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● *Original Contribution*

AUTOMATIC SEGMENTATION AND PROBE GUIDANCE FOR REAL-TIME ASSISTANCE OF ULTRASOUND-GUIDED FEMORAL NERVE BLOCKS

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Abstract—Ultrasound-guided regional anesthesia can be challenging, especially for inexperienced physicians. The goal of the proposed methods is to create a system that can assist a user in performing ultrasound-guided femoral nerve blocks. The system indicates in which direction the user should move the ultrasound probe to investigate the region of interest and to reach the target site for needle insertion. Additionally, the system provides automatic real-time segmentation of the femoral artery, the femoral nerve and the two layers fascia lata and fascia iliaca. This aids in interpretation of the 2-D ultrasound images and the surrounding anatomy in 3-D. The system was evaluated on 24 ultrasound acquisitions of both legs from six subjects. The estimated target site for needle insertion and the segmentations were compared with those of an expert anesthesiologist. Average target distance was 8.5 mm with a standard deviation of 2.5 mm. The mean absolute differences of the femoral nerve and the fascia segmentations were about 1–3 mm. (E-mail: ersmistad@gmail.com) © 2016 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Regional anesthesia, Femoral nerve, Segmentation, Assistant.**

INTRODUCTION

The use of regional anesthesia (RA) is increasing because of its benefits over general anesthesia (GA), such as reduced morbidity and mortality (Beattie et al. 2001; Rodgers et al. 2000; Urwin et al. 2000), reduced postoperative pain, earlier mobility, shorter hospital stay and lower costs (Chan et al. 2001). Despite these clinical benefits, RA remains less popular than GA. One reason is that GA is more successful and reliable than RA. Ultrasound has been used to increase the success rate of RA (Dolan et al. 2008; Griffin and Nicholls 2010). However, ultrasound-guided RA can be challenging, especially for inexperienced physicians. Good theoretical, practical and non-cognitive skills are needed to achieve confidence in performing RA and to keep complications to a minimum. Studies indicate that RA education focusing on illustrations and text alone is not sufficient (Worm et al. 2014). The RASimAs project (Regional Anaesthesia Simulator and Assistant, http://www.rasimas.eu) is a European research project that aims at providing a virtual reality simulator to improve the training of doctors performing RA, as well as an assistant to lessen the cognitive burden and help perform RA procedures.

One way to lessen the cognitive burden is to provide segmentation of the ultrasound image, indicating the most important structures and thereby aiding the user in interpreting the images. The image segmentation may also be used to guide the movement and positioning of the ultrasound probe. Hadjerci et al. (2014) segmented the median nerve from ultrasound images using *k*-means clustering for finding hyper-echoic tissue; then a texture analysis method based on a support vector machine classifier was used to identify the nerve. A segmentation method for the sciatic nerve in ultrasound images was presented by Hafiane et al. (2014). Their method included a probabilistic Gaussian mixture model, edge detection, gradient vector flow and active contours. Yu et al. (2013, 2014) proposed a system for automatic needle insertion and probe guidance for ultrasound-guided epidural anesthesia. They used a template matching technique to identify the optimal needle insertion point. A guidance system for spine anesthesia was presented by

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Brudfors et al. (2015). Their approach involved scanning the spine with 3-D ultrasound followed by alignment and overlay of a statistical model of the lumbar spine on the ultrasound images.

This article focuses on creating an assistant for ultrasound-guided RA to block the femoral nerve. The femoral nerve is located lateral to the femoral artery and is hyper-echoic. Still, this nerve is generally hard to distinguish from surrounding tissue. Thus, anatomic knowledge of the shape and location relative to other structures must be employed. Another important aspect of the segmentation is that to be useful in this application, the segmentation must work in real time and be fully automatic. This article is a continuation of Smistad and Lindseth (2016), who introduced methods for real-time segmentation and reconstruction of the femoral artery in ultrasound images, as well as a model-to-ultrasound registration method. Here, novel methods for the segmentation of additional important structures such as the femoral nerve, fascia lata and fascia iliaca are described. Methods for estimating the target needle insertion site and visualizations for guiding the positioning of the ultrasound probe are also proposed.

METHODS

In this next section, we describe the hardware setup for the proposed assistant and then provide an overview of the assistant software. The assistant components are described in the order they are executed. The first component, the femoral artery tracking procedure, is followed by target estimation, model-to-ultrasound registration, probe guidance and finally the fascia and femoral nerve segmentation methods. At the end of this section, the evaluation of these methods is described.

Hardware setup

In terms of hardware, the assistant consists of an ultrasound system (Ultrasonix SonixMDP, Analogic, Boston, MA, USA) and a high-end computer for running the assistant software. The ultrasound rack was modified with a larger screen (Dell 24-in.), and the high-end computer was attached on the side. The ultrasound scanner is equipped with an L14-5 linear probe and SonixGPS electromagnetic tracking of both the probe and the needle. The high-end computer has an Intel i7-5820 3.3-GHz CPU, AMD Radeon R9 Fury GPU and 16 GB of RAM. Spatial calibration was done using a calibration matrix from the manufacturer (Ultrasonix 2011). Harmonic imaging was used with frequency 6.6 MHz and gain at 55%. The images were streamed from the ultrasound system to the assistant computer with an Ethernet cable, the Plus toolkit and the OpenIGTLink protocol (Lasso et al. 2014).

Software overview

The assistant software starts in an inactive state where only a probe contact detection algorithm is executed for each ultrasound image frame. This algorithm uses the change in image intensity to determine if the ultrasound probe is in contact with the skin of the patient. When contact is achieved, the assistant starts to guide the user in scanning the femoral region. In this process, an artery detection method is used to find the femoral artery. After the artery has been discovered, artery tracking takes over and the user is asked to first move the probe upward, that is, toward the head of the patient. The user is asked to move the probe upward until the artery descends into the abdomen; the assistant then directs the user to move the probe downward. When enough of the artery has been scanned to estimate the target area for needle insertion, the assistant directs the user toward the target. Finally, as the target is reached, the segmentation of fascia lata, fascia iliaca and femoral nerve is executed.

To achieve real-time performance, the presented methods are all implemented using the framework for heterogeneous medical image computing and visualization (FAST) (Smistad et al. 2015a). This framework enables efficient computation and visualization on heterogeneous systems, which include different processors such as multicore CPUs and GPUs. GPUs have been found to have great potential in accelerating medical image segmentation (Smistad et al. 2015b) and registration (Fluck et al. 2011).

Femoral artery segmentation and 3-D reconstruction

Methods for femoral artery detection, tracking and reconstruction from ultrasound images were described in Smistad and Lindseth (2016). Only a short description of these methods is provided here for completeness.

The femoral artery is modeled as an ellipse. The artery is first detected by a GPU-based algorithm, which initializes the artery tracking. This algorithm is completely automatic and requires no user interaction. The method does a brute-force search for black ellipses in the ultrasound image. A measure of fit is calculated by comparing the image gradients of the smoothed ultrasound image with the normals of an ellipse. Each pixel in the image is investigated, and several different major and minor radii ranging from 3.5 to 6 mm are used. The best scoring ellipse is kept, and if the score is above a certain threshold, it is accepted and used to initialize the tracking of the artery. The artery tracking is achieved with an extended Kalman filter and the ellipse model. The Kalman filter predicts the position and shape of the artery for each image frame. The prediction is corrected by edge measurements performed along the normals of the current ellipse. This is used to create an estimate of the