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Evaluation of cerebral artery occlusion by simple measurement of pulse wave at carotid artery

頚動脈波の簡易計測による脳動脈閉塞の評価手法の検討

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1. Introduction

For screening cerebral artery occlusion in the emergency medical care, a rapid, inexpensive and portable system, which measures biological signals and detects the cerebral artery occlusion, is required. We focus on the characteristics of the pulse waveform to evaluate occlusion in the main artery of anterior circulation. The pulse wave is a temporal variation of the displacement of the skin surface caused by pressure waves propagating in the artery. We constructed a carotid artery wave measurement device using an inexpensive, commercially available piezoelectric sensor for ultrasound[1]. To develop such a system, we focus on the pulse wave as the biological signal. We then propose a system containing the following three functions: measurement of the pulse wave, extraction of the dynamic features from the pulse wave, and detection of the cerebral artery occlusion using the dynamic features.

Since occlusion in the main artery of the anterior circulation rarely occurs simultaneously in the left and right sides. Using this device, we measured pulse waves at the left and right carotid arteries of patients with occlusion and healthy subjects. The classifier logistic regression, which is embedded in the system, outputs the probability that the cerebral artery occlusion exists. We report the design, development, and experimental evaluation of our proposed system in this paper.

2. Measurement method and subjects

Pulse waves were measured at the common carotid arteries using a piezoelectric transducer (MA40 E7R, Murata Manufacturing)[2]. Figure 1 shows the pulse wave measurement using a piezoelectric sensor and the small system. The output of the transducer was amplified by 40 dB and recorded by AD conversion at a sampling frequency of 1 kHz. In this system, the differential waveform of the skin displacement (pulse wave) was observed, and the waveform were integrated to obtain the pulse wave. Subjects were healthy 11 males and 9 females (ages: 20s-60s), in addition to 16 male and 7 female patients with an occlusion at the main artery of the anterior circulation (ages: 50s-90s). The subjects lay down in the spine position and in the resting state during measurements. 10 waveforms were obtained from left and right common carotid arteries of each subject, and averaged waveforms were obtained. Figure 2 shows measured pulse wave and differential pulse wave.

Fig. 1 Pulse wave measurement using a piezoelectric sensor.

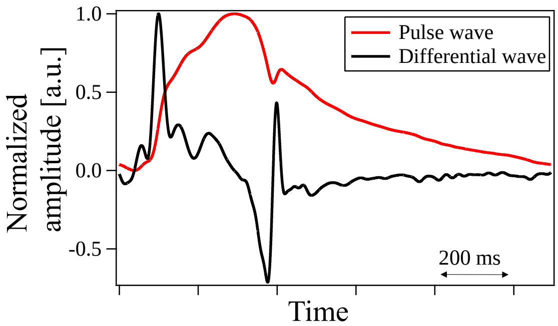

Fig. 2 Pulse wave and differential pulse wave obtained from a male patient (61 years old).

The waveform analysis was performed following our previous report[3]. All studies were approved by the medical ethics committees of Doshisha University and Nara Medical University.

3. Waveform analysis methods

As shown in Fig. 3, the left and right differential waveforms were often different due to occlusion.

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The following four dynamic features ((a)~(d)) were selected for the waveform analysis.

(a) Maximum value of the cross-correlation function of the left and right averaged differential pulse waves.

(b) Left-right difference in the number of positive and negative peaks of the averaged differential pulse wave.

(c) Maximum amplitude fluctuation of 10 continuous differential pulse waves.

(d) Left-right difference in peak after incision of differential pulse waves.

The analysis was performed using the logistic regression model (eq. (1))[4].

$$p = \frac{1}{1 + \exp[-(\mathrm{b}_0 + \boldsymbol{b} \cdot \boldsymbol{x})]} \qquad (1),$$

where p is the probability that the subject has an occlusion in the main artery of the anterior circulation. $\boldsymbol{b}=(b_1,b_2,b_3,b_4)$ is the weight of each dynamic feature and b_0 is intercept of the logistic regression model created, and $\boldsymbol{x}=(x_1,x_2,x_3,x_4)$ is dynamic feature of pulse wave. Here b_1 is the weight coefficient for (a), b_2 is for (b), b_3 is for (c) and b_4 is for (d). To obtain a logistic regression model, 11 test data and 32 learning data were randomly selected and divided into training and test sets 20 times. Accuracy and the weights of input variables of all trials were estimated.

4. Result and discussion

Figure 2 shows an example of the measured differential pulse wave at carotid artery of patients. In case of patients, pulse waveforms measured at left and right carotid arteries were different, which was opposed to the healthy persons. Figure 3 shows 5 continuous differential pulse waves (occlusion side). The dynamic feature (c) was evaluated by calculating the standard deviation of the maximum amplitude of 10 continuous differential pulse waves. The average of accuracy by the logistic regression was 0.80 and the standard deviation of accuracy was 0.11. Compared to individual accuracies of (a) 0.30 and (b) 0.17, the accuracy was obviously improved. Table 1 shows the weights of 4 dynamic features obtained by the analysis. Dynamic features with large weights are important for occlusion diagnosis. It is known that pressure waves propagating in a blood vessel partially reflect at the occlusion[5] . Dynamic features (a) and (b) concern this reflection. The dynamic feature (c) is a character that is more affected by the atrial fibrillation. The dynamic feature (d) shows that small reflected waves may exist during diastole period. The effects of the reflected wave at the occlusion site seemed large, because (b) shows the largest weight.

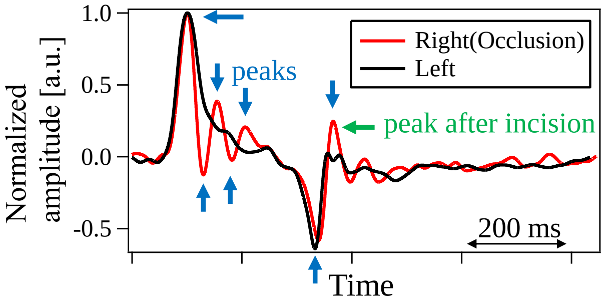

Fig. 2 Averaged differential pulse waves (A female patient with an occlusion at right internal carotid artery (82 years old)).

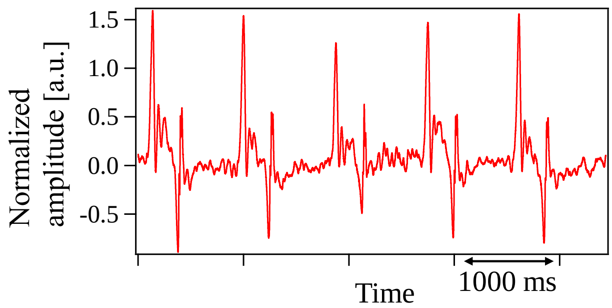

Fig. 3 Observed continuous right differential pulse waves of a female patient (82 years old).

Table 1 Weights of parameters.

	b_1	b_2	b_3	b_4
Average	0.45	0.84	1.29	0.37
Standard deviation	0.27	0.28	0.21	0.29

5. Conclusion

The left and right carotid artery pulse wave of healthy subjects and patients with occlusion were measured and compared. We selected 4 dynamic feature to evaluate the occlusion and accuracy of 0.80 was performed by the logistic regression. These data imply the possible evaluation of occlusion in the carotid artery by the pulse wave measurement. The measurement is simple and non-invasive, which may be used in the emergency medicine in the future.

Acknowledgment

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Reference

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