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Rotatable flexible neck-model for the evaluation of minimally invasive operation procedures with the help of an ultrasound-based navigation system

Nils Jansen, Thorsten Brennecke, Julia Hirschfeld, Lena Colter, Joerg Raczkowsky, Heinz Woern and Joerg Schipper

Abstract— **Future minimally invasive neck surgery requires a navigation system adapted to the actual intraoperative bedding of the patient. The detection of the bedding-caused tissue shift is essential for a safe orientation for the surgeons' new endoscopic operation procedures in neck surgery. It is essential to visualize the relation between important anatomic landmarks and operation instruments at any time. Within the scientific project SACAS we focus on developing an ultrasound supported navigation system based on preoperative imaging which considers the intraoperative tissue shift. A rotatable, flexible neck-model provides the basis for our analyses to evaluate the tissue shift and to invent the new navigation system for endoscopic neck surgery. The total registration error of the system was 2 mm.**

I. INTRODUCTION

DUE to the good visibility of the neck region patients wish to retain only small scars after undergoing surgery in this area. Therefore we consider the innovation of new minimally invasive operation procedures which leave only small scars in head and neck surgery as very important. A well-known problem in minimally invasive neck surgery is the upcoming tissue shift in comparison to preoperative imaging caused by the bedding of the patient on the operating table. This tissue shift is up to this point a great impediment to the invention of a computer assisted and imaging based navigation system for minimally invasive operation procedures in cervical surgery.

Within the DFG-founded scientific project SACAS (Sonographic Aided Computer Assisted Surgery) we are developing a new intraoperative navigation system for minimally invasive cervical surgery which is based on the data of the preoperative imaging of the patient and which uses intraoperative ultrasound imaging after the bedding of the patient prior the operation to define the individual tissue shift [1].

To establish this navigation system and to investigate the grade of tissue shift we also invented a new flexible full-size neck-model which is mostly made of *polyvinyl alcohol (PVA)* [2]. A human neck served as a pattern for the model mold. In this early stage of invention the neck-model only contains important anatomic structures, such as carotid artery or jugular vein. The neck-model is suitable for multimodality imaging such as CT, MRI and sonography. A socket was invented, which was used to set up predefined neck-model rotations.

The socket and the neck-model are needed to develop and evaluate the navigation system. Our aim is to use ultrasound imaging to detect the individual tissue shift in order to align the preoperative imaging to the actual position of the patient during the surgery. The neck-model is used to evaluate the system.

II. MATERIALS AND METHODS

A. Phantom

The basis of the presented scientific studies is the first PVA-based flexible, full-size neck-model. We used a human neck as a pattern to design a mold. Important anatomic landmarks such as the carotid artery are implemented by using of silicone drainage tubes (Redax S.r.l., Mirandola Italy). The PVA neck-model imitates the characteristics of human neck tissue very well. Further details regarding the material properties details see [3, 4]. Due to the selected materials, it can be easily evaluated by ultrasound-, CT- and MRI-imaging (see Fig. 1). In order to test the bond between the used materials, we did not use other additives that improve the connectivity.

With the help of the casting pattern and the designed socket (see Fig. 2) it is possible to reproduce identical neck-models. Relinquishing the idea of integrating more anatomic structures to the neck-model, it was possible to focus on the most important anatomic landmarks and their position influenced by the intraoperative neck tissue-shift.

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Nils Jansen is with the Clinic for ENT, Duesseldorf University Hospital, Duesseldorf 40225 Germany (phone: +49-211-8117570; e-mail: Nils.Jansen@med.uni-duesseldorf.de).

Thorsten Brennecke is with Karlsruhe Institute of Technology, Karlsruhe, 76137 Germany. (+49-721-60847993; e-mail: brennecke@kit.edu).

Julia Hirschfeld is with the Clinic for ENT, Duesseldorf University Hospital, Duesseldorf 40225 Germany, (e-mail: Julia.Hirschfeld@med.uni-duesseldorf.de).

Lena Colter is with Clinic for ENT, Duesseldorf University Hospital, Duesseldorf 40225 Germany

Joerg Raczkowsky is with Karlsruhe Institute of Technology, Karlsruhe, 76137 Germany. (e-mail: joerg.raczkowsky@kit.edu).

Heinz Woern is with Karlsruhe Institute of Technology, Karlsruhe, 76137 Germany. (e-mail: heinz.woern@kit.edu).

Joerg Schipper is with the Clinic for ENT, Duesseldorf University Hospital, Duesseldorf 40225 Germany. (e-mail: Joerg.Schipper@med.uni-duesseldorf.de).

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We attached CT- and MRI-fiducial markers (BRAINLab, Feldkirchen, Germany) to the neck-model socket to be able to register the different types of imaging and their rotation positions with each other (see Fig. 3).

The fiducials were changed depending on the different types of radiological examination. The base plate of the markers can be also used as marker point for a pointer and for calibration of the navigation system.

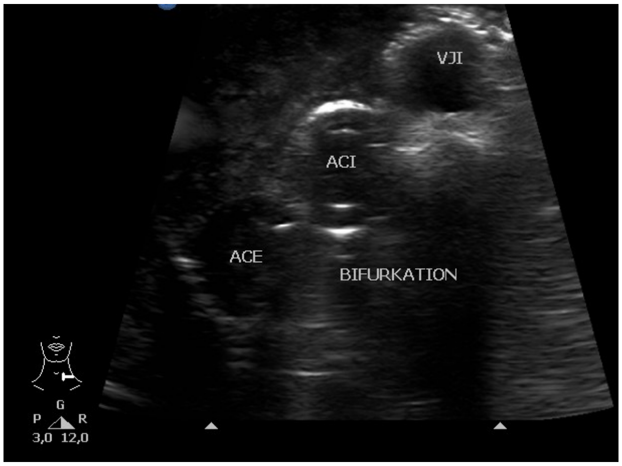

Fig. 1. Ultrasound picture of the bifurcation of left arteria carotis and vena jugularis (Philips HD11XE; L12-3)

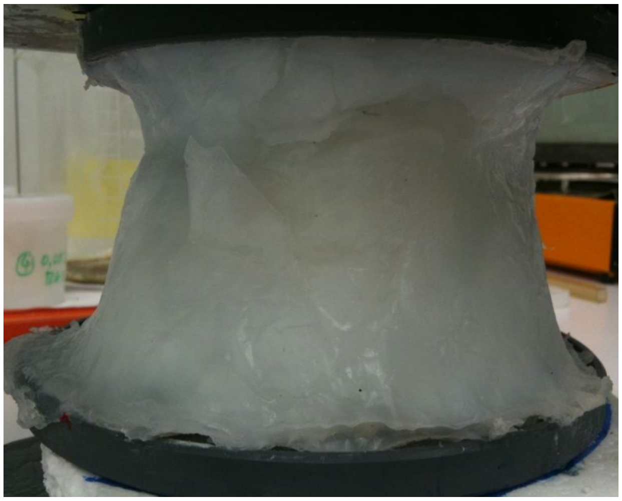

Fig. 2. Neck-model in its socket

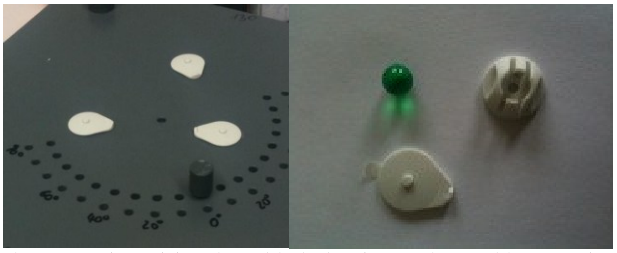

Fig. 3. Neck model socket with device for rotating positions, marker plates and components (Brainlab, Feldkirchen, Germany)

B. *Navigation system*

As components for the surgical navigation system, the Fraunhofer DiPhAS ultrasound research platform [5] with a 7.5 MHz Vermon L7 transducer with custom navigation marker mount, a NDI Polaris tracking system, the PLUS toolkit [6] and a neck-shift-model using the Finite Elements method were used. In the following experiments, the neck-shift-model will also be used, to which a navigation reference was attached for registration. The most imported parts are shown in Fig. 4.

The ultrasound images are streamed to the PLUS toolkit using OpenIGTLink [7]. PLUS is used for acquiring tracked ultrasound images and vwolume reconstruction, i.e. a freehand 3D ultrasound reconstruction, which is an important part of the system. The freehand 3D ultrasound was spatially calibrated with an error of 0.75 mm.

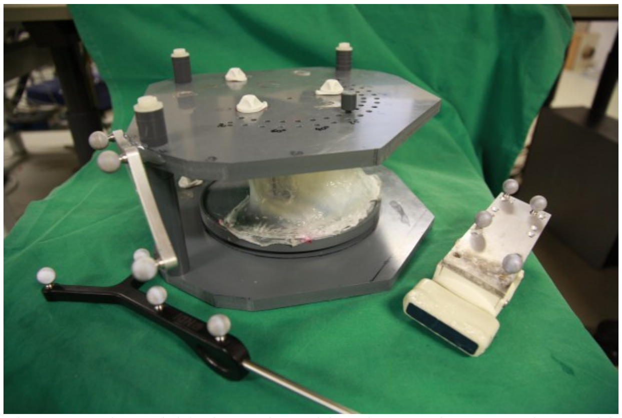

Fig. 4. Neck-model in its socket with pointer and US transducer with attached navigation markers

The ultrasound parameters were chosen with respect to the model material PVA, which has similar acoustic properties like human tissue [4]. We are using a relatively small depth to maximize the frame rate.

C. *Evaluation*

The purpose of the phantom is to simulate real-time ultrasound guidance during minimally-invasive procedures, which is reflected in the evaluation. With the navigation system we acquired a volume of the model following the course of the internal structure representing the carotid artery. We registered the MRI-imaging volumes of the neck-model within the volumes recorded by the navigation system to the model attached navigation reference. To evaluate the error we measured carotid diameter in different slices of the volumes and compared them.

III. RESULTS

The method outlined above allows us to reproduce the model as required reliable accurate. The PVA model was sonographically examined to evaluate the quality of the PVA-gel. Especially air pockets influence the imaging quality negatively. It turned out that no relevant interference structures were observed.

The first socket design for the neck-model did not consider the size of the MRI head coil. The design had to adapted to the size constraints of this coil.

The used CT fiducials fulfilled the expectations and were clearly visible in the scan. The MRI fiducals had some drawback regarding the T2-weighted scans. The spin echo was very low so a clear detection of the fiducials was very difficult. A good result could be achieved in T1-weighted scans, where the markers were clearly visible. To ensure we can still use the more suitable T2-weighted scan, we had to register both scans types. The contrast was still good enough to identify the fiducials.

During the scans it was possible to achieve constant rotation angles from 0° to 50°. The setup of the socket with the desired angle was uncomplicated. In spite of the large number of rotation adjustments and the great resulting material stress no degeneration or other changes could be observed. In addition the PVA was nonperishable during the experiments. So PVA turned out to be a suitable material for the flexible neck-model. Fig. 5 shows the MRI scans in neutral position (0° rotation) and 40° rotation position.

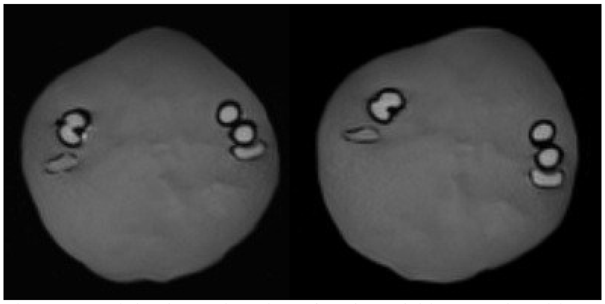

Fig. 5. T2-teighted MRI imaging of neck model in neutral position (0° rotation) and 40° rotation position

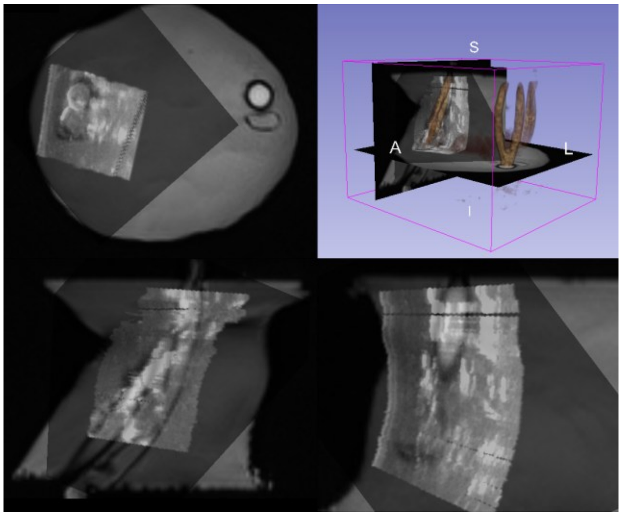

Fig. 6. The Registered MRI- and ultrasound volumes.

Choosing fitting ultrasound parameters was an important part during the scans with the navigation system. The used materials offer excellent ultrasound properties. PVA as well as the silicone used for the internal structures were suitable for the recording process.

A drawback was however that the bonding between both materials was not adequate. Due to that air pockets formed at the boundary especially with an adjusted rotation. In CT- and MRI-imaging there air pockets were negligible. In sonography this caused large artifacts which lower the quality of the acquired volume.

Fig. 6 shows the registered MRI and freehand 3D volumes in 0° rotation. Between the different rotations no significant difference could be observed. So the following results refer to the 0° rotation. The measurements in the registered volumes resulted in an absolute deviation of 2 mm; the relative deviation was 0.19 mm. The carotid artery diameter seems to be underestimated in the ultrasound data. Table II shows the measurement results in detail.

TABLE II
RESULTS OF THE CAROTID ARTERY DIAMETER MEASUREMENT

	MRI	Sonography
Mean	10.8 mm	8.8 mm
Standard deviation	0.38 mm	0.22 mm

The resulting deviations between the registered MRI and freehand 3D ultrasound volumes.

IV. CONCLUSIONS

In the course of the SACAS project and with the help of our established neck-model and MRI- or CT-imaging data we are confident to establish a navigation system for minimally invasive neck surgery which will visualize the tissue shift influenced anatomy of the neck region for the surgeon within a endoscopic operation procedure. The neck-model imitates the attributes of human skin and tissue very well and can be easily investigated by any kind of radiologic imaging. This phantom provides a suitable test bed for improving the FEM neck model.

For the development of a navigation system an estimation of the intraoperative tissue shift due to the patient's bedding is necessary. We focused on characteristic anatomical landmarks such as carotid artery and detected and evaluated the tissue shift. We registered the volumes of different landmark structures in different types of imaging and compared the result. In comparison to MRI, the ultrasound imaging volumes of the registered structures resulted in a size shift of by 2 mm. We discovered that the aberration is not rising with increasing rotation degrees. The amount of the rotation-caused shift of the carotid artery in the neck model is very similar to what we observed in the MRI-examinations is of patients in different rotation positions [8]. At this point of invention, the volumes of the different structures are registered manually but we are hopeful to perform the registration process automatically in future examinations. One of the problems so far is that very small inclusions of trapped air between the silicone tubes and the PVA influence the accuracy of our ultrasound results. In the next trails solutions for this issue will be evaluated (e.g. adhesion).

To be able to design a higher number of reproducible neck-models we are planning to invent a casting mold with the help of a rapid prototyping system which integrates parts of the socket. It is also possible to use the built up model to perform endoscopic operation procedures with this neck-model. Therefore the neck-model can play an important role in the education of young surgeons to learn new operation procedures with the help of the neck model before performing a neck operation on a patient.

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