In Vivo Treatment of Spine Tumors Using Needle Based Therapeutic Ultrasound with Under Image Guidance with 3D Electromagnetic Tracking

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BACKGROUND

Spinal metastatic disease and multiple myeloma affects nearly 600,000 people every year in the United States and cause progressive bone destruction that results in incapacitating pain, fractures, and the inability to walk. Minimally invasive thermal therapies such as RF and ultrasound ablation techniques have proven to be effective for treating tumors outside the spine. The successes of such treatments rely on accurately controlling the direction and shape of the ablated region and avoid damaging anatomical sites such as the spinal cord.

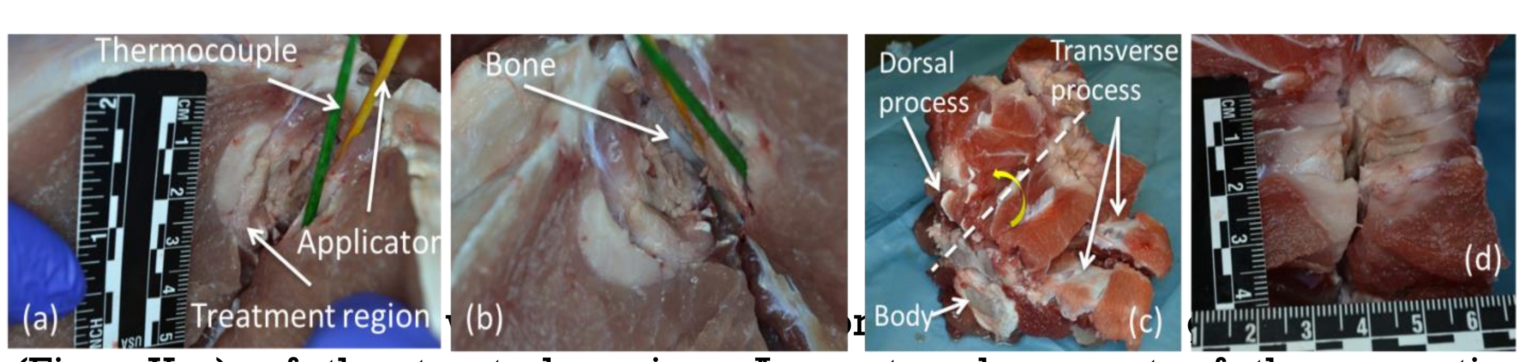
PURPOSE

Minimally invasive catheter/needle based procedures are widely investigated for treatment of various diseases since it is one of the least invasive procedures with potential for minimal or no bleeding and can have good to excellent target accuracy. High-intensity ultrasound catheter/needle based devices have been created for several clinical applications. Catheter based ultrasound therapy has been under investigation for treatment of prostate and uterine applications. Synergistic therapy by combining catheter based ultrasound applicator delivery and radiation have shown excellent results. Interstitial ultrasound is a novel tool for 3D control of thermal ablation, with potential advantages for thermal ablation of tumors near the spine and highly osteolytic tumors within the vertebrae. Preferential ultrasound absorption at the bone/tumor boundary would help ensure that the entire tumor is heated to lethal temperatures. The ultrasound applicator can be inserted directly into the tumor, and power distributions controlled along the length and circumference of the applicator. As there are several highly sensitive structures near the spine, such as the spinal cord, nerves, blood vessels, lungs, etc., great care must be taken during treatment planning. The applicator's placement, the applicator type, and the applied power distribution must be carefully tailored to each patient's anatomy so the tumor is fully ablated without damaging any sensitive structures nearby.

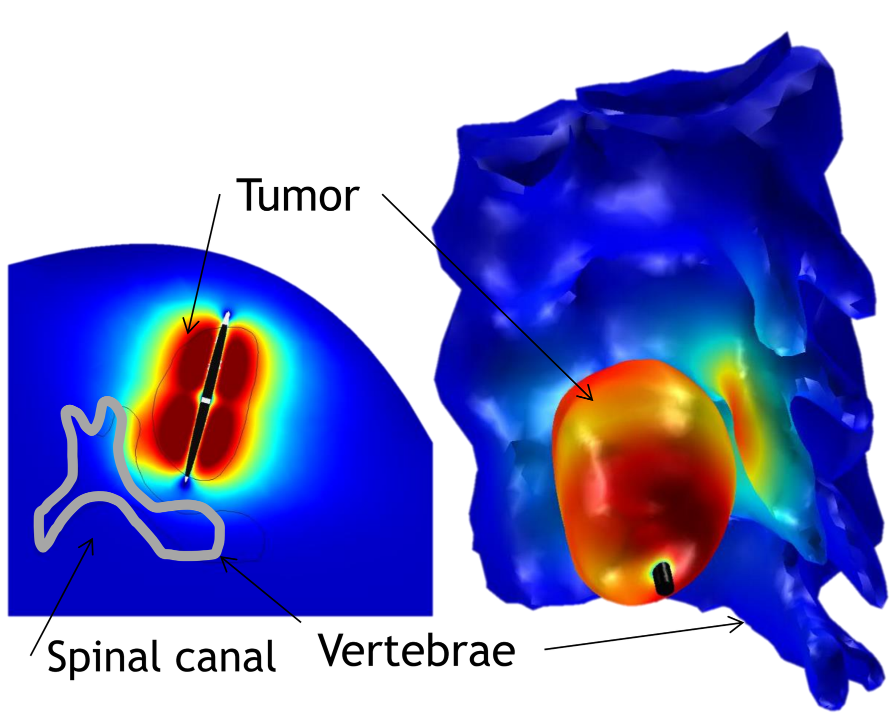
The purpose of the present study was to investigate incorporating electromagnetic (EM) tracking combined with ultrasound imaging to guide a high intensity ultrasound interstitial needle insertion for ablation of tissue adjacent to the vertebral body and spinal process in an *in vivo* human sized porcine model. Finally, gross anatomical pathology of the ablation zone and surrounding region was performed and documented.

RESULTS

The ultrasound applicator was successfully inserted as per treatment plan using combined ultrasound imaging EM tracking guidance system. During treatment a maximum temperature of 60-70 °C and dose of 10^5-10^7 equivalent minutes at 43°C was observed at a distance 10 mm from the center of the ablation transducer for a treatment time of 5-7 minutes. The dose distribution was analyzed and compared with the gross pathology (Fig. 2) of the treated region.

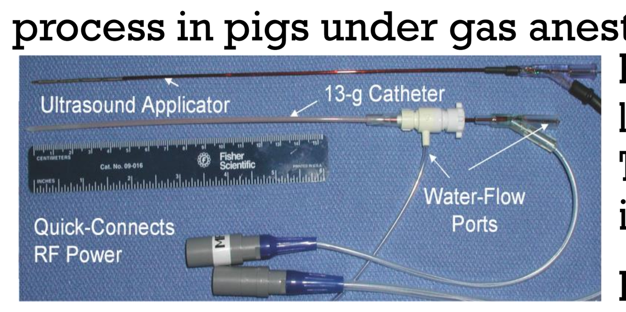


(Figs. X-y) of the treated region. Accurate placement of the acoustic applicator and temperature sensors were achieved using the combined image-guidance and the tracking system. Ultrasound energy direction was controlled based on transducer design and electronic excitation to avoid other structures.



MATERIALS AND METHODS

Two element tubular PZT transducers (10 mm long, 1.5 mm outer diameter) were used to manufacture the catheter based ultrasound interstitial applicator (Fig. 1a). The transducers were mounted on a polyamide tube and the applicator inserted into the tissue for treatment using a 13g implant catheter. Degased water was circulated through the applicator and the catheter for cooling the transducer during ablation. Transducers with either 360° or 180° active zones were used for the experiments. Interstitial high intensity treatment applicators operating between 6-7 MHz were placed 5 mm from the dorsal process in the region at the intersection of the dorsal and transverse process in pigs under gas anesthesia (Fig 1b).



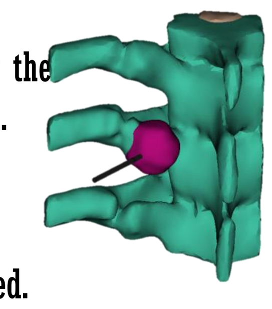


Fig 1 Left: Interstitial applicators. There is a row of cylindrical transducers near the left tip that emit ultrasound radially outwards, each with separate power control. The lower applicator is shown within a water-cooled implant catheter that is inserted directly into or adjacent to the tumor.

Right: Tumor (magenta) invading vertebrae (green) with applicator (black) inserted.

Applicators were placed percutaneously using ultrasound image guidance. Linear array temperature sensors were placed at two locations to provide dosimetry information. The dose distribution was estimated from the temperature recorded by each of the thermocouples. Ultrasound imaging was performed using a Sonix Touch (Ultrasonix, Inc. Richmond, BC Canada) with an L14-5/38 linear probe combined with EM tracking to guide the insertion of the applicator (Fig. 3). Ultrasound imaging and tracking was performed using the PLUS software and Open IGT Link. The EM sensor was located at the tip location of the applicator and stylus was inserted into the target tissue using the ultrasound image guidance. The three-dimensional (upper) and two-dimensional (lower) views are shown. An in-house custom software system was developed to communicate with the hardware, ultrasound imaging, tracking system and treatment control.

After confirming the treatment location and the catheter position, the EM sensor ir replaced by the ultrasound ablation probe for treatment. Thermocouple array sen at different distances from the ultrasound applicator and dose was calculated sensor.

$$t_{43} = \sum_{t=0}^{t=final} R^{(43-T_t)}\,\Delta t, \qquad \begin{cases} R = 0.25 \text{ for } T < 43°C \\ R = 0.50 \text{ for } T \geq 43°C \end{cases}$$

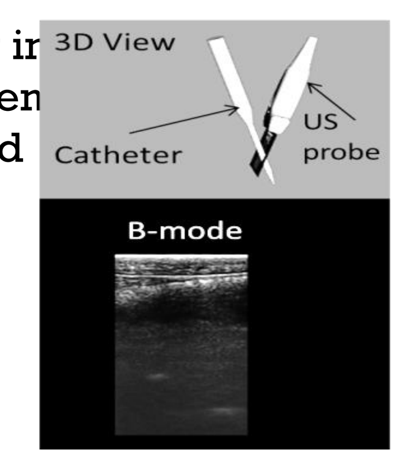
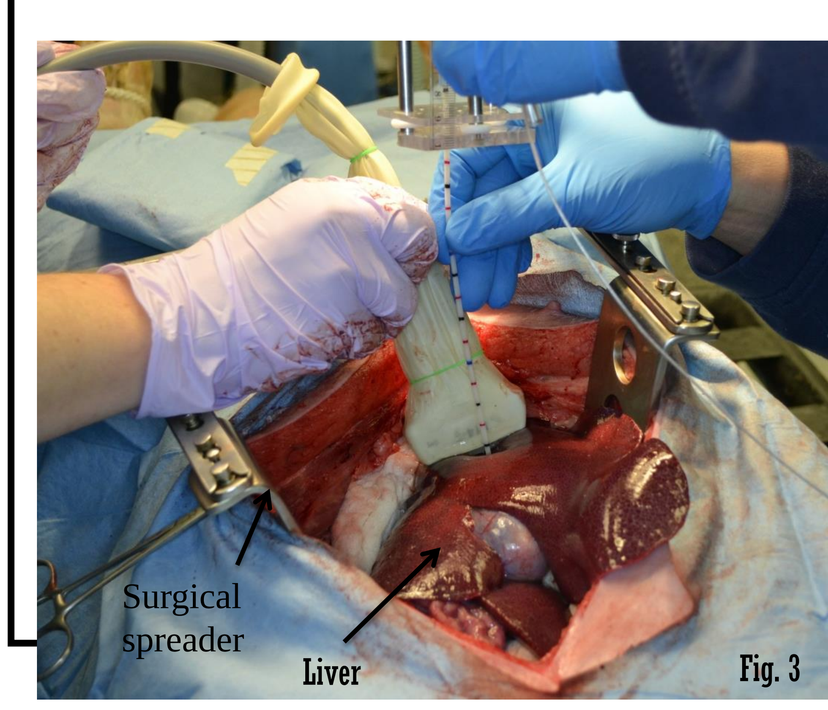
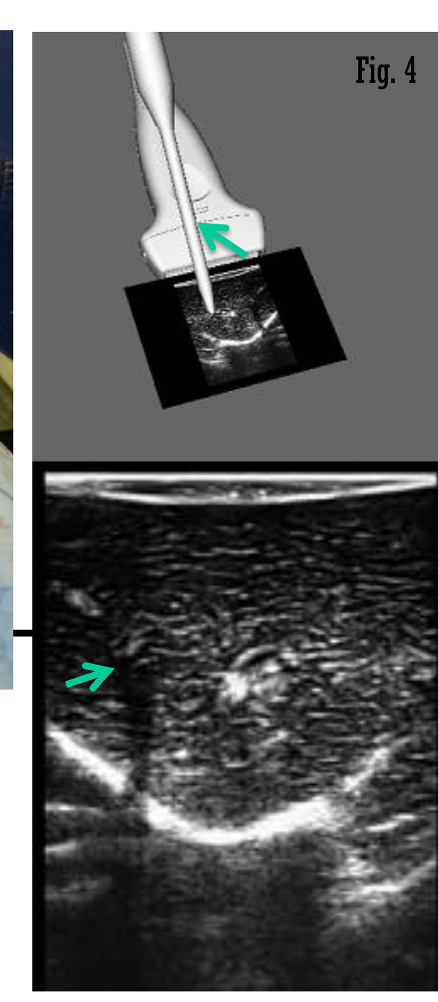


Fig 2: Image guided with EM tracking for applicator insertion.

The in-house software architecture was developed to communicate with the hardware, ultrasound imaging (SonixTouch, Ultrasonix, Richmond, BC, Canada) and tracking system. Specifically the ultrasound imaging and tracking was performed using the PLUS software and Open IGT Link. Typically 7 W (acoustic power was delivered to the tissue by the ultrasound applicator. Thermocouples at 5 mm, 10 mm and 15 mm radially from the applicator were inserted using the custom template (Fig 5) for the purpose of dose confirmation.





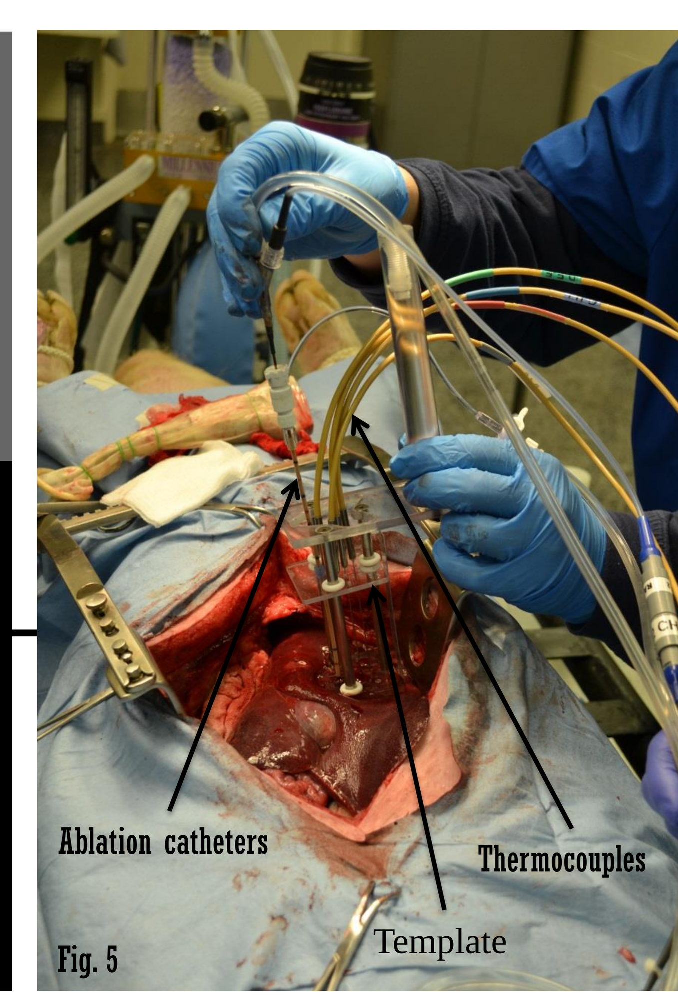


Fig3: Insertion of ultrasound ablation applicator under guidance of combined ultrasound imaging and tracking system.
Fig 4: Ultrasound imaging and applicator position in 2D and 3D plane corresponding to the setup shown in Fig 3. (Arrows indicate the catheter in the 3D view and shadow by the catheter in the B-mode image). Fig 5: Treatment setup.

CONCLUSIONS

The experimental results demonstrated that the directionality and shape of the ablation zone can be controlled using catheter based high intensity sectored ultrasound transducers. The 180° sectored transducers helped in creating desired ablation pattern without damaging the nearby vein/vessels in the tissue verified from gross pathology inspection .Our results suggest that tracked targeting coupled with directionality and shape of the ablated region could accurately control ablation zones using the proposed technology.

BIBLIOGRAPHY

The list of publications are included on a separate handout available below the poster.

NATIONAL CENTER FOR IMAGE GUIDED THERAPY IGT
ACOUSTIC MEDSYSTEMS
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
UCSF University of California San Francisco
Queen's UNIVERSITY

ACKNOWLEDGEMENTS

The authors acknowledge acknowledge the assistance of Lance Frith and Bruce Komadina in set up and during the experiments. This work was supported by the National Cancer Institute (National Institutes of Health, Bethesda, MD) under NIH Grant R44CA134169. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.