Auditory Support for Navigated Radiofrequency Ablation

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Abstract:

Radiofrequency ablation is applied to treat a lesion using a needle inserted into the patient, which delivers local radiofrequency energy. Guided surgical methods allow surgeons to view the placement of the needle in relation to the patient to aid in guiding the tip of the needle to the target point. Unfortunately, such methods require that surgeons remove attention from the patient in order to receive guidance information from a screen. We introduce a novel method to align and insert an ablation needle using auditory display, allowing the surgeon to retain attention on the patient. First evaluation results show that novice users can successfully guide a needle towards a target point using primarily auditory display. We hypothesize that successful auditory display will lead to increased attention on the patient and reduce unnecessary operator head and neck movements.

Keywords: auditory display, radiofrequency ablation, computer-assisted interventions

1 Problem

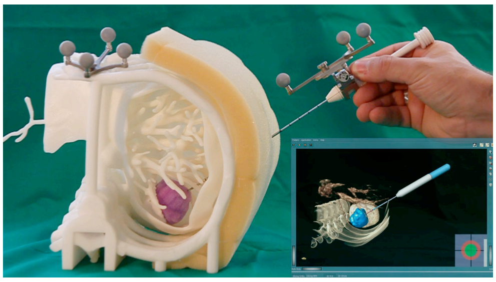
Radiofrequency ablation is used to locally apply heat to malignant lesions and destroy them. The task requires the physician to place the tip of the needle on the surface of the patient, aligning the needle to a pre-planned angle, and then inserting the lesion to a sufficient depth to place the tip of the needle inside the lesion. After the tip of the needle has been placed inside the lesion, radiofrequency energy is applied for a specified duration, effectively destroying the lesion. This process may be repeated and applied to multiple lesions in the patient.

To aid the physician in transferring preinterventional needle placement planning to the operating environment, navigation systems have been developed [1] to display the position of the ablation needle with respect to the patient's body in 3D space. This information is either displayed on a screen or projected directly on the patient [2], [3]. These navigational methods, however, have several limitations. Screens in the operating room require that the surgeon remove attention from the patient to observe guidance information elsewhere in an operating environment already overloaded with visual cues [4]. Displaying guidance information onto the patient by means of video projectors or lasers [3] onto the local area of interest is interrupted by surgeon's hand and instrument movements. In addition, no instant notification of progress or completion is given when the surgeon inserts and reaches the target lesion.

We hypothesize that the introduction of auditory display to the task of ablation needle placement can fill a void in navigated interventions by allowing the physician to keep focus on the patient during the three primary ablation needle placement tasks of tip placement, shaft alignment, and insertion towards the target lesion. Auditory display has been used in anesthesia [5] but is very uncommon as a modality for navigated interventions. Woerdeman et al. [6] and Hansen et al. [7] have described basic evaluations of employing auditory display for navigated surgery using phantom models.

2 Materials and Methods

Navigation System: Currently, visual guidance cues for radiofrequency ablation employ a crosshair and both a small and a large circle to relay the position of the needle tip and the angle of the shaft [3] (Fig. 1). The distance of the small circle to the crosshair origin denotes the distance of the tip of the needle to the planned insertion point (when within 30 mm from the insertion point), and the distance of the large circle denotes the distance of the shaft to the planned insertion angle. When both tip and shaft angle are correct, then the needle is ready for insertion. The insertion depth and target are visualized as a vertical progress bar showing the distance of the tip to the lesion goal.



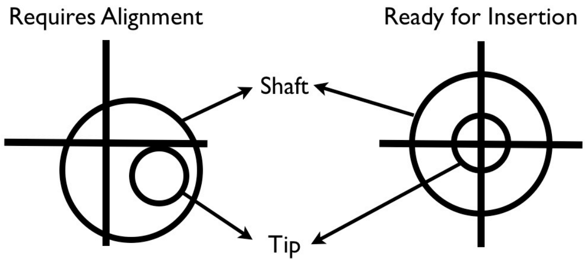


Figure 1: Left: Phantom model with ablation needle. Right: Model of visual alignment aid for tip and shaft

Auditory Display: The auditory display extension to the existing navigation system utilizes the same crosshair paradigm as the visual method, transmitting the distance of the tip and the shaft angle in two dimensions relative to the crosshair origin. In addition, the insertion depth is transmitted in one dimension. Two auditory display methods were developed to aid tip placement and shaft alignment. Both methods may be used for both tip placement and shaft alignment.

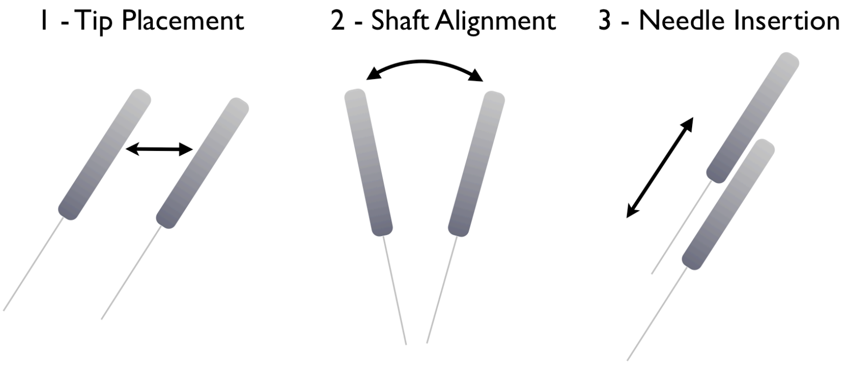


Figure 2: Three steps towards final ablation needle insertion

The auditory methods were designed to correspond to tasks being completed in sequence: tip placement, shaft alignment, and finally needle insertion (Fig. 2). In the first auditory method (Fig. 3, left), two repeated pulses of different pitches (260 Hz and 520 Hz, respectively) are played alternatively. Changes in absolute distance to the y-axis (for tip, between 30 and 0 mm from origin) are linearly mapped to speed between pulses, beginning slowly at the left and right edges (4 pulses per second), progressing faster towards the center (10 pulses per second). Changes in absolute distance to the x-axis are mapped to the change in pitch of the alternating pulses (at aforementioned frequencies), which converge towards the center, much like tuning a guitar using a reference tone. At the top and bottom edges of the local area within 30 mm distance to origin, the pitches are spaced one octave apart. When approaching the center, the lower-pitched pulse rises in pitch until it reaches the same pitch as the higher pulse. When the tip or shaft is within a defined distance, a confirmation tone is played (a bank of three sine waves with amplitude modulation of 2 Hz), signaling to the user that the tip placement or shaft alignment is acceptable.

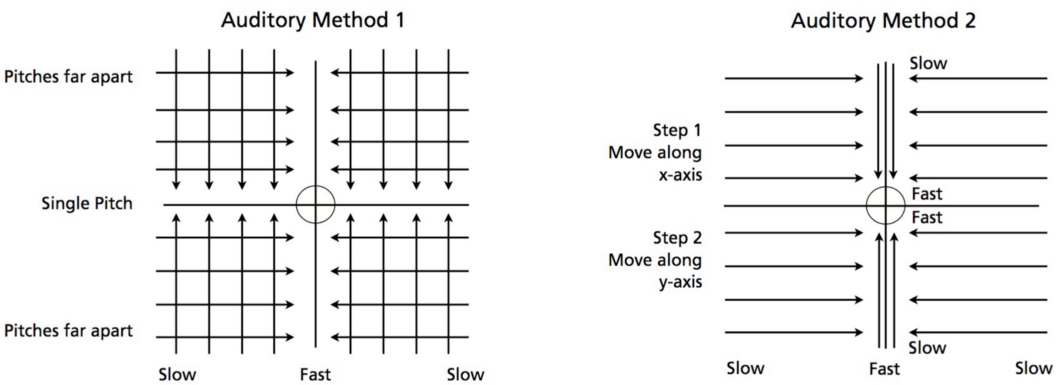


Figure 3: Left: Auditory display methods 1 and 2

In the second auditory method (Fig. 3, right), a single repeating pulse is played. Changes in absolute x distance (from 30 to 0 mm) are linearly mapped to both speed between pulses (from 4 to 10 Hz) and pitch of each pulse. The auditory method requires a two-step movement. First, the user approaches from either the left or right side of the local area, first aligning the tip or shaft so that it is along the y-axis. Second, once the tracked element is on the y-axis (or, i.e., within a defined distance), a second pulse replaces the first, with similar speed between pulses but a higher pitch mapping (one octave higher). Thus, the user approaches from either side and when near or on the y-axis, proceeds to approach the center. This division of movement allows the user to concentrate on one degree of movement at a time.

Insertion depth is transmitted via two alternating tones with an interval of separation of one octave (between 520 and 1040 Hz) before insertion and rising to equal pitch when reaching goal depth. When the tip of the ablation needle reaches the target lesion, and bell tone is played (a recorded sample of a dinner-style bell). Removal of the needle from the body may also be guided using the same insertion auditory display method albeit in reverse.

Evaluation: A preliminary evaluation with two females and six volunteers was conducted using a think-aloud method to encourage active responses about what users were doing, thinking and feeling (according to Lewis [8]). All participants were scientific researchers with no direct experience with either navigated radiofrequency ablation or the auditory display methods. Of the eight subjects, none claimed to be particularly musical, although one participant had basic knowledge of digital audio synthesis.

Test participants were first shown the navigation system and then introduced to each of the audio methods. A short experimental session occurred, after which the subjects completed each task: positioning the tip, adjusting the angle of the handle, and inserting the needle until the target had been reached. This was repeated for both audio and visual modalities. Using the video screen was also permitted during auditory guidance.

3 Results

We present a new auditory display for navigated radiofrequency ablation. A post-experimental analysis of written and verbal comments of the subjects indicates that subjects were comfortable with both the visual and the auditory modalities. All subjects claimed the auditory methods to be at least as precise as the visual methods. Subjects noted that the tasks of placing the tip, aligning the shaft, and inserting the needle were easier to accomplish and provided more confidence than with the visual method, although many participants used the video screen at the end of each auditory-guided task as a means of confirmation that the needle was correctly placed. For tip placement and shaft alignment, more participants preferred auditory method 2 because it divided the guidance into sequential x-axis, then y-axis movement instead of transmitting both simultaneusly. For needle insertion, all participants felt confident in stopping the insertion motion based on the auditory display.

One cited disadvantage of the auditory method was that it only provides sequence-wise guidance – for instance, no guidance for the tip placement is given during shaft alignment and needle insertion. None of the participants was annoyed by the sounds. All participants understood that sound speed and pitch reflected the urgency of the current position. However, participants suggested choosing more instrumental timbres rather than basic synthesized tones.

4 Discussion

This work has presented a novel method to aid physicians complete radiofrequency ablation needle placement tasks using auditory display. Two methods were evaluated for tip placement and shaft alignment, and one method for needle insertion.

The proposed method for auditory display opens up completely new possibilities for navigated interventions, but it is not without drawbacks. Whereas the recent concept of navigated interventions is solely based on the visualization of image data and planning models, no explicit navigation commands are provided through these visual methods. Incidentally, this eases the clearance of surgical navigation systems for clinical trials because the navigations systems provide only implicit navigation support. With auditory display, explicit navigation commands and notifications can be provided even if the surgeon does not look on the screen. Future evaluations of such systems during clinical interventions must be carefully prepared with regard to legal and ethical requirements. In addition, the registration errors of deformable organs must still be addressed before such methods can be practically applied.

In summary, the methods developed in this work contribute to the field of computer-assisted interventions and have the potential to improve the safety of radiofrequency ablations by helping physicians keep focus on the patient instead of a computer screen. While auditory display for radiofrequency ablation needle guidance is not meant to completely replace visual guidance, it could become a useful extension to reduce physician stress and improve the overall interaction with such needles.

5 References

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