönnqvist et al. 1995). Paravertebral block (PVB) is one such technique and involves the injection of local anesthetic solution alongside the vertebral column, targeting the spinal nerve roots as they exit intervertebral foramina. The specific target for the injection is known as the paravertebral space, bounded posteriorly by the superior costotransverse ligament and anteriorly by the parietal pleura. This space contains the intercostal blood vessels, artery and vein, and the associated intercostal nerve. In addition to PVB, there is the intercostal nerve block (ICB) technique, a regional anesthetic procedure commonly used to provide analgesia after thoracic or upper abdominal surgery (Abrahams et al. 2010). The injection in this technique is lateral to that of the PVB, directly in the intercostal space (Peng and Narouze 2009).

Multiple techniques are used for guidance of PVB and ICB, including recognition of landmarks, loss of resistance, nerve stimulation, ultrasound-based measurement of the distance from the skin to the transverse process and live fluoroscopic or ultrasound guidance (Boezaart et al. 2003; Chelly 2012; Lang 2002; Richardson et al. 1996). Techniques without live visualization of anatomy have been associated with less-than-desirable levels of analgesia (Najarian et al. 2003; Pusch et al. 1999). The primary imaging tools for live guidance are fluoroscopy and ultrasound. Fluoroscopy involves exposure of the practitioner and the patient to radiation, posing health risks to both (Peng and Narouze 2009). However, diagnostic ultrasound imaging has no known side effects and is relatively inexpensive. Because of the evidence of improved outcomes, higher success rates and reduced needle-related complication rates, ultrasound-guided techniques have emerged as the preferred approach (Chelly 2012; Peng and

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Narouze 2009). As ultrasound technology continues to evolve, its use in PVB and ICB will only continue to increase (Abrahams et al. 2010). Real-time visualization of the needle aids the practitioner in placement and in avoiding penetration of the parietal pleura, for both PVB and ICB. In addition, the correct positioning can be confirmed by observing the injection of the local anesthetic, which displaces the pleura anteriorly (Chelly 2012). Despite these advantages, risk remains and is associated primarily with intra-arterial or intra-neural injection. The intercostal nerve itself is difficult to visualize—it is small, has an acoustic scattering intensity similar to that of the surrounding tissue and is in close proximity to the rib, particularly in the intercostal space (Chelly 2012; Peng and Narouze 2009). In addition, imaging the ventral nerve roots inside the paravertebral space is challenging with current technology because of bony shadowing and the small space. The associated intercostal vessels can sometimes be located via color Doppler ultrasound, but they are also difficult to visualize because of the non-normal angle of incidence required for effective Doppler imaging. Based on data collected in this study, adequate Doppler imaging was obtainable only approximately 31% of the time (34 Doppler loops with visible vessels from 110 sets of images of intercostal spaces), suggesting that an alternate method for more consistent and adequate identification and visualization of the vessels would be beneficial. This confirmed the anecdotal experience of the anesthesiologists in our group and motivated this pilot study investigating the use of random forests with spectral parameters. Although Doppler can be visible on occasion, it is only being used in this case as a mechanism to provide gold-standard information regarding the location of the vessels. However, once the database is built, spectral analysis can be used without Doppler, providing a mechanism for vessel identification that is available more often than Doppler alone.

Traditional gray-scale ultrasound imaging is a measure of the intensity of the reflected echoes, but does not utilize the frequency content in the radiofrequency (RF) signals. Work in ultrasound tissue characterization has revealed relationships between various spectral parameters and different tissue structures; for example, the slope and y-intercept of a regression line and the mid-band fit are representative of scatterer size and intervening attenuation (Lizzi et al. 1983, 1987). These ideas have been expanded to other application areas, including breast cancer (Sadeghi-Naini et al. 2013), prostate cancer (Pareek et al. 2013), skin cancer (Andrėkutė et al. 2016) and fatty liver disease (Acharya et al. 2015). Investigating RF analysis for coronary plaque characterization, Nair et al. found that a parametric approach using an autoregressive (AR) model is more suited for the non-stationary, short-time biologic signals, particularly when choosing regions of interest (ROIs) of limited size to target specific tissue types for analysis (Nair et al. 2001b; Wear et al. 1995). In addition, the order of the AR model can be adjusted based on the application, making the parametric spectral estimation approach adjustable based on the application (Akaike 1969; Nair et al. 2004a). The objective of this study was to determine if spectral analysis of RF signals could identify intercostal blood vessels, via ultrasound imaging of the paravertebral space and the intercostal space. More specifically, the study intended to address three specific aims. The first was to build a database of ROIs of two classes: those including intercostal blood vessels, and those outside the blood vessels in the surrounding tissue. The second was to compare the performance of a set of random forests built with varying AR orders, bandwidths for spectral estimation and ROI sizes. The third was to select one of the random forest classifiers, based on its performance in a set of training data, and evaluate its performance in identifying the vessels in a set of test data.

METHODS

Ultrasound RF data acquisition

A pilot observational study was approved by the Cleveland Clinic Foundation Internal Review Board, and four healthy human volunteer subjects were enrolled for ultrasonic data acquisition. Inclusion criteria were: (i) age ≥18, (ii) body mass index ≤30, (iii) English-speaking and able to provide consent and (iv) no previous spinal surgeries and no history of significant spinal pathology. For each of the volunteers in this pilot study, scans were performed at up to 10 different levels (between each rib from T1–2 to T10–11) on both the right and left sides of the spine, resulting in up to 20 different levels for each volunteer. Specific paravertebral scans and intercostal scans were performed at each level. However, if no adequate acoustic window was present in the immediate paravertebral space, the probe was moved laterally and tilt was applied as necessary to image the far paravertebral space and the medial intercostal space. The ultrasound backscatter data were collected using a Siemens S3000 Imaging System and a 9L4 linear array transducer (Siemens Medical Solutions USA, Inc., Malvern, PA, USA) with default transmit and receive characteristics. The transmit focus was set to 3 cm for each case, with a set depth of 4.5 cm. Dynamic receive focusing was enabled with a Hamming window applied on the receive aperture and a target *F*-number of 0.8. These same settings were used for both the human volunteer and reference phantom data acquisitions. When suitable Doppler imaging was feasible, color Doppler loops were recorded in each acquired image plane to use as a reference location for the intercostal artery or vein. Additional tilt was used where necessary for adequate imaging and for the appropriate non-normal angle for Doppler location of the vessel. The Siemens S3000 was modified by