Three-Dimensional Motion Analysis of Hepatic Tissue for Focal Spot Tracking based on Portal Vain Structure

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Introduction MRgFUS for the abdominal organs such as the liver requires the target tracking technique to "lock on" the focal spot to the target. The technique based on relative displacements of blood vessels using sagittal MR images was effective for translational motion and deformation in superior-inferior (SI) and anterior-posterior (AP) directions [1,2]. The three-dimensional technique based on portal vain structure was proposed for tracking out-plane motion [3]. The method was based on the assumption that the deformation of portal vain structure was negligibly small. In this study, we have analyzed three-dimensional transformation and deformation of the hepatic tissue using image set of multiple slice under slow free breathing and proposed three-dimensional tracking method based on branching vessel structure.

Methods and Materials Multiple sagittal plane images of healthy volunteer's liver were acquired by 1.5T MRI (Signa Excite 11, GE Healthcare UK Ltd.) with Fast Image Employing STeady state Acquisition (FIESTA). Imaging conditions were as follows: TR/TE, 3.8/1.3 ms; slice thickness, 5mm; pixel size, 0.78 x 0.78 mm^2; field of view, 400 x 400 mm^2; spatial matrix, 512 x 512; flip angle, 90 degrees. 65 image set of interleaved four slices were acquired under slow pace respirations which cycle was 20 seconds per a breath. For the reference, the breath holding multiple slice images of the whole liver were acquired. 24 set of images were used for transformation and deformation analysis and the other 26 set of images were used for examination of three-dimensional tracking method.

First, Image set were sorted by respiratory phase position as following steps: 1) Divide multiple slice image set into inspiratory or expiratory group on the basis of diaphragmatic positions. 2) Sort image set in each group by the diaphragmatic position of the center slice. 3) Arrange each image set to the isotropic voxel images by linear interpolation method. Next, the portal vessel structures were extracted with following steps: 1) Smooth the images with moving average filter. 2) Extract the vessels by threshoulding from the smoothing images. 3) Apply three-dimensional region growing process. 4) Smooth the images with the three-dimensional Gaussian filter. 5) Extract the skeleton of the vessel structure using the Euclidean distance transformation.

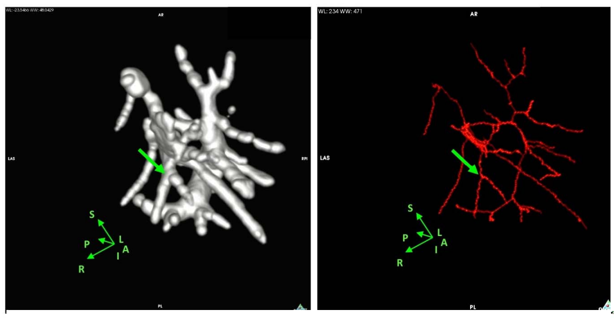

Figure 1 The reconstructed three dimensional vessel structure model. The green arrow indicates the branching vessel for interest.

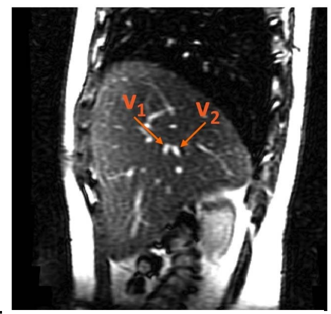

Figure 2 The diverged vessels for interest (v1 and v2).

Figure 1 shows the reconstructed three dimensional vessel structure model. In Figure 2, v_1 and v_2 were the vessels for interesting. When the vessel moved in the direction of an arrow as shown in Figure 3, the distance from branching point to sagittal plane become h from h_{ref}. On the assumption that the vessel only translated in direction of an arrow and the vessel was rigid wedge shape, the distance between v_1 and v_2 after moving would be $d' = h * d_{ref} / h_{ref}$. Actually, the distance after moving was d because there was deformation of liver tissues. Then, we defined the deformation factor $y = d' / d$. The deformation factor y was a constant value or a function of respiratory phase.

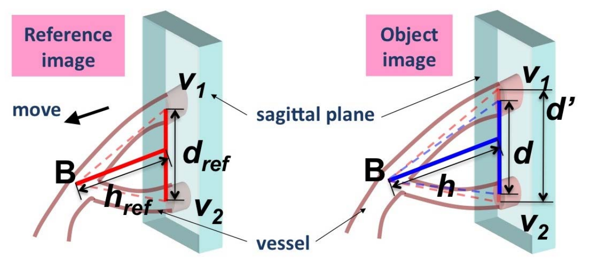

Figure 3 The vessel of object image translated and deformed from the position of reference image. d is distance between v_1 and v_2 after translating and deforming with respiratory motion. d' is distance between v_1 and v_2 on the assumption that the vessel is rigid.

Results The analysis of the first 24 image set shows that the maximum out-plane displacement of the branching vessels (h) was 3.12mm, and the maximum distance between the vessels for interest (d) was 2.44mm. The maximum deformation of the branch angle was 12.1 degrees. The other two healthy volunteer's liver images were acquired and analyzed. These results indicated that the hepatic tissue motion and deformation in out-plane (left-right direction: LR) was not negligible. In this report, the deformation parameter y was the mean of the deformation factor of each image set. y was 103 percents. Figure 4 shows the estimated distance between the branching point and the sagittal image plane. The average of the error between the estimated distance and the measured distance was 1.39mm.

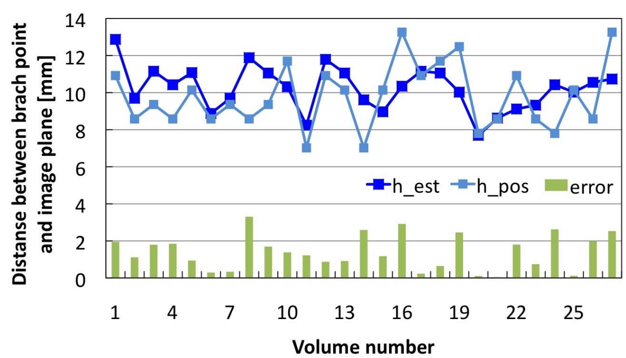

Figure 4 Distance between branching point and image plane. "h_est" is estimate distance derived by proposed method. "h_pos" is measured distance from volume data. "error" is the absolute value of difference between "h_est" and "h_pos".

Discussion and Conclusions

The results demonstrated the out-plane displacement of the hepatic tissue could be measured with dividing the displacement of the distance between the vessels for interest by the factor of the displacement and deformation. The three-dimensional target tracking will be able to implement by arrange this proposed technique and our two-dimensional target tracking method [2].

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