A Patient-mounted Miniature Navigation System for CT-guided Needle Placement

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INTRODUCTION:
Image-guided needle placement is commonly performed in many clinical interventional procedures, such as biopsy, percutaneous vertebroplasty, percutaneous drainage, and radiofrequency denervation. Among imaging techniques, fluoroscopy is more widely used than computed tomography (CT) and the popularity of fluoroscopy is mainly due to its real time visualization feedback to radiologists. However, CT offers high spatial resolution and superior 3D tissue information to make it becoming a competitive alternative.

CT-guided needle placement procedures are routinely performed in an iterative fashion. The radiologist identifies the target site in the CT console system outside the CT room, and then inserts the needle with freehand technique by mentally mapping the location and angulation of the needle trajectory into the patient anatomy. Repeat the procedure until the desired position is reached. For such procedures, the lack of the real time association between images and patient anatomy makes the time-consuming iteration inevitable and the performance even degrades more in the large angulation and double angulation cases. Therefore, the further acceptance of CT-guided needle placement requires the improvement of its guidance performance.

In this research, we proposed a patient-mounted miniature navigation system for CT-guided needle placement. By employing fluoroscopy-like user interface, auto-registration, and light-weight and patient-mount design, we were in an attempt to achieve real time visualization guidance comparable to fluoroscopy. To verify the accuracy of the system within an acceptable range, an acrylic and porcine phantoms were used to verify the systematic and operation errors respectively. A performance test with the porcine phantom was carried to record the operation time of each step as the benchmark of guidance performance.

METHODS:
Our navigation system consisted of a reference frame unit, a miniature tracking unit, and an imaging unit (Fig. 1). The reference frame unit was made of non-radiopaque plastic with four fiducial marker balls installed in predefined positions. Auto registration was achieved by automatically identifying marker images and then matching the image positions with the predefined marker positions. Once registered, we attached the tracking unit to the reference frame unit and were ready for navigation. The tracking unit was made of upper and lower Selective Compliance Assembly Robot Arms (SCARA) with gimbals at the end effectors of both arms. A guide rod passing thru the upper and lower gimbals accommodates a guidance tube for needle insertion. The dual arm tracking unit has 40x40 mm of working area, ±20° of angular adjustment, and 80 mm of depth insertion. The unit weights about 130g. To facilitate visualization feedback, the imaging unit provided two simulated fluoroscopic images out of CT images. One fluoroscopic image showed the image viewing from needle punch direction, helping the radiologist in determining the punch location and angulation. The other image showed the lateral image for insertion depth control. The imaging unit loaded CT images via wireless networking to the hospital PACS.

Two types of accuracy tests were performed to verify the accuracy of the system. The first accuracy test was carried out on an acrylic phantom with five hollow aluminum tubes as the targets. The test can reveal the systematic error because of the fully rigid arrangement. The second accuracy test was carried out on a porcine phantom with three hollow aluminum tubes as the targets. The test can reveal the operation error. A performance test was carried out on the porcine phantom with a modified CT-guided denervation on medial branch of the dorsal ramus protocol. The protocol included six operations: (1) mount the reference frame on the phantom before the first CT scan, (2) CT scan and load images to the imaging unit, (3) auto registration, (4) navigate to the target, (5) punch needle to the target, and (6) detach needle. The performance was recorded by the time of each operation.

DISCUSSION:
An in-vivo study using laser guidance [1] reached a target error of 2.4±1.4mm within 936±984sec operation time. Peter Messmer et. al. proposed a modality-based navigation system [2] for needle placement. In their study, they reached the target error of 1.9±1.1 mm. Compared with their results, our navigation system can perform CT-guided needle placement effectively while maintaining a comparable accuracy.

In conclusion, our CT-guided miniature navigation system can offer real time visualization feedback for needle placement that is comparable to its fluoroscopy counterpart. It can improve the performance and confidence in the difficult cases, such as large angle and double angle needle approach. We currently apply the system to radiofrequency stimulation on dorsal root ganglion (DRG), and a new reference frame is designed to meet the requirement of multiple needle placements.

REFERENCES:

ACKNOWLEDGEMENT:
National Health Research Institute, Taiwan (NHRI-EX97-9733E) National Science Council, Taiwan (NSC 97-2628-E-002-224-MY2) National Taiwan University Hospital, Taiwan