DEVELOPMENT OF PROTOTYPE FOR NAVIGATED REAL-TIME SONOGRAPHY FOR THE HEAD AND NECK REGION

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Abstract: Background. To date, few imaging methods have been established for the head and neck region, in particular for soft tissues, that allow adequate visualization and simultaneously adequate real-time orientation.

Methods. We report a new method using a navigated ultrasound device and a navigated surgical instrument that allows—even in the absence of bony landmarks—appropriate visualization and reliable orientation in real time.

Results. The practical applicability of the system was tested. Good handling and acceptance of the system could be shown. The “3-dimensional error” derived from the deviations in all 3 dimensions lies at 0.64 mm.

Conclusions. With this ultrasound-guided navigated procedure, an accurate approach of soft tissue structures with a surgical instrument is possible. Changes of the situs are represented in real time. ©2007 Wiley Periodicals, Inc. Head Neck 30: 215–221, 2008

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Because of the special anatomical situation of the head and neck region, there has been the desire for improved visualization and, particularly during invasive procedures, orientation to distinguish pathologic findings from healthy tissues in ear, nose, and throat (ENT) surgery.

Established visualization methods are CT and MRI. These techniques are normally carried out before an invasive procedure and represent the status at that particular moment. The major disadvantage of both methods is that they are “static” and not “dynamic”: changes that occur during invasive procedures cannot be shown directly. Therefore, all now-common navigated computer-assisted surgery for the head and neck region has its limitations. Furthermore, these imaging techniques are only reliable in direct proximity to bone structures serving as landmarks. In soft tissue surgery without such landmarks, “tissue shift” makes the navigation quite inaccurate.

Here sonography offers an alternative. For many years, sonography has been an important and indispensable instrument for noninvasive and invasive diagnostics: visualization of individual anatomical sites, depiction of pathologic find-
ings (eg, size, positional relationship, spread), ultrasound-guided biopsies and punctures of suspect structures. In the last few years, sonography also has been increasingly used for therapeutic procedures, for example, intraoperative orientation (seeking and visualizing suspect target structures for surgery) and definition of adequate resection limits.

Sonography provides the following advantages: (1) possibility of immediate visualization, (2) “dynamic” method (ie, direct representation of changes during the invasive procedure), (3) easy handling, (4) widespread use, (5) inexpensive technique, (6) high resolution and good in-depth representation, (7) no radiation exposure.

The main problem with invasive diagnostic or intraoperative sonography is adequate visualization, for example, of an instrument, since it can only be shown accurately when it is exactly on a level with the two-dimensional (2D) ultrasound image.

Remedy is offered by a new method that we refer to as navigated real-time sonography (NRTS) (Figure 1). With NRTS, a navigated ultrasound probe is combined with a navigated surgical instrument. The position of the instrument tip (3-dimensional [3D] dataset) is simultaneously integrated into the 2D dataset of the ultrasound image. The navigation technique allows accurate representation of the very position of the instrument in relationship to the individual anatomy. Information as to direction and distance between the instrument and the target structure is made available. Furthermore, this technique enables the investigator to move the instrument into the ultrasound image and to aim the instrument “virtually” (insertion angle, penetration depth) at the target structure. The actual positional relationship is represented on the computer display, and the necessary information concerning the direction and distance of the instrument from the target is made available.

MATERIALS AND METHODS

The prototype of this NRTS was designed for NRTS of the head and neck region.

System Components. Figure 2 shows the following system components: ultrasound device with navigated ultrasound probe, navigated surgical instrument, computer and software, coordinate sensor, and 2 passive rigid bodies.

Procedural Steps/Program. The procedural steps involved in NRTS are calibration, determination of targeting accuracy, and visualization and practical application.

Ultrasound Device and Navigated Ultrasound Probe. A conventional ultrasound system was used (Echo Blaster 128 INT-1Z, Telemed, Lithuania) with a 6-MHz linear probe and an 80-mm window. The ultrasound probe was equipped with
an interface to the rigid body for navigation. A fixed holding device for the rigid bodies was installed so that the position of the rigid bodies cannot be altered.

Navigated Instrument. A pointer was fitted with an interface to the rigid body, so that the tip of the instrument could also be calibrated.

Computer and Software. A Dell Precision 380 (Round Rock, Texas) with the following system specifications was used as the hardware component: pentium 4 CPU 2.8 GHz, 512 MB RAM, MS Windows XP; graphics card: NVIDIA Quadro FX 1400; MS Visual Studio C++.

Special software for the instrument calibration procedure and for the application was developed.

Coordinate Sensor. The highly sensitive Optotrak-System (Northern Digital, Canada) was used as a video-optical infrared coordinate sensor for the one-off calibration procedure. The root mean square error of this system in finding a point in space is 0.09 mm.

The Polaris-System (Northern Digital, Canada) was used to determine the targeting accuracy and as sensor during the subsequent practical application. The accuracy in finding a point in space is 0.24 mm.

Calibration Procedure. The object of the calibration procedure is to combine the 2D ultrasound image of the navigated ultrasound probe with the navigation coordinates of the surgical instrument. The calibration is performed using an Optotrak coordinate sensor. It is performed only once, because the holding device for the rigid bodies is fitted onto the ultrasound probe in a fixed, unalterable position. Thus, the data recorded in this calibration procedure can be relied on, during subsequent applications. Only the rigid bodies are exchanged each time before the practical application.

The calibration procedure described herein was developed for this application (Figure 3). Specifically, the calibration body consists of 9 filaments arranged in 3 different planes in the shape of an N. The location of these filaments had been previously determined by precise measurement using a UMM 850 coordinate measuring machine (Zeiss, Germany). For calibration, the ultrasound probe was placed in a holder on the calibration body. The calibration body and the ultrasound probe were both fitted with a passive rigid body. The coordinates of the ultrasound probe and the calibration body were conveyed to the coordinate sensor. The calibration device was immersed in water. The speed of sound here was 1540 m/sec-ond, nearly the same as in body tissue. The filaments were then visible in the ultrasound scan. An individually developed software (contour-seeking algorithm) calculated the position of the filament center to acquire the exact position of the thread points. The position of the ultrasound probe in relation to the calibration body could be precisely determined from the distances between these points.
Determining the Targeting Accuracy. To determine the actual targeting accuracy and to find possible deviations, distortions, or inaccuracies in the ultrasound or the navigation system, we scrutinized our calibration data. This was also a one-off procedure: no repetitions were necessary during subsequent practical applications. To determine the accuracy of the ultrasound navigation, a phantom cross was used (a metal plate with a cross of specified geometry). This metal plate was located in the coordinate system of the water-filled container (Figure 4) and its position was previously defined using the UMM 850 coordinate measuring machine (Zeiss, Germany). The container was fitted with a reference transmitter. The navigated ultrasound probe was mounted on a movable arm. It was then moved stepwise toward the point of intersection of the lines until it reached the point exactly.

To ascertain the accuracy of the ultrasound image in the different areas, that is, also in those sections of the image that are not in direct proximity to the ultrasound probe, 9 sectors of the ultrasonic image were defined. Measurements as described earlier were also carried out in all 9 sectors (Figure 5). A specially developed algorithm was used to identify the contours and to calculate the point area. The Polaris system, which is used in the subsequent practical application (see below), was used to define the coordinates. The values recorded show the accuracy of spotting a point in the ultrasonic image. Each measurement was repeated 10 times. The values gained by this
method were compared with the results from the precision measuring room for verification.

**Visualization and Practical Application.** The system for practical application comprised the following components: ultrasound device with navigable ultrasound probe, navigated instrument, computer, and Polaris coordinate sensor. The pointer and the ultrasound probe each were fitted with a passive rigid body. An individual software was designed for the application in the head and neck area: the ultrasonic image was displayed on screen in digitized form in real time, that is, the image units were converted into millimeters.

The surgical instrument could be tracked by the navigation system in 6 degrees of freedom (df). The virtual image of the instrument tip was displayed on the screen, so that the 3D position of the instrument tip and its relationship to the ultrasound image was known at all times.

The handling of the real-time ultrasonic navigation was investigated by 2 ENT surgeons in vitro: a target structure (metal ball) was installed in a water container. The Polaris system was used as the coordinate sensor. The investigator held the navigated ultrasound probe in 1 hand and the navigated instrument in the other (Figure 6). First, the target structure was depicted sonographically and marked on screen by mouse-click. From then on, this marked structure was tracked with the help of the contour-seeking algorithm described. When the marked structure moved on the ultrasound image, the red “target point” moved with it. The navigated instrument was then moved toward the target point with no visual control. The position of the navigated instrument was shown on the display. Green arrows supported the navigation by showing the direction in which the instrument must be moved (left/right or up/down). The third dimension was indicated by the size and color of the coordinate cross: if the instrument was far away from the marked structure, then the cross was large. The green color meant that the navigated instrument was in front of the ultrasound plane (Figure 7). As the instrument moved closer to the structure, the cross became continuously smaller. If the navigated instrument broke through the ultrasound plane, that is, it was behind it, the color changed and the coordinate cross became red. When the instrument was situated exactly in the ultrasound plane, a circle appeared around the cross and a sound signal was emitted.

**RESULTS**

To determine the targeting accuracy, the points resulting from the ultrasonic navigation were compared for all 9 sectors of the ultrasonic image with measurements of the UMM 850 coordinate measuring machine. The measurements were repeated 10 times for all sectors. The following deviations of the $x$, $y$, and $z$-values were obtained: 

$x = 0.31 \pm 0.28$ mm; $y = 0.21 \pm 0.15$ mm; $z = -0.53 \pm 0.14$ mm.

This corresponds to a 3D mean error of $0.64 \pm 0.34$ mm.

The practical applicability of the system was tested on a model by 2 ENT surgeons. Good handling and acceptance of the system was shown. The navigation aids on the display (arrows, size, and color of the coordinate system cross) allowed rapid and accurate orientation of the instrument toward the target.

**DISCUSSION**

A prototype of an NRTS was developed, which permits NRTS of head and neck structures. The ultrasound probe and a surgical instrument are navigated, so that their 3D position is known
simultaneously. This novel navigation technique facilitates precision targeting of a sonographically depicted structure by a navigated instrument. The distance of the instrument and its relationship to the ultrasound plane as well as to the target structure (region of interest [ROI]) is integrated into the 2D ultrasound image using an appropriate form of presentation, making accurate targeting of the ROI possible. The advantage of this method is a real-time visualization, which can display changes in the 3D relationship of the ROI immediately.

The manufacturer of the ultrasound device specifies its accuracy at 0.3 mm (lateral) and 0.3 mm (axial) for the given frequency of 6 MHz. The “system deviation” using our prototype lies at 0.64 mm (“3D error” derived from the deviations in all 3 dimensions). This is absolutely within the limits of acceptability for the user and surmounts the accuracy of other navigated methods reported recently. One possible explanation could be that the ultrasound probe in our model was calibrated with the extremely accurate Optotrak coordinate sensor. Perhaps the navigation procedure can be blamed for the minimal residual inaccuracy between the results of the ultrasonic navigation and the accuracy of the ultrasound device, but this is negligible in practical application.

Advantages of the technique described with regard to subsequent application are as follows.

First, in contrast to other common navigation procedures (eg, in surgery close to the base of the skull or in bone surgery), it is not necessary to attach a fixed reference rigid body to the patient’s body. The function of such a reference rigid body, which must be attached in direct proximity to the operating site, is to guarantee reliable navigation even when either the pointing device or the location of the object is altered. To avoid navigational inaccuracies or deviations, the reference rigid body should be situated in direct spatial proximity to the rigid body of the navigated instrument. The system described in this paper functions without a fixed reference rigid body, since the ultrasonic probe and the instrument are navigated in real time. This means that any alterations occurring in operating site and the change in location of the instrument are immediately displayed in the ultrasonic image. The advantage of this navigation method for soft tissue surgery in the neck is that in this region there are no anatomical structures in direct proximity to the operating site that would allow easy fixation of a reference body.

Second, changes or shifts that occur during real-time navigation (eg, intraoperatively through resection) are immediately visible in the ultrasonic image (ie, the ultrasonic imaging provides the actual status at all times). In contrast to previously described sonographic navigation techniques in the head and neck region, there is no...
need for preoperative imaging (CT or MRI) to provide orientation for the navigation.

The prototype for NRTS in the head and neck region described in this paper offers a very precise navigation method. Further in vitro investigations to establish the accuracy, acceptance, and simplicity of handling of this system as well as any inaccuracy factors it may contain are planned, followed by practical application in vivo during a subsequent phase.

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**REFERENCES**