

Implementation of an Electromagnetic Tracking System for Accurate Intrahepatic Puncture Needle Guidance: Accuracy Results in an In Vitro Model¹

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Rationale and Objectives. Electromagnetic tracking potentially may be used to guide percutaneous needle-based interventional procedures. The accuracy of electromagnetic guided-needle puncture procedures has not been specifically characterized. This article reports the functional accuracy of a needle guidance system featuring real-time tracking of respiratory-related target motion.

Materials and Methods. A needle puncture algorithm based on a “free-hand” needle puncture technique for percutaneous intrahepatic portocaval systemic shunt was employed. Preoperatively obtained computed tomographic images were displayed on a graphical user interface and registered with the electromagnetically tracked needle position. The system and procedure was tested on an abdominal torso phantom containing a liver model mounted on a motor-driven platform to simulate respiratory excursion. The liver model featured two hollow tubes to simulate intrahepatic vessels. Registration and respiratory motion tracking was performed using four skin fiducials and a needle fiducial within the liver. Success rates for 15 attempts at simultaneous puncture of the two “vessels” of different luminal diameters guided by the electromagnetic tracking system were recorded.

Results. Successful “vessel” puncture occurred in 0%, 33%, and 53% of attempts for 3-, 5-, and 7-mm diameter “vessels,” respectively. Using a two-dimensional accuracy prediction analysis, predicted accuracy exceeded actual puncture accuracy by 25%–35% for all vessel diameters. Accuracy outcome improved when depth-only errors were omitted from the analysis.

Conclusions. Actual puncture success rate approximates predicted rates for target vessels 5 mm in diameter or greater when depth errors are excluded. Greater accuracy for smaller diameter vessels would be desirable for implementation in a broader range of clinical applications.

Key Words. Electromagnetic tracking; abdominal phantom; liver interventions; image guidance.

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Accurate placement of needles within the liver for percutaneous interventions may be accomplished using computed tomography (CT), magnetic resonance imaging (MRI), or ultrasound guidance. Modality-specific limitations include requiring ionizing radiation, nonmagnetically susceptible instruments, or adequate acoustical window without interposed osseous or gas-filled structures. In more complex intrahepatic vascular procedures such as transjugular intrahepatic portocaval systemic shunt (TIPS), shunt creation between portal and hepatic veins is most often accomplished without direct real-time guidance, although planar and three-dimensional ultrasound (1,2) and MRI guidance has been reported (3). Alternatively, the target portal vein can be identified fluoroscopically.

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cally by several techniques, including wedged hepatic venography using iodinated contrast or carbon dioxide (4), transhepatic portography, or percutaneous placement of target guidewires or markers in the portal vein (5,6).

Respiratory motion interferes with accurate needle placement in static CT-guided interventions, although real-time imaging with ultrasound, CT fluoroscopy, or MRI with breath-hold can help compensate for target excursion with respirations. In an alternative approach, static images would be registered with positional data obtained from an electromagnetic tracking system, allowing the position of electromagnetically tracked instruments to be displayed on the static image. Electromagnetic tracking could be enhanced to track the respiratory related motion of the target organ with retrievable embedded fiducials. The electromagnetic tracking system would then provide 1) real-time location of the tracked needle or instrument and 2) real-time location of the target during the respiratory cycle-related target excursion.

Electromagnetic sensors and tracking technology have found numerous applications in medicine, including surgical simulation and training and biomechanical analysis. Real-time motion can be captured in terms of (x,y,z) translation coordinates and (y,p,r) yaw, pitch, and roll coordinates, respectively (7). A complete tracking system typically consists of an electromagnetic field generator, sensors, and an interface device that communicates sensor data to a computer. Electromagnetic tracking as a guidance system for interventional procedures offers several advantages, including the lack of a requirement for ionizing radiation, high data sampling rates, and no line-of-sight interference issues. Electromagnetic tracking alone cannot display data in image form and must be registered with a specific image volume to function as an intervention guidance system. Electromagnetic tracking systems are additionally limited by field distortion caused by nearby metallic or electronic devices, diminished positional accuracy at increased distances from the field generator, and, to a lesser extent, positional display latency.

Recently, an interactive image guidance system featuring electromagnetic tracking coupled to previously acquired three-dimensional CT images was used to display the real-time position of the intrahepatic puncture needle during TIPS in a swine model (8). This system featured respiratory gating consisting of an electromagnetic sensor placed on the animal's abdomen, allowing updating of the needle position only during a designated portion of the respiratory cycle. This algorithm required the placement of 10–20 metallic markers on the animal's skin to permit

image registration. The system accuracy was reported to be 3 mm.

In this article, we report our preliminary accuracy results with an electromagnetic tracking system featuring real-time monitoring of respiratory-related target organ motion by a percutaneously placed retrievable fiducial. We also have selected the creation of an intrahepatic portosystemic shunt as our procedural model because the successful simultaneous puncture of two vessels demands a higher degree of accuracy in the performance of multiple steps in the procedure; the needle puncture path and specifically the puncture entry site is necessarily constrained by the alignment and diameter of the two vessels as well as the presence of interpositioned organs. By comparison, successful targeting of a single nodule simulating a simple biopsy can be achieved despite significant surface puncture site selection error. Although the presence of ascites might preclude the percutaneous transhepatic approach for routine application, electromagnetic tracking-guided percutaneous intrahepatic portocaval systemic shunt (PIPS) might be an alternative to TIPS if jugular access could not be achieved.

Our strategy for needle placement and manipulation for PIPS is patterned after the stepwise conventional "free-hand" procedure for static image-guided needle biopsies, but the puncture of the hepatic and portal veins would be performed percutaneously instead of a transjugular approach. Such an approach for intrahepatic portocaval systemic shunt may be technically feasible in up to 75% of patients (9). The role of the electromagnetic tracking guidance algorithm would be to enhance the accuracy of the transhepatic needle puncture and reduce the number of puncture attempts required for success.

In the electromagnetic tracking-guided needle puncture algorithm, puncture site and trajectory planning are determined with the assistance of a graphical user interface (GUI), a single intrahepatic fiducial needle, and a preoperatively obtained CT dataset. In our model, the CT dataset would be obtained at end-expiration in the animal model by suspending mechanical ventilation of the animal and allowing complete exhalation of the respiratory tidal volume to occur. Although mechanical ventilation would continue throughout the puncture procedure, guided needle advancement would be performed only when the internal tracked needle fiducial and GUI indicate that respiratory-related organ motion has ceased during the typically observed approximately 1.4 seconds regular end-expiratory phase pause (10). At this point, the actual alignment of the selected skin puncture site and intrahe-

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