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A Preliminary Study of Portal Veins' 3D Respiratory Motion Analysis with 3D Ultrasound

３次元超音波を用いた門脈の３次元呼吸性移動解析に関する予備的検討

Iori Terada‡, Tomohiro Ueno, Koichi Ishizu, Yasutomo Fujii, Tsuyoshi Shiina, and Naozo Sugimoto (Grad. School of Med., Kyoto Univ.)
寺田　伊織‡，上野　智弘，石津　浩一，藤井　康友，椎名　毅，杉本　直三 (京大院　医)

1. Introduction

Monitoring portal vein's function is useful for assessing hepatic and gastrointestinal function.[1)] Therefore, we have tried to develop a new 3D ultrasound imaging system which can monitor the portal vein for long time.[2-4)] It is necessary to capture the portal vein at the same position during the monitoring. However, the portal vein moves under the influence of respiration. It is generally known that the respiratory motion is stationary during the end-expiration phase. That was also observed in our previous study.[4)] It was assumed that a gating system which monitors the portal vein during only the end-expiration phase might be useful for accurate monitoring. To put that into practice, we have to quantitatively know how stationary the portal vein's motion during the end-expiration phase is. In this study, we visualized the frequency distribution of the portal vein's position in three dimensions and quantified its respiratory motion.

2. Materials and Methods

2.1 Image Data Acquisition

For the respiratory motion analysis, we used the image tracking results acquired in the previous study.[4)] Three healthy subjects (SA, SB, and SC) were monitored by a LOGIQ7 ultrasound system (GE Healthcare, US) with a 4D3C-L probe, a mechanical 3D/4D convex type transducer. The probe was held by a hand-made probe holder.[2)] All subjects rested in the supine position and breathed freely during the recording. Three-dimensional imaging for approximately 200 s after approximately 13 s to allow data storage was repeated several times. The voxel size of the acquired images was 0.31 mm^3. **Figure 1** shows the 3D ultrasound images in SA's data. It is observed that the portal vein's motion is stationary during the end-expiration phase. Image acquisition and data processing were carried out under the approval of Ethics Committee Graduate School and Faculty of Medicine Kyoto University (No. R0614).

2.2 Image Tracking

The image tracking was performed by the 3D rigid template matching. The template volume included the bifurcation and the main trunk of the portal vein. The center of the bifurcation in each volume was defined as a reference point. As a result of tracking, we could obtain the position of the reference point and the rotation angle around the reference point of each volume. As the matching measure, we adopted the residual sum of squares (RSS) of the intensities between each volume and the template volume. In this study, the data during the approximately 600-s period obtained by three times imaging was analyzed.

2.3 Respiratory Motion Analysis

We quantified the portal veins' respiratory motion by using the image tracking results. The position where the reference point located with highest frequency was defined as the stationary position. We picked up the positions where the reference point located farthest from the stationary position in a respiratory cycle. The average position of those was defined as the turning position. We transformed the coordinate of the tracking results so as to locate the turning position on y-axis with the origin of the stationary position. From the transformed tracking results, we made the 3D relative frequency distribution maps of the reference points at each position. We calculated the cumulative frequency distribution (CFD) of the number of the reference points within the distances from the stationary position. The forty percent of

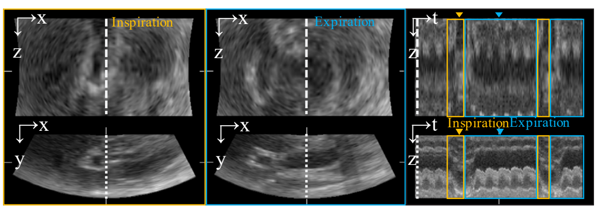

Fig. 1 Left and middle images are B(lower)/C(upper)-mode images in the inspiration/expiration phase. Right images are M-mode images of the white dotted line on B/C-mode images during the 20-s period in SA's data.

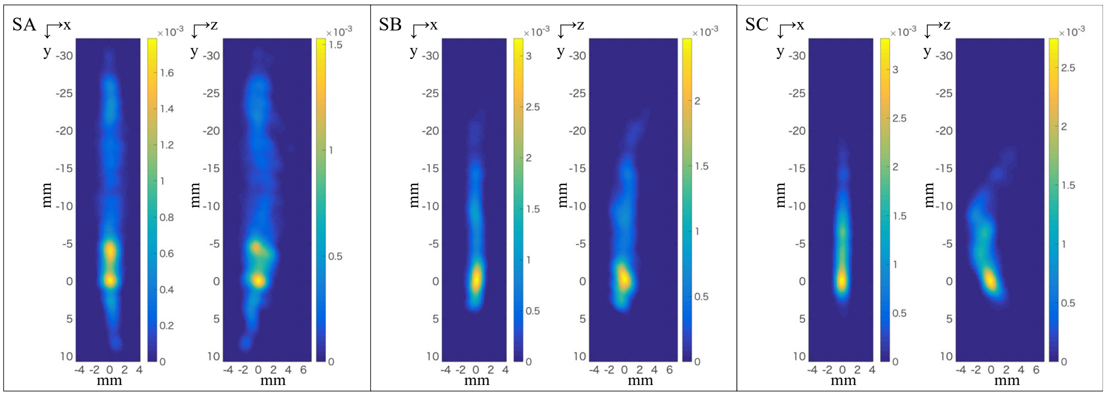

Fig. 2 Three-dimensional relative frequency distribution maps of the portal veins' bifurcation in SA's, SB's, and SC's data for approximately 600 s are projected in x-y plane and y-z plane. Each axis shows the distance (mm) from the stationary position.

the reference points in the CFD were estimated as the end-expiration points. The standard deviations of the points' position in each direction, and the average and the standard deviation of the rotation angle at the points were calculated. Also, the RSS at the points was recalculated with the template volume extracted at the stationary position.

3. Results and Discussion

Figure 2 shows the projection images of the 3D frequency distribution maps in all data. The respiratory motion was observed almost linearly along y-axis in the SA's and SB's data and was bent only in one direction in SC's data. Two peaks were observed clearly in SA's data. Although the 2nd peak was not observed in **Fig. 2(SB, SC)**, for both SB's and SC's data, small 2nd peak was observed in one dimensional plot of the 3D frequency distribution maps. It suggests that there may be two positions where the portal vein's motion is stationary. These 2nd peaks located on the y-axis in SA's and SB's data, and not in SC's data. However, in SC's data, the 2nd peak also located in the motion direction from the stationary position.

The distances covering 40% of the reference points in the CFD of the three subjects were 4.1 mm, 2.0 mm, and 2.4 mm, respectively. The 2nd peak of SA's data was included in the estimated end-expiration points, but not of the other data. The standard deviations of the end-expiration points' position in the y-axis of the three subjects were 2.0 mm, 1.0 mm, and 1.0 mm, respectively. Those in the other axis were less than 1 mm. Although the average of the rotation angles at the end-expiration points was almost zero in all data, the standard deviation was 2.4° at most. In our previous study,[4] we measured the main trunk diameter locating approximately 18 mm away from the reference point. In this case, 0.8 mm shift is occurred by 2.4° rotation. These results show that a few millimeter misregistration will occur with the gating system. Then, it will be necessary to use the gating system with the image tracking together.

The average RSS per voxel at the end-expiratory points of the three subjects was 20, 19, and 13, respectively. These values were on the same level with 16 of the noise level estimated in our previous study.[3] It suggests that the rigid transformation will be enough for the image tracking.

Although the respiratory motion analysis was performed for the gating system applied to our monitoring system, it may be useful for other applications such as the tracking system of the liver biopsy or the catheterization, and the treatment plan of the radiation therapy.

4. Conclusion

We quantified the portal veins' respiratory motion and visualize the frequency distribution of the portal veins' position in three dimensions for approximately 600 sec. We could quantify the portal veins' motion stability during the end-expiratory phase. In the next step, we will study the method to implement the gating system to our monitoring system.

References

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