Ultrasound in Med. & Biol., Vol. ■, No. ■, pp. 1–12, 2015

0301-5629/$ - see front matter

ELSEVIER

http://dx.doi.org/10.1016/j.ultrasmedbio.2015.03.012

● *Original Contribution*

PANORAMA ULTRASOUND FOR NAVIGATION AND GUIDANCE OF EPIDURAL ANESTHESIA

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(*Received* 20 *October* 2014; *revised* 6 *February* 2015; *in final form* 9 *March* 2015)

Abstract—Despite the common use of epidural anesthesia in obstetrics and surgery, the procedure can be challenging, especially for obese patients. We propose the use of an ultrasound guidance system employing a transducer-mounted camera to create 3-D panorama ultrasound volumes of the spine, thereby allowing identification of vertebrae and selection of puncture site, needle trajectory and depth of insertion. The camera achieves absolute position estimation of the transducer with respect to the patient using a specialized marker strip attached to the skin surface. The guidance system is validated first on a phantom against a commercial optical tracking system and then *in vivo* by comparing panorama images from human subjects against independent measurements by an experienced sonographer. The results for measuring depth to the epidural space, intervertebral spacing and registration of interspinous gaps to the skin prove the potential of the system for improving guidance of epidural anesthesia. The tracking and visualization are implemented in real time using the 3D Slicer software package. (E-mail: rohling@ece.ubc.ca) © 2015 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Epidural anesthesia, 3-D panorama ultrasound, Optical tracking, Ultrasound guidance.**

INTRODUCTION

Motivation

Epidural anesthesia is a common procedure in obstetrics and surgery. Lumbar epidurals are used in obstetrics to provide pain relief during labor and cesarean delivery as an effective alternative to general anesthesia (Liu et al. 2005), and the use of thoracic epidurals has steadily increased as the standard of care in areas of abdominal, chest and vascular surgery (Afzal et al. 2002). An epidural procedure involves insertion of a needle into the epidural space between the ligamentum flavum (LF) and dura mater that covers the spinal cord in three main steps: identification of vertebrae, selection of desired puncture site and insertion of the needle into the epidural space. In current practice, the vertebrae are identified and the puncture site is selected by palpation of the spine; the anesthetist feels the spinous processes close to the skin and counts up or down from a known landmark such as the iliac crests, C7 vertebrae or 12th rib (Reynolds 2000). Studies indicate that palpation identifies the interspaces correctly in only 29% of cases for lumbar vertebrae (Broadbent et al. 2000), so injections are often performed one or more vertebral levels away from the desired level, increasing the risk and severity of spinal cord injury from needle overshoot. The anesthetist inserts the needle by feeling the loss of resistance to saline or air injection as the needle tip passes through the LF. This technique is the current gold standard for finding the correct depth of insertion into the epidural space.

As the interfaces among LF, epidural space and dura mater are encountered several millimeters apart, these blind methods can be technically challenging, especially in obese patients. Epidural failures include: needle insertion failure including bone contact, which would require withdrawal and re-insertion at a different angle and position, thereby increasing the duration of the procedure and the discomfort for the patient; epidural nerve injuries

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(with an incidence rate of 5%–12%); difficulty in delivering effective analgesia from incorrect identification of the vertebrae; and needle overshoot, which can result in accidental puncture of the dura mater and post-puncture headaches (occurring in 86% of lumbar cases with dural perforation) (Harney et al. 2005; Horlocker 2000; Sprigge and Harper 2008; Veering 2003). Complications are higher for anesthesiologists in training, because of the steep learning curve associated with these procedures (de Oliveira Filho 2002). These complications may include temporary or permanent neurologic deficit and inhibit the more widespread use of epidural anesthesia. The ideal guidance system would assist in identification of vertebrae and interspinous gaps, selection of the puncture site for the desired vertebral level and estimation of needle trajectory and depth to the epidural space.

Interest has been growing in ultrasound (US) imaging for epidural anesthesia, as a safe, low-cost and real-time imaging modality capable of depicting the spinal anatomy and the epidural space (Karmakar et al. 2012). In previous research, pre-puncture US has been used in lumbar epidurals to locate the puncture site at the desired intervertebral level and measure the depth to the epidural space (Grau et al. 2002a; Tran et al. 2009). Several attempts have been made to provide real-time US guidance, yet it is challenging to perform scanning and needle insertion simultaneously (Tran et al. 2010). Specialized image processing techniques have also been developed for automatic depth measurement of the epidural space (Tran and Rohling 2010). US imaging has also been used for pre-puncture detection and guidance of the thoracic epidural space (Grau et al. 2002b; Rasoulian et al. 2011). Current evidence suggests that US-guided procedures lead to several patient-oriented benefits including reduced procedure time and improved needle placement (Liu et al. 2009). Therefore, it is believed that with an improved guidance system, in the long term, the procedures can be performed more safely and efficiently.

The research described here proposes a panorama US navigation and guidance system for epidural anesthesia that allows tracking of individual US images with six degrees of freedom (DoF) with respect to the patient and creation of 3-D US volumes from the spine, and provides absolute (not relative) US position information with respect to the patient skin, thereby allowing the transducer to be removed and replaced. The volumes are created from a standard 2-D transducer, for reasons of simplicity and cost. Panoramas are obtained by reslicing the 3-D volumes in two different planes: the parasagittal plane, revealing the epidural space for selecting needle trajectory and depth of insertion, and a more lateral sagittal plane, depicting the lamina as wavelike patterns with clear interspinous gaps for identifying the vertebrae and the puncture site. Extended panoramas are created to provide a single view of all vertebrae of interest and allow counting from a desired location on the spine. The guidance system is designed to be integrated into existing, clinically approved US machines to be used in two stages for clinical practice: (i) pre-puncture scanning of the patient to create panoramas for identifying the levels and selection of puncture site, trajectory and depth of insertion; (ii) real-time guidance of needle insertion in the operating room. Absolute positioning is therefore needed to allow for real-time guidance during the procedure and is achieved by repositioning the transducer at the desired skin location as determined from the panorama images. Needle insertion is performed using a combination of US guidance and traditional loss of resistance (Tran et al. 2010), as loss of resistance is still the standard of care and provides a clear endpoint for needle insertion into the epidural space. Therefore, the accuracy of the panoramas must be sufficient to identify the vertebrae and select an approximate puncture site and trajectory. The accuracy is determined by a combination of factors including the measurement accuracy of the interspinous distances, interspinous gap locations and depth measurements to the LF (with a thickness of 5–6 mm [Chestnut 2004]). The LF is the smallest anatomic structure that needs to be identified for guiding initial needle insertion; thereafter, loss of resistance is used over the last centimeter of the insertion.

Background

Compound 3-D US data sets have been obtained from 2-D US images by using position sensors to measure the spatial relationships of the images (Rohling et al. 1997). US panorama images have also been generated without the use of position sensors, from partially overlapping data sets, using image processing techniques for automatic identification of the vertebrae (Kerby et al. 2008). Commercial systems such as SieScape (Siemens Ultrasound, WA, USA) and LOGIQView (GE Medical Systems, Waukesha, WI, USA) can also create panoramas from 2-D US images by detecting regions of overlap in sequential moving real-time images. Tracking the relative position of US images to acquire freehand 3-D US is possible without the use of sensors by aligning image features to extract the relative motion of consecutive frames (Gee et al. 2006). These methods are based on image registration and speckle tracking techniques, which suffer from drift errors and are not feasible for the spine because of the complex anatomic structures that result in spatially varying shadows and artifacts. Therefore, explicit tracking of the transducer is preferred. This has been achieved conventionally using different optical and electromagnetic (EM) technologies (Mercier et al. 2005; Pagoulatos et al. 2001). EM systems have