Transcutaneous vessel imaging is a frequently used ultrasound imaging modality in medicine. The measurement of vessel diameters can be done with conventional B-mode imaging systems, which work at frame rates up to 100 Hz. Furthermore, there are special systems available, which can track vessel walls very precisely using the phase of signals that are sent at frame rates up to several thousand Hertz. Though, such systems are usually not able to provide the examiner with 2D images of the object. With respect to brachial artery flow-mediated vasodilatation (FMD), which is frequently used as a measure of endothelial function, it is necessary to observe diameter changes of small arterial vessels non-invasively for several minutes at a high resolution. In the past, the diameter had to be measured manually in tedious postprocessing of ECG-gated image sequences. We developed a system composed of a Siemens Omnia ultrasound system with a VF13-5 transducer (9 MHz center frequency) and a personal computer, that is capable of calculating vessel diameter changes with an accuracy below the wavelength of the ultrasound system in real-time at a frame rate of 27 Hz. We implemented a two-dimensional active contour model using the Viterbi-algorithm and a phase-sensitive vessel wall tracking algorithm, in order to guarantee both, geometric information and accuracy. We could verify experimentally that the accuracy of the measurements is below 1 mm. Results from clinical measurements of carotid and brachial arteries show that arterial pulsations below 0.1 mm can be visualized reliably over several minutes. Furthermore, we can present examples from clinical FMD measurements, where the pulsation of the brachial artery is visible as well as an increase in arterial diameter after the deflation of a forearm cuff, which was used to produce an ischaemia for 5 minutes. With this system we want to find out, if FMD is suitable for an individual assessment of the risk for cardiovascular diseases.

Session: P1G
THERAPY AND BIOEFFECTS
Chair: L. Crum
University of Washington

P1G-1
CHARACTERIZATION AND FEA SIMULATION FOR A HIFU PHANTOM MATERIAL
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Recent work by Bronskill, Lafon, and their collaborators has shown the utility of a HIFU (High Intensity Focused Ultrasound) phantom material made of polyacrylamide gel with a small amount of Bovine Serum Albumin (BSA) added as a temperature sensitive marker. The phantom provides a close match to the acoustic and thermal properties of tissue. The BSA protein denatures as a function of temperature, so that application of HIFU to the material leaves opaque lesions that mimic those formed in tissue. We will present a phantom
formulation that offers a high degree of optical transparency that may be useful for protocol development and quality control of HIFU systems, and provides a unique basis for non-invasive comparisons between computer simulations and experiments.

The full characterization of the material will be presented, including both methods and results. The acoustic properties are impedance = 1.61 Mrayl, velocity = 1600 m/sec, and attenuation = 0.6 dB/cm/MHz. Thermal properties significant for HIFU (specific heat and conductivity) are practically the same as for water, as shown by experiments and a simple mixture theory. We will also present an optical characterization of the threshold for lesion formation made in a temperature-controlled water bath which shows that this material forms tissue mimicking lesions at a threshold temperature of approximately 70 deg Celsius. Using the characterization data, we will show that an FEA model tracks growth of a lesion, as indicated by comparison to a digital video made of lesion growth in sub-cavitating HIFU fields.

P1G-2

NOVEL ADAPTIVE CONTROL METHODS FOR ULTRASOUND THERMAL TREATMENT WITH A TWO-DIMENSIONAL TAPERED ARRAY
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For thermal treatment of prostate disease using ultrasound hyperthermia or focused ultrasound surgery, two novel adaptive control methods (self-tuning regulator (STR) and model reference adaptive control (MRAC)) as well as an ultrasound pattern synthesis method were proposed and tested with a recently developed 64-element two-dimensional (2-D) tapered phased array. The goal of an efficient hyperthermia treatment is to quickly heat the prostate to therapeutic temperatures and maintain a constant temperature over 30 minutes. Two significant advantages of these innovative adaptive control methods are: 1) there is no need of a priori knowledge of the tissue properties and 2) the controller could adaptively change the amplitudes and phases of the array's driving signal according to the perfusion rate or other dynamic properties. In vitro control experiments for hyperthermia treatment with this 2-D phased array were performed with temperature probes placed in the array's focal point inside porcine liver. With STR, recursive identification of the system parameters was initiated, the control variables were adaptively tuned based on parameters update. Results demonstrated that the focal point temperature rose from 37.0 ± 0.3°C to 43.0°C with 5±0.5 minutes rise time, no overshoot and ±0.5°C oscillation indicating strong regulator control. With the same setting, MRAC was also tested, which converged output to reference by temperature gradients. The temperature at the focal point reached 43.0°C within 3.5±0.5 minutes and with ±0.3°C oscillation even with system mismatch. To achieve more efficient hyperthermia treatment, a uniformly large heating pattern was synthesized using
pseudo-inverse method for this 2-D phased array. A $2 \times 2 \times 4 \text{ cm}^3$ volume of tissue was heated during a single sonication. For a focused ultrasound surgery heating process, the same array was tested with both adaptive control methods. In vitro experimental results demonstrated that the temperature at focal point rose to $65^\circ\text{C}$ without overshoot and oscillation during 10 seconds period of tissue ablation with lesion size 2 mm in diameter. Implementation of these novel adaptive control methods for the first time demonstrated robust control for application with both ultrasound hyperthermia and focused surgery.

This work was supported by the Whitaker Foundation (RG-00-0042).

P1G-3

A NEW BRACHYTHERAPY SEED DESIGN FOR IMPROVED ULTRASOUND VISUALISATION

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In permanent brachytherapy treatment of prostate cancer, typically 80 to 100 small radioactive seeds are implanted guided by transrectal ultrasound (TRUS) imaging. Analysis of clinical ultrasound and X-ray images show that only one third of implanted conventional seeds are visible with TRUS imaging, and that seed visibility is highly dependent on the angular orientation of individual seeds to the ultrasound beam. To facilitate accurate seed placement and intraoperative ultrasound based radiation dosimetry estimation, a new seed design, EchoSeed™, has been developed with a modified outer seed surface shape. The new seed is essentially identical to OncoSeed™ (Amersham Health) with respect to radiation dosimetry and outer dimensions. A simulation model of the seed ultrasound reflection properties based on diffraction theory was developed to optimize the seed design. The model was verified by in-vitro measurements of the angular dependency of the seed backscattered intensity. Prototypes were further evaluated by imaging of seeds implanted in excised dog prostates. While conventional seeds were only detectable over the tissue background for rotational angles of $\pm 10^\circ$, EchoSeeds were visible over the entire investigated range of $\pm 60^\circ$. The new design was further evaluated in an in-vivo dog prostate model. Conventional seeds were implanted on the right side of the prostate midline and EchoSeeds on the left side in 3 dogs. 8–17 seeds were implanted on each side. TRUS imaging of the prostate was performed with a B&K Falcon™ scanner connected to a Life Imaging 3-D imaging system. Seeds in each half of the prostate were identified and counted in the 3D ultrasound images by a consensus panel of three observers. For reference, fluoroscopy imaging was performed after implantation in-vivo, while CT was performed post mortem. Ultrasound identified 99.2% (relative to fluoroscopy) of the implanted prototype EchoSeeds compared to 36.7% of the conventional seeds. The numbers identified by CT were close to 100% for both seed types. The new EchoSeed design gives a substantial improvement in seed visibility on ultrasound, and detection compares favorably to CT demonstrating a potential for improved ultrasound guided seed implantation and ultrasound based radiation dosimetry.
3 DIMENSIONAL ULTRASONIC MONITORING OF INTERSTITIAL TUMOUR THERAPIES - IN VIVO RESULTS

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One of the most important problems of interstitial thermal therapies of liver metastases is the non-invasive localisation and measurement of the coagulated volume. Recently, it was shown that ultrasound can be used for monitoring the coagulation process in vitro and in vivo [1,2] by measuring the variation of the sound attenuation and sound velocity before, during and after thermal treatment [3]. It was also found that to use these methods in practical surgery, it is necessary to compensate artefacts that arise under in vivo conditions due to physiological and patient movement. In this study we propose to use 3 dimensional (3-D) information to evaluate the precision of ultrasound monitoring of thermal tumour therapies under in vivo conditions. In our study a custom-made freehand 3D ultrasound system, which was calibrated for geometric and spectral system parameters, was used in an animal study on pigs for acquiring in vivo ultrasound data during interstitial thermo therapy. For evaluation 3D-reconstructions of optical thin slice data of the coagulation volume are compared to 3D-reconstructions of attenuation change ultrasound datasets. The derivation of differential attenuation volumes is demonstrated and the comparison to optical volume measurement is performed. The coregistration of both volumes is possible. Motion artefacts can be overcome.

The results of 3 dimensional ultrasound monitoring of Nd:YAG laser induced (LITT) and radio frequency induced (RFITT) coagulation within in vivo pig liver specimen are presented. The comparison of ultrasonically and optically measured 3D-coagulation volumes show good geometric agreement.

IMAGING OF THE EFFECT OF ACUPUNCTURE NEEDLING ON HUMAN CONNECTIVE TISSUE IN VIVO

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The therapeutic effects of acupuncture from its beginnings in ancient China have been well documented over the past three millennia. However, only recently have there been significant attempts to understand the underlying mechanisms. This study investigates the hypothesis that during needle rotation, winding of connective tissue around the needle results in mechanical coupling between needle and subcutaneous tissue. To test this hypothesis, ultrasonic imaging using an ATL HDI 1000 scanner at 7-11 MHz was performed on the left and right thigh muscles of 15 human subjects during rotation (4 and 32 (360°) revolutions) of a needle (0.25 mm in diameter) using a computer-controlled acupuncture needling instrument. Displacements were estimated using the ultrasonic (B-scan) frames and crosscorrelation techniques as previously described in Elastography [1] with a 4 mm window and a 90% window overlap. It was found that in human subcutaneous tissue, tissue displacement could be estimated using the stimulus caused by the needle movement. Tissue preconditioning with needle rotation (32 revolutions) had a pronounced effect on tissue motion with axial needle movement: tissue displacement amplitude increased by up to an order of magnitude and its spatial extent by up to a four-fold (repeated measures ANOVA, p<0.001). This preconditioning effect was not statistically significant when only 4 revolutions were used. Therefore, a threshold for the accentuation of the acupuncture effect by rotation should lie between 4 and 32 revolutions. With both 4 and 32 revolutions, however, tissue displacement during needle rotation was positively correlated (r=0.6) with independent force measurements during final pullout of the needle. Tissue preconditioning by needle rotation might play an important role in determining the amplitude of the mechanical signal delivered to the tissue with axial needle movement. These results show that needle/tissue mechanical coupling is enhanced by significant needle rotation. This coupling may in fact prove to be the key to acupuncture’s therapeutic mechanism and the proposed imaging technique the method of choice for monitoring this effect. [1] Konofagou EE, Ophir J., Ultras. Med. and Biol. 24(8): 1183-1199, 1998.

This study was supported in part by NIH grants 5 R21 AT000300-02 (University of Vermont) and in part P01 CA64597 02 (University of Texas and University of Vermont).