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Nerve Block Using a Navigation System and Ultrasound Imaging for Regional Anesthesia

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Abstract—**During the last few years, regional anesthesia using ultrasound imaging has increased dramatically in both clinical and research areas. This method provides a direct noninvasive imaging of the targeted nerve and the tissue around it in real time. Furthermore, it allows anesthetists to observe the injected anesthetics for optimal distribution. However, there are still some major limitations to this method such as poor visibility of the standard needle tip and shaft, tricky location estimation of needle tip, and difficult needle alignment before and during insertion.**

This article presents the concept of a new application field of medical navigation for regional anesthesia using ultrasound imaging, to avoid the above-mentioned drawbacks. In addition, a laboratory experiment on a phantom to verify the effectiveness, safety, precision and handling of the navigation method in comparison with standard ultrasound-guided regional anesthesia is described. During the experiment ten test persons who have no experience in this field should touch a target in a phantom, avoiding contact with the simulated blood vessels and nerve. Each test person was asked to repeat the test five times with and without navigation assistance, respectively. Thereafter, a two-sample one-tailed paired *t*-test with a significance level of 1% was applied to statistically analyze the difference.

The results show that navigation assistance significantly improves effectiveness, safety, precision and handling of ultrasound-guided regional anesthesia.

I. Introduction

In order to 'put the right dose of the right drug in the right place' [1], localizing the nerve in the regional anesthesia is very important. Four major methods are used in performing peripheral nerve blocks to find the right place: application of anatomical surface landmarks, elicitation of paresthesia, nerve stimulation [2-4] or ultrasonography [5-7].

Known anatomical surface landmarks help to find puncture points for subsequent invasive exploration with a block needle. However, anatomical surface landmarks are often not adequate due to the various body-types of patients (e.g., size and body habitus).

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Paresthesia elicited during needle exploration indicates that the needle is located in the proximity of a sensory nerve. This method is currently applied less frequently in clinical practice, since it is seldom felt by patients during nerve block [8] and it is uncomfortable for patients when it is felt.

Nerve stimulation has been established as the gold standard for many years. Using an electrical impulse applied to a needle, the proximity to a targeted nerve can be estimated based on the stimulation threshold that elicits muscle twitches. This electrical stimulation helps to determine the proper puncture point on the skin nearest to the superficial nerve and to determine the endpoint of needle insertion.

Unlike the above techniques, ultrasonography gives a direct noninvasive imaging of the targeted nerve and the tissue around it in real time. Furthermore, it enables the observation of the injected anesthetics to ensure optimal distribution. There are two common insertion approaches: the *in-plane* approach and the *out-of-plane* approach. Applying the *in-plane* approach, the block needle is advanced along the long axis of the ultrasound probe, so that it is always visible in the ultrasonic image during the entire block procedure. With the *out-of-plane* approach, the needle is not inserted along the image plane of the probe and is only visualized, if the needle intersects with the image plane.

Surgical navigation has been widely used for neurosurgery, ear-nose-throat surgery, and other surgeries in recent years. A navigated biopsy system using an optically tracked ultrasonic probe was introduced in [9]. That system visualizes the intersection point between the ultrasound image and the axis of the needle, facilitating a precise and safe biopsy procedure. Other systems are comparable to this. In recent years, some companies have offered ultrasonic systems in combination with electromagnetic tracking systems. To the best of our knowledge, such a system is applied to regional anesthesia has never been published, although it is also in theory possible.

Despite the advantages of ultrasound-guided regional anesthesia, there are some significant drawbacks to its use: (a) Poor visibility of the needle tip and shaft in the ultrasonic image makes recognition more difficult, particularly at a steeper angle; (b) The location of the needle tip is difficult to estimate, especially with the *out-of-plane* approach; (c) An accurate needle alignment before and during needle insertion is only possible with plenty of experience.

In this article, the concept of a new application field of medical navigation for ultrasound-guided regional anesthesia is presented to avoid the above-mentioned disadvantages. In addition, a laboratory experiment to verify the effectiveness, safety, precision and handling of the navigation method in comparison with standard ultrasound-guided regional anesthesia is described.

II. Material and Method

A. Concept of regional anesthesia using a navigation system and ultrasound imaging

The aim of the combination of navigation and ultrasound imaging is to assist the anesthesiologist in advancing the block needle to the desired endpoint in proximity to a targeted nerve. A stereocamera (*cam*) tracks, with a frequency of 20 Hz, the actual position and orientation of the ultrasonic probe with a tracker (*ust*) and a block needle (*bn*) with a tracker (*bnt*) (as shown in Fig. 1). Firstly, the 4x4 transformation matrix ${}^{img}\mathbf{T}_{bn}$ between the coordinate system of the block needle and that of the ultrasound image is determined by (1). Based on ${}^{img}\mathbf{T}_{bn}$, the intersection point *p*, between the axis of the block needle and the ultrasonic image, can be computed by (2). Additionally, the distance *d* from the needle tip to the ultrasonic beam along the needle axis is calcuted with (3). Subsequently, this point and the distance information are visualized in the ultrasonic image to assist the operator before and during needle insertion. Such visualizations should help to increase safety and effectiveness as published in [10].

$$
\begin{aligned}
{}^{img}\mathbf{T}_{bn} &= {}^{img}\mathbf{T}_{ust} \cdot \left({}^{cam}\mathbf{T}_{ust}\right)^{-1} \cdot {}^{cam}\mathbf{T}_{bnt} \cdot {}^{bnt}\mathbf{T}_{bn} \\
&= \begin{pmatrix} {}^{img}\mathbf{R}_{bn} & {}^{img}\mathbf{t}_{bn} \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} x_n & x_o & x_a & x_t \\ y_n & y_o & y_a & y_t \\ z_n & z_o & z_a & z_t \\ 0 & 0 & 0 & 1 \end{pmatrix}
\end{aligned} \tag{1}
$$

$$
{}^{img}\mathbf{P}_{p} = {}^{img}\mathbf{t}_{bn} + \left(-\frac{z_t}{z_a}\right) \cdot \begin{pmatrix} x_a \\ y_a \\ z_a \end{pmatrix} \tag{2}
$$

$$
d = \left| -\frac{z_t}{z_a} \right| \tag{3}
$$

B. Experiment

The experiment was carried out by ten test persons, who have no experience in ultrasound-guided regional anesthesia, on a specially-made phantom, analogous to a liver phantom [10]. No trained anesthetists were selected as test persons, in order to avoid the effect of training on the results. The phantom was mounted with four rows of three metal rods each, simulating a nerve and two blood vessels (illustrated in Fig. 2). The metal rods, with a diameter of 3.2 mm, were fixed on two base plates, so that the relative distances between them were kept constant. The metal rods were connected at each end to a device that is capable of detecting contact with the needle. The Terason ultrasonic system (TeraTech Inc., Burlington, USA) and the *liver assist* system [10], [11] (MIMED, Garching, Germany) were used.

The block needle was inserted with the *out-of-plane* approach, while administrating ultrasound-guided regional anesthesia on the phantom. The needle tip was tracked by the navigation system. Each test person was supposed to touch a target (*tgt*), with and without the navigation assistance (visualized intersection point and distance information). The target was defined by the position that lies 4 mm along a line, which is perpendicular to another line going through the top points of the two blood vessels in the image. The target, locating about 5-15 mm under the surface, was estimated by

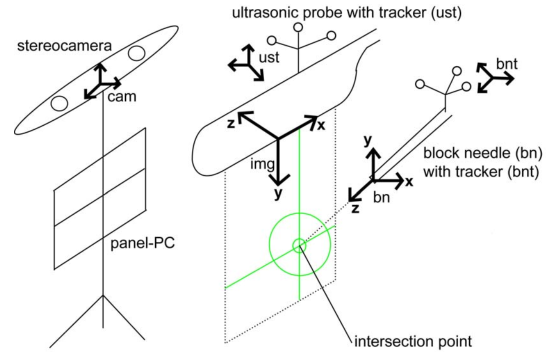

Fig. 1. Schematic representation of the concept of regional anesthesia using a navigation system and ultrasound imaging. The system consists of a stereocamera, a panel-pc, an ultrasound probe with a tracker (*ust*) and a block needle (*bn*) with another tracker (*bnt*). The intersection point between the needle axis and the image plane as well as the distance from the needle tip to the image plane are calculated and visualized in the real-time image.

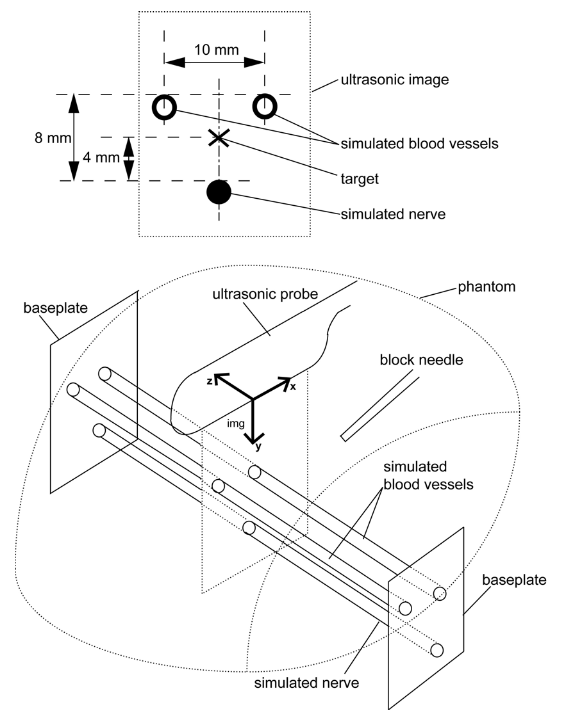

Fig. 2. Schematic illustration of the experimental setup without navigation assistance. For the experiment a phantom made of gel with three embedded metal rods simulating a nerve and two blood vessels was used. The test persons were supposed to touch a target that lies 4 mm vertically above the simulated nerve with a needle using the out-of-plane approach. The test persons performed this procedure with and without navigation assistance.

TABLE I

MEANS OF MEASURED VALUES AND RESULTS OF THE EVALUATION.

	$\overline{n_i}$		$\overline{t_e}$		$\overline{n_c}$		$\overline{d}$		e	
	without	*with*	*without*	*with*	*without*	*with*	*without*	*with*	*without*	*with*
P1	4.6	1.2	60.2	92.2	1.6	0.4	2.7	1.4	5	8
P2	2.6	1.6	11	18.4	0.2	0.2	3.7	3.5	4	7
P3	5.2	1.2	43.2	24.2	2.6	0	3.4	2.1	3	10
P4	4.4	1	33.4	20.6	2	0	5.7	1.2	3	10
P5	3	1.6	14.8	35.8	0.6	0.4	4.8	1.6	7	7
P6	3.4	1.8	44.8	82.8	2.4	0.4	3.9	2.2	2	8
P7	5	1	59.2	17	2	0	3.6	1.5	1	8
P8	5.6	1	59	37	2.2	0.4	3.7	2.7	3	6
P9	1.2	1	10.6	15	0	0	4.0	1.4	5	9
P10	2.4	1	31.8	34	0	0	3.9	2.0	4	7
Calculated *t*-value (P1-P10)	5.14		-0.11		3.62		5.21		-5.76	

each test person in the ultrasound image and was not specially marked. With the help of navigation assistance, test persons could first align the needle at the target before the insertion and then advance it towards the target. If the test person noticed that the needle was not advancing in the correct direction, the needle was supposed to be pulled out and inserted again. Every test ended once the test person was sure that the needle tip had reached the target or was in proximity to the target. At that moment, a screenshot and the transformation matrix ${}^{img}\mathbf{T}_{bn}$ were saved separately in two files. Two criteria were fulfilled to terminate the insertion by the test persons while using navigation assistance: the intersection point was close to the virtual target in the image, and the distance information was between -1 mm and 1 mm. Without navigation assistance, the needle advancing was stopped as soon as the tip was visible in proximity to the target. Each test was repeated five times by the same test person. After the tests the test persons were asked to evaluate the handling on a scale from 1 (= very difficult) to 10 (= absolutely easy).

As quantitative measurement values the following parameters were recorded during or determined after the experiment:

- Number of needle insertions n_i
- Execution time t_e (the time from needle insertion until the target was reached)
- Number of contacts with nerves or blood vessels n_c
- Difference (Distance) d between the needle tip and the target (d has the same sign as the z-coordinate of ${}^{img}\mathbf{t}_{bn}$. Negative values mean the needle tip lies in front of the imaging plane and vice versa) ($|d| = |{}^{img}\mathbf{t}_{bn} - {}^{img}\mathbf{p}_{tgt}|$, where ${}^{img}\mathbf{p}_{tgt}$ is the target coordinates that are determined manually in the image after the experiment, as shown in Fig. 3.)
- Evaluation of the handling e.

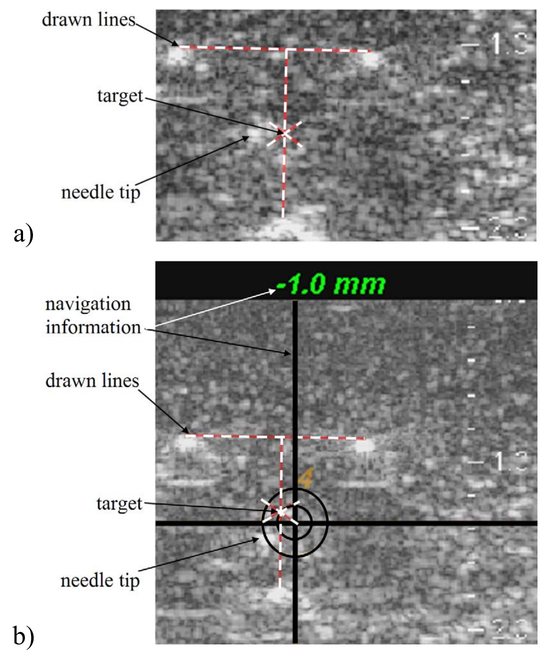

Fig. 3. Determination of the target coordinates in ultrasonic images through manual analysis of the screenshots. The broken lines were drawn in screenshots after the experiment. a) A screenshot of a test without navigation assistance. b) A screenshot of a test with navigation assistance (visualization of the intersection point and distance in the ultrasonic image).

C. Statistical analysis of the data

At first, the mean of each measured parameter (excluding evaluation e) was computed separately for every test person with and without navigation assistance. For the means and the results of the evaluation, two-sample one-tailed paired t-test with a significance level of 1% was applied. The corresponding critical t-value is 2.821.

III. RESULTS

The means of measured parameters, the results of the evaluation of each test person, and the calculated t-values for with and without navigation assistance are shown in Table I. The calculated t-values for all the parameters (except execution time t_e) are larger than the critical t-value. Therefore, during ultrasound-guided regional anesthesia on the phantom without navigation assistance, n_i, n_c and d are larger than those with navigation assistance at a significance level of 1%. At the same time, the evaluation value e of the handling is smaller without navigation assistance. There is no statistical difference with respect to execution time t_e. A comparable result dealing with the insertion number and execution time were found during tumor puncture with a dissector in [10].

IV. Discussion

The results show that navigation assistance provides a significant improvement with respect to safety, precision and easy handling for ultrasound-guided regional anesthesia on phantoms. The effectiveness is also increased by the use of navigation assitance with a comparable execution time, since the number of needle insertions could be reduced significantly. While using navigation, most of the execution time is spent in aligning the intersection point with the target before the needle insertion. Obviously, this could be improved by brief training. Thereafter, the effectiveness of navigation assistance can be increased even more after a few training sessions. These advantages of navigation assistance can be expected during real ultrasound-guided regional anesthesia on patients. They are made possible by the navigation assistance which helps to accurately align the needle direction even before insertion and to visualize the needle tip and the tip-image distance. Without navigation assistance, identifying the needle tip in an ultrasonic image was very difficult when using the *out-of-plane* approach because of the fine needle tip. The identifications were almost always too late when the needle tip had passed the ultrasonic beam. The difference between with and without navigation assistance might less significant when trained personnel were selected in the experiment. Thereby, the navigation assistance is especially beneficial for the training of novices.

Nevertheless, there are still some disadvantages to such navigation assistance: high equipment costs, fluctuation of intersection point in the display due to statistical measurement characteristic, line-of-sight problem, and setup time. The additional costs associated with a navigation system could be compensated for by the advantages and distributed across a large number of procedures. A digital filter could minimize the fluctuation of the intersection point in the visualization. In order to prevent the line-of-sight problem, the stereo camera should be positioned correctly, for each individual procedure. An electromagnetic navigation system might completely resolve this problem, but there are other problems such as poor spatial and angular resolution, vulnerability to external influences, and electromagnetic radiation. The setup time of the navigation system can be reduced by system optimization (e.g., direct integration in an ultrasound system) and training.

It has also been observed that the insertion path changed frequently during needle advancement with navigation assistance. The frequent path change is initiated by normal human ability and could be easily avoided, if a commercial mechanical needle-guidance system is used.

V. Conclusion

The primary advantages of the application of medical navigation for ultrasound-guided regional anesthesia have been verified quantitatively and qualitatively in a phantom experiment. Thereby, effectiveness, patient safety, puncture precision and handling are improved significantly. With navigation assistance, many of the problems which arise during ultrasound-guided regional anesthesia could be avoided. The experimental results may be transferable to other applications for ultrasound-guided interventions. However, these advantages should be verified in clinical procedures. Furthermore, the visualization of the applied system for the experiment is not specialized for regional anesthesia. It should be adapted to clinical routine procedures. The software could be simplified and the needle shaft can also be visualized. The optimal way is to integrate the navigation assistance in an ultrasound system.

References

[1] N.M. Denny, and W. Harrop-Griffiths, "Location, location, location! Ultrasound imaging in regional anaesthesia," *Br J Anaesth*, vol. 94, pp. 1–3, 2005.

[2] R. Ganta, R.A. Cajee, and R.W. Henthorn, "Use of transcutaneous nerve stimulation to assist interscalene block," *Anesth Analg*, vol. 76, pp. 914–5, 1993.

[3] W.F. Urmey and P. Grossi, "Percutaneous electrode guidance: noninvasive technique for prelocation of peripheral nerves to facilitate peripheral plexus of nerve block," *Reg Anesth Pain Med*, vol. 27, pp. 261–7, 2002.

[4] X. Capdevila, S. Lopez, N. Bernard, C. Dadure, F. Motais, P. Biboulet, O. Choquet, "Percutaneous electrode guidance using the insulated needle for prelocation of peripheral nerves during axillary plexus blocks," *Reg Anesth Pain Med*, vol. 29, pp. 206–11, 2004.

[5] A.T. Gray, "Ultrasound-guided regional anesthesia. Current state of the art," *Anesthesiology*, vol. 104, pp. 368-73, 2006.

[6] P. Marhofer and V.W. Chan, "Ultrasound-guided regional anesthesia: current concepts and future trends," *Anesth Analg*, vol. 104, pp. 1265-9, 2007.

[7] B.D. Sites and R. Brull, "Ultrasound guidance in peripheral regional anesthesia: philosophy, evidence-based medicine, and techniques," *Curr Opin Anaesthesiol*, vol. 19, pp. 630-9, 2006

[8] P. Karaca, A. Hadzic, Yufa M, J.D. Vloka, A.R. Brown, A. Visan, K. Sanborn, and A.C. Santos, "Painful paresthesiae are infrequent during brachial plexus localization using low-current peripheral nerve stimulation," *Reg Anesth Pain Med*, vol. 28, pp. 380–3, 2003.

[9] E. Jank and T.C. Lueth, "Ein einfaches System zur Unterstützung ultraschallgezielter Biopsien," *at – Automatisierungstechnik*, Band 52, Issue 11, pp. 549, 2004.

[10] J. Schwaiger, M. Markert, N. Shevchenko, and T.C. Lueth, "The Effects of Real-Time Image Navigation in Operative Liver Surgery," *Int J Comput Assist Radiol Surg*, 2011 May 5. [Epub ahead of print].

[11] N. Doerfler, B. Seidl, N. Shevchenko, R. Stenzel, and T.C. Lueth, "Blood Vessel Detection in Navigated Ultrasound: An Assistance System for Liver Resections," in *Proceedings of IEEE International Conference on Complex Medical Engineering (CME 2011)*, Harbin, China, May 22 to May 25, 2011.