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RF Signal-Based Tracking of Swallowing-related Muscle Movement

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1. Introduction

Quantitative diagnostic method for swallowing function has not been well established. In order to accurately determine the progression of the disease and the effectiveness of therapeutic intervention, there is a need to establish and standardize evaluation methods for swallowing function. Therefore, we aim to develop a new ultrasound assesment method of swallowing-related muscle function by tracking the movement of the geniohyoid muscle, which is one of the major swallowing-related muscles.

A related research topic, elastography to assess tissue strain, generally uses template matching [1)]. Although it may also be useful in tracking hyoid muscle behavior, template matching methods during swallowing activity have not been studied in detail. Here, we compare a template matching method using RF data of the geniohyoid muscle with a method using only envelope data, and propose a muscle behavior tracking algorithm suitable for the geniohyoid muscle movement during swallowing.

2. Method

2.1 Tracking algorithm

Two-dimensional muscle movement was estimated by manually placing tracking points on the images and calculating the similarity of the kernel around each tracking point between frames.

Three algorithms were compared in this study.

Method 1 utilized envelope data with tracking, using normalized cross-correlation as a similarity measure.

Method 2 used an iterative coarse-to-fine approach[2)3)]. The coarse scale data was generated by down sampling the envelope data. The down-sampled data were generated in two stages, and normalized cross-correlation was used as the similarity measure.

Lastly for Method 3, the searching window was narrowed after Method 2, and the displacement was finally estimated with the cross-correlation function[4)] using the complex RF data. Tracking process in Method 2 and Method 3 are described in **Fig.1**.

For all algorithms, subpixel estimation was performed using parabolic interpolation[5)].

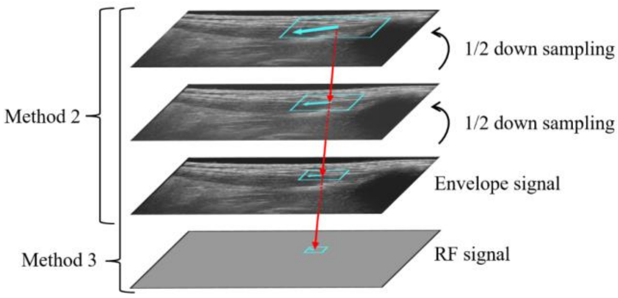

Fig.1 Tracking process in Method 2 and Method 3

2.2 Data acquisition

The volunteer in a sitting position swallowed 10 cc of water and the movement during swallowing of the sagittal section of the geniohyoid muscle was recorded. The ultrasound post-beamformed RF data was acquired using a Vantage System (Verasonics, USA) with L11-5V linear probe at a center frequency of 7.6 MHz at 100 fps. The transmission parameters are shown in **Table I**. In this study, only the cephalocaudal diastole of the sagittal section of the geniohyoid muscle was extracted and used for algorithm validation. This study was approved by the local ethics committee of Graduate School of Medicine, Tohoku University (No. 2023-1-273).

Table I Transmission parameters and algorithm settings

Parameter	Value
PRF [kHz]	6.25
Number of transmissions	14
Angle [°]	-5°~5°
Pixel resolution [mm/pixel]	0.051
Kernel size [pixels]	13×13
Method 1 : Searching window [pixels]	53×53
Method 2&3 : Searching window for envelope tracking [pixels]	25×25
Method 3 : Searching window for RF tracking [pixels]	17×17
Number of frames	123

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2.3 Data analysis

Tracking points were set up on the fascia of the geniohyoid muscle as shown in **Fig. 2 (a)**. In this study, two points parallel to the axial direction were set every 2 mm in the lateral direction, for a total of six points. Each of these tracking points was tracked frame by frame. The displacement of each tracking point was manually estimated every 10 frames as a basis for comparing tracking accuracy, and spline interpolation was used to estimate between frames. Kernel sizes and regions of interest for each tracking method are shown in Table I.

3. Results and discussion

From the tracking results of each method, absolute distance values between tracking points were calculated and compared with the results of manual displacement estimation. Axial and lateral motions corresponded to the cephalocaudal stretch (**Fig.2 (b)~(d)**) and the ventrodorsal stretch of the muscle (**Fig.2 (f)~(h))**.

Tracking errors could be divided into two major categories: the first case was that the tracking point disappeared from the image and the second case was that the similarity was accidentally increased at a point that was not the original tracking feature. Both erroneous cases caused a sudden change in the slope of displacement. Therefore, the tracking results were differentiated from each other and the RMSEs of manual and tracking were calculated to compare the accuracy. For all patterns in Figure 2(b)-(h), the RMSE value was highest for Method 1 and lowest for Method 3. In Fig. 2(d), (g), and (h), the RMSE of Method 1 and Method 2 ranged from 0.3 to 0.5, while that of Method 3 was less than 0.1, suggesting that Method 3 was more accurate than Method 1 and Method 2.

The erroneous tracking results of Method 1, where the tracking errors occurred and the slope of the displacement clearly changed, were observed to be corrected in the results of Method 2. It was suggested that the coarse-to-fine approach could prevent large tracking errors in the geniohyoid muscle tracking. The tracking errors remained in Method 2 was improved by interspersing the RF-based tracking introduced in Method 3. Fine displacement estimation was also suggested to result in more accurate hyoid muscle tracking by utilizing phase information of the post-beamformed RF signals.

4. Conclusion

In this study, three algorithms were tested on the geniohyoid muscle motion tracking. A approach of the coarse-to-fine envelope tracking followed by RF-based tracking was found to be effective.

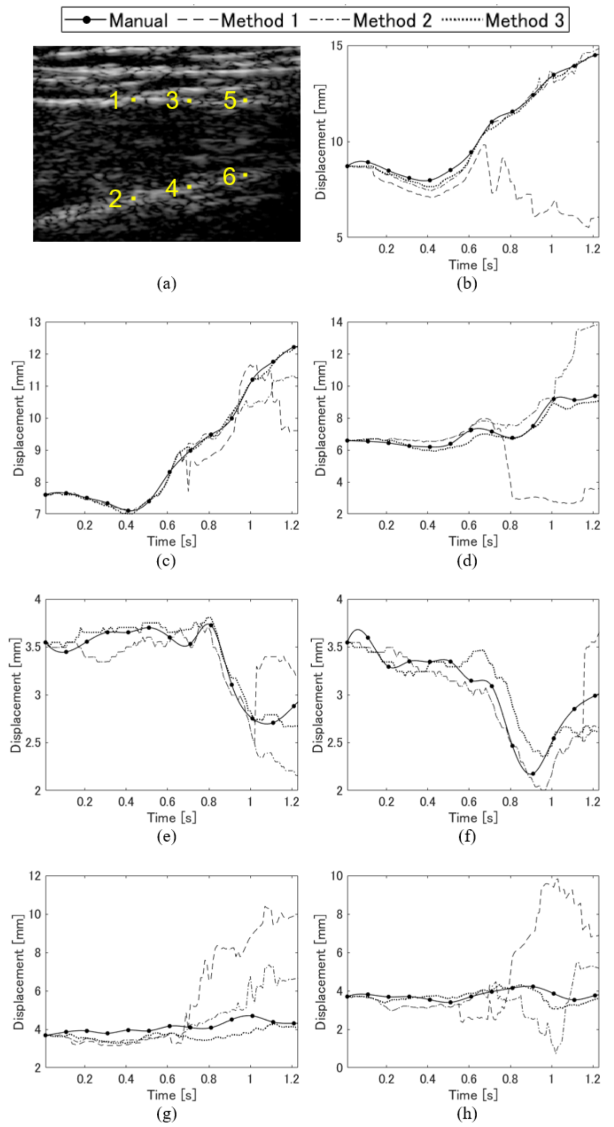

Fig.2 (a) Location of manually set tracking points on the fascia of the geniohyoid muscle. (b)-(h) Comparison of manual displacement measurement and tracking results for absolute distance between two points. (b) Point 1 – Point 2. (c) Point 3 – Point 4. (d) Point 5 – Point 6. (e) Point 1 – Point 3. (f) Point 3 – Point 5. (g) Point 2 – Point 4. (h) Point 4 – Point 6.

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