Three Dimensional Targeting for Liver MRgFUS Based on Vessel Tree Tracking

E. Kumamoto[1], Y. Takao[2], D. Kokuryo[3], A. Okada[4], T. Murakami[5], T. Kaihara[2], and K. Kuroda[6,7]

[1]Information Science and Technology Center, Kobe University, Kobe, Hyogo, Japan, [2]Graduate School of Engineering, Kobe University, Kobe, Japan, [3]National Institute of Radiological Sciences, Chiba, Japan, [4]Iseikai Hospital, Osaka, Japan, [5]School of Medicine, Kinki University, Osaka, Japan, [6]Graduate School of General Science and Technology, Tokai University, Hiratsuka, Kanagawa, Japan, [7]Institute of of Biomedical Research and Innovation, Kobe, Hyogo, Japan

Introduction The purpose of this study is to develop a magnetic resonance technique for tracking a target tissue point in abdominal organs such as the liver, which moves and deforms with respiration, under focused ultrasound surgery (FUS). In order to provide a sufficient thermal dose to the target and to protect the surrounding normal tissues, the focal spot has to be "looked on" the target, and thus the temperature distribution around the target has to be vidualized even if the position and shape of the organ change. The "referenceless" or "self-reference" thermometry[1,2], which does not acquire baseline, is robust for organ displacement and deformation as far as the target point is tracked. The navigator-echo-based techniques [3,4] are effective for translational motion, but not for deformation. In thecombined target-tracking and multiple-baseline technique based on the assumption of periodic organ motion [5], errors may increase when the periodicity of motion is lost. As an alternative approach, we had proposed a target tracking technique based on relative displacements of blood vessels in the liver [6, 7]. In this technique, the displacement in the LR direction was neglected for simplicity of the first implementation. To extend this two dimensional (2D) technique to be three dimensional (3D), in this study, we have proposed a novel technique of through plane vessel tracking based on the tree-like structure of blood vessels.

Methods Multiple sagittal plane images of healthy volunteer's livers were acquired by a 1.5T MRI (Signa Excite 11, GE Healthcare Inc, Milwaukee, WI) with Fast Image Employing STeady state Acquisition (FIESTA) under following conditions; TR/TE, 1.13/4.24 ms; slice thickness, 5mm; field of view, 300×300mm^2; spatial matrix 512×512; flip angle, 60 degrees. Under these conditions, the cross sections of the vessels appeared sufficiently as hyper-intense in the T2/T1 contrast because of the in-flow effect. The displacement of the centers of gravity of contours of any three vessels of interest (vessels #1, #2, #3) with some branch and endmost points, as depicted in Figure 1, were recorded during several respiratory cycles to investigate the through-plane translation and deformation of the tissue. The branch point and the endmost point were extracted by thinning process after vessel extract process

When the cross section of a vessel shifted or disappeared in a particular image as shown in Figure 2, it was supposed that the tissue moved through the plane. If the displacement of the endmost point was d in an image, the translational distance along the L-R direction (d_{LR}) would be $d_{LR} = d\sin\theta$, where θ is an angle between the vessel and the transverse vector of the image plane. To calculate the angle θ from three dimensional vessel structure, Sagittal multi slice MR images were acquired with FIESTA under following conditions; TR/TE, 1,14/4.44 ms; slice thickness, 5mm;field of view, 300x300mm^2; spatial matrix 512x512; flip angle, 60.The voxcel size of original images was 0.59x0.59x5.0mm^3. To decrease aliasing of vessel structure, the original images were arranged to the isotropic voxcel images by linear interpolation method. The vessels were extracted by images processing and the structure information of the vessels of interest were calculated.

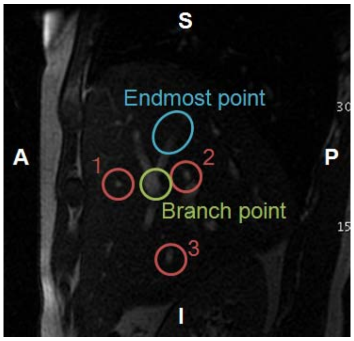

Figure 1 The vessels of interested #1 - #3, the branch and the endmost point of branch vessel for displacement analysis.

Results Figure 3 shows the displacements of the vessels, the branch point and the endmost point in SI and AP direction for one breath cycle. The displacement ranges of the vessels of interest were from -2.4 to 23.6 mm in SI direction and from -3.5 to 0.6 mm in AP direction, from -1.8 to 24.2 mm in SI direction and from -1.8 to 0.6 mm in AP direction in the branch point, and from -3.5 to 30.1 mm in SI direction and from -4.7 to 3.0 mm in AP direction in the endmost point.

The angle between MR image and the center line of the branch vessel was -76.9 degrees calculated From the extracted three dimensional vessel structure. Figure 4 shows displacement of the branch vessel of LR direction. The displacement range was from -3.4 to 11.3 mm.

Discussions The techniques for measuring three dimensional transformation and deformation of liver tissue are increase accuracy of target tracking. Even if the vessels crossing to MR image approximately perpendicularly displace of the LR direction, the shape does not almost change. In our calculating method of displacement of out-plane direction, displacement of the vessel of LR direction was from -3.4 to 11.3 mm with respiration. This result suggests that three dimensional target tracking method is required for highly accuracy target tracking. Next step, three dimensional target tracking method can be accomplished by modifying our tracking method [6].

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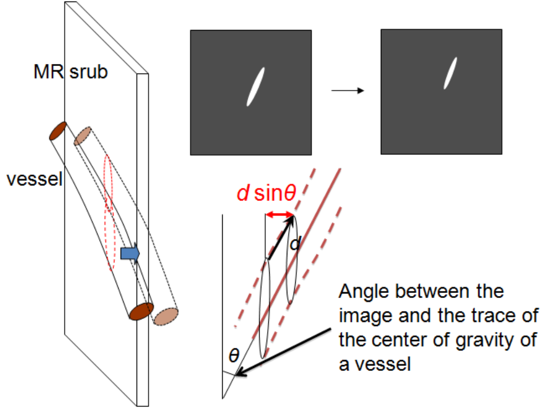

Figure 2 Through plane displacement of a vessel appeared on an image plane and the method for calculating the displacement using the traveling distance of an edge point of the vessel.

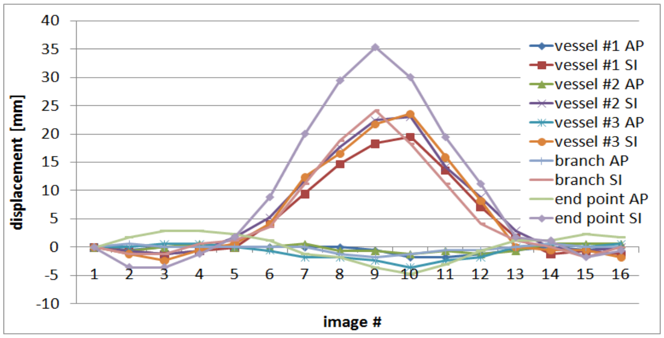

Figure 3 Relationship of displacements of the vessels from base positions for one respiratory cycle.

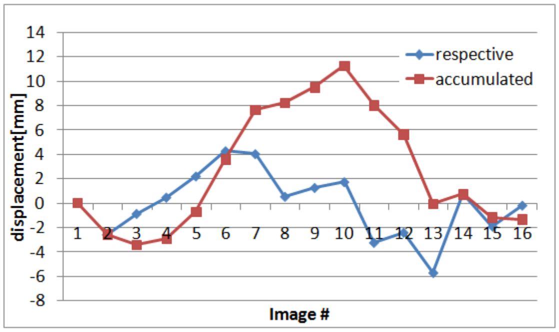

Figure 4 Relationship of displacement of the edge point of LR direction. 'Respective' is displacement from the image before that. 'Accumulated' is displacement from the base image(#1).