Variation of Radial Pulse Wave Contour Influenced by Contact Pressure

Dianning He, Li Zheng, Jia Liu, Ning Geng, Guan Dejun, Lisheng Xu*

Abstract— **In this paper, the radial pulse waveforms of the same subjects under various contact pressures were measured. Then, the feature points of the pulse wave contours were extracted and the physical parameters were calculated corresponding to different contact pressures. The various trends of parameters, including peripheral augmentation index, peripheral subendocardial viability ratio, and peripheral resistance, influenced by contact pressures were analyzed. By comparing the variation trend between different subject groups, it is notable that there exists a significant difference between the parameters of young healthy people and elder patients (P<0.01). Moreover, the peripheral augmentation index, SEVR and the peripheral resistance descend with increased contact pressure, because of the variation of pulse wave contour.**

I. INTRODUCTION

Pulse wave signal, one of the most important physiological signals, is commonly extracted by applying a fixed pressure sensor on the radial artery. However, on account of the influence of the transmural pressure, the measured pulse wave changes with the variation of the contact force between the sensor and the measurement site [1,2]. The change of pulse wave contains the difference of the amplitude and the contour of pulse waves. Therefore, a large number of research about the relationship between the contact pressure and the measured pulse wave was done to analyze to the influence of the contact pressure on the pulse contour analyze [3-5]. Nevertheless, the impact of contact pressure to the result of cardiovascular parameters based on the analysis of pulse contour was not studied. Thus, in this paper, we compared the parameters obtained from the pulse waves at different contact pressures, and then we analyzed the relationship between them.

The parameters, including peripheral augmentation index, peripheral subendocardial viability ratio, peripheral resistance, etc, were analyzed. The spread of the pulse waves from the heart to peripheral circulation is accompanied by reflections from peripheral sites. This phenomenon lead to backward traveling pulse waves, which heighten pressure at the heart. This kind of augmentation is central augmentation index. Meanwhile, pulse pressure spread and reflection within the arm lead to the augmentation of the peripheral pulse waves. The ratio of the increasing of the pulse because of this phenomenon is peripheral augmentation index (pAI) [6].

Subendocardial viability ratio (SEVR) is a physiological parameter, which is calculated from the contour of radial artery pulse wave. The SEVR represents the ratio between myocardial oxygen demand and supply [7,8].

The peripheral resistance and resistance compliance can be calculated through the Windkessel model. Windkessel are used as model to estimate the physical parameters of human, hydraulic load total arterial resistance and compliance, from pressure and pulse waveforms.

In order to analyze the influence of pulse wave contour variation to the above cardiovascular parameters, this paper calculated these parameters through different pulse wave signals at the various contact pressure, and then compared the difference between them, as well as the different variation trend among different subjects groups.

The remaining of this paper is organized as follows, firstly the methods of the research, including the information of study samples, the method of preprocessing of the pulse wave signal and the calculation of the cardiovascular parameters; as well as the results of the research, containing the influence on the various parameters by the changing of contact pressure.

II. METHODS

A. Study sample

We studied 10 healthy subjects, in the age of around 25 years old; 10 elder subjects with ages between 52 to 78 years old in the health condition; and 10 patients, with newly diagnosed untreated, who referred to the Cardiology Inpatient Unit of the First Affiliated Hospital of China Medical University and the Second Affiliated Hospital (Sheng Jing Hospital) of China Medical University, located in Shenyang, China. All subjects gave informed consent and underwent the usual clinical examination, and laboratory work-up.

B. Acquisition of the pulse wave and signal processing

In this paper, pulse wave measurement was performed, using our developed pulse wave acquisition device with a pressure sensor, being placed on the radial artery of the right arm. The pressure sensor has function of adjusting the contact

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Dianning He, Li Zheng, Jia Liu are the graduates of Northeastern University, Shenyang 110819.

Ning Geng is the associated professor of China Medical University, Shenyang.

Guan Dejun is the lecturer of Shenyang Open University.

Lisheng Xu is the full professor of Sino-Dutch Biomedical and Information Engineering School, Northeastern University; and he is also the professor of the Key Laboratory of Medical Image Computing, Ministry of Education, e-mail: xuls@bmie.neu.edu.cn.

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pressure to the measurement site, and the accordingly contact pressure of the detected pulse can be recorded (Fig. 1). The subjects were made in the rest condition, and then we increased the contact pressure of sensor step by step. The interval of each two steps was 20g, and at each step the pulse waveforms were collected for more than 20 seconds. The collection of each subject in different contact pressures were all done during a period of time while the subject was in a steady condition. Thus we can get the different pulse signals with according contact pressure.

The signal from the pressure sensor was digitized using a 12-bit analogue-to-digital converter with a sampling frequency of 1 kHz [9]. The patient was in the lying position after he or she had rested for at least 10 min. The noise of pulse wave signal was removed while the baseline wander was corrected by the method of wavelet [10]. Then the related feature points were extracted and calculate the value of cardiovascular parameters. After that, the relationship of contact pressure to calculated parameters is examined in subjects with different cardiovascular health condition.

C. Calculation of parameters

1) The extraction of feature points

As shown in the Fig. 1, the pulse waveform in the above figure is called a triple-humped wave, and it has 3 wave peaks. In this paper, all the 3 peaks of the 3 waves were extracted, as well as the wave trough between the waves.

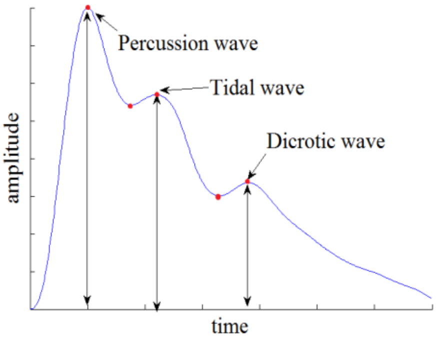


Figure 1. The waveform of a triple-humped waveform, including the percussion wave, tidal wave, and dicrotic wave are three separate waves, and the feature points.

In the Fig. 2(a), the point of SBP2 is the peak of the tidal wave, i.e. the second humped. However, for some pulses, their pulse waveforms may have two peaks or even one peak. The above figure in the Fig. 2(b) shows a pulse sample without tidal wave. In the pulse sample, the point SBP2 is not a peak, but a 'shoulder'. Therefore, we used the derivative signal of the pulse to detect if SBP2 is a peak or shoulder, then we extracted the point of SBP2. Moreover, for the pulses without the dicrotic wave, i.e. the third peak in Fig. 1, the similar method can be used to extract the 'shoulder' of dicrotic wave [11,12].

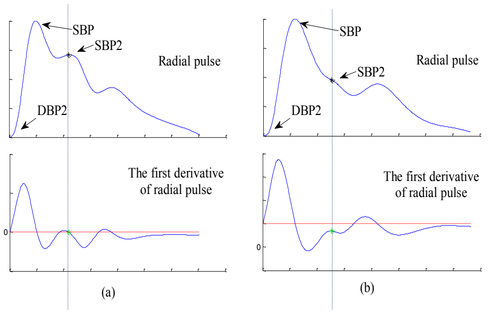


Figure 2. Radial pulse and its first derivative. The late systolic shoulder (SBP2) of the peripheral arterial waveform is defined as the point which the derivative is closest to zero. The second systolic peak occurs when the second peak of derivative is above zero, and its location corresponding to the zero point of derivative as shown in the figure, whereas an inflection point occurs when the second peak of derivative is below zero.

As the SBP is the peak point of pulse waveform while SBP2 is the peak point of the differential of pulse, therefore, they can be extracted accurately and be rarely affected by the noise.

2) The calculation of peripheral augmentation index

The pAI is calculated based on the feature points of SBP2 and the peak of the pulse wave, SBP (as shown in Fig. 3). DBP is the value of the beginning of the systole. Thus, we can get the height of SBP, SBP minus DBP; and the height of SBP2, SBP2 minus DBP. Therefore, pAI refers to the ratio of the height of SBP2 to the height of SBP [13].

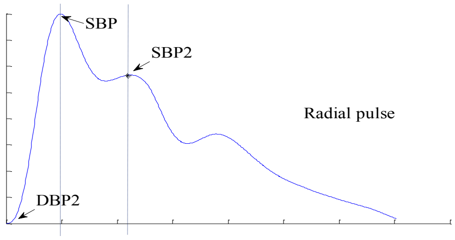


Figure 3. The calculation of peripheral augmentation index (pAI). pAI can be obtained from the ration of the height of the second peak of the pulse to the first peak of the pulse.

3) The calculation of peripheral subendocardial viability ratio

As shown in Fig 4, SEVR describes the relationship between supply and demand, i.e., between the myocardial blood supply and myocardial oxygen requirement. It is calculated using the formulas

$$\mathrm{DPTI}=\int_b^c f(pulsewave)dt \tag{1}$$

$$\mathrm{SPTI}=\int_a^b f(pulsewave)dt \tag{2}$$

$$\mathrm{SEVR}=\mathrm{DPTI}/\mathrm{SPTI} \tag{3}$$

DPTI represents the area under the diastolic portion of the pressure wave, obtained by the integral of the pulse wave curve during diastolic time (DT); while SPTI represents the area under the systolic portion of pressure wave, obtained by the integral for the pulse wave curve during left ventricular ejection time (LVET).

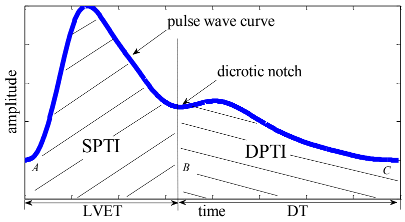


Figure 4. The illustration of the calculation of SEVR. SEVR is represented as the ratio of DPTI to SPTI. DPTI is the area under the pressure wave, on the left of the dotted line, which represents the myocardial blood supply. Moreover, SPTI is the area under the systolic portion of pressure wave, which represents the myocardial oxygen requirement. Thus SEVR reflects the relationship of myocardial oxygen demand and supply.

4) *The calculation of peripheral resistance and compliance*

As shown in the Fig. 5, voltage (*v*) is similar to mean pressure in the left ventricle, the first capacitor (*C1*) to central, large artery compliance, while the second capacitor (*C2*) to distal or small artery compliance, electrical current (*i*) to blood flow, inductance (*L*) to inertance the blood, and the resistor (*R*) to peripheral resistance.

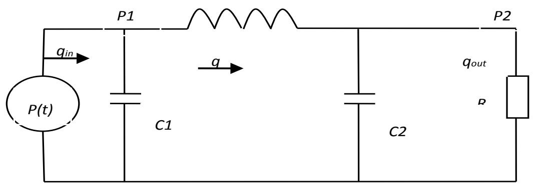


Figure 5. Circuit model of third-order Windkessel.

In this paper, we set the inductance *L* of subjects as a constant, 0.025 *mH*, and then use the third-order Windkessel model to calculate peripheral resistance *R* and compliance *C1* and *C2*, with the pulse contours [14].

III. RESULTS

A. *Variation of pulse amplitude*

The different pulse signals were compared in the Fig. 6. From the figure, it can be found that the amplitude of pulse increases while the contact pressure rises until the pressure gets the optimum value. At this value, transmural pressure is zero, and then arterial pulsation begins to diminish since the artery becomes occluded by the excessive external pressure.

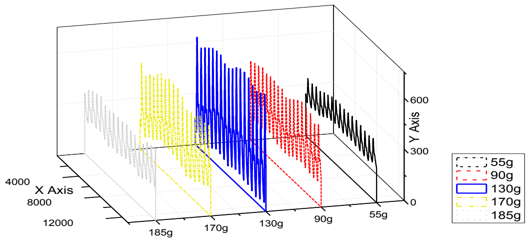


Figure 6. Pulse wave series in various sensor contact pressure.

Then the relationship of pulse amplitude and contact pressure can be obtained, as shown in Fig. 7.Moreover, as the trend of the parameters variation is close to the contour of Gauss curve, therefore a Gauss fit was done, to illustrate the variation trend and compare the difference between this relationship. The Gauss curve is also shown in Fig. 8.The Gauss function is shown in formula (4). Consequently, the parameters of Gauss fit: y_0, x_c, w and A were obtained. The illustration of Gauss fit is in Fig. 10.

$$y = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-2\frac{(x-xc)^2}{w^2}} \tag{4}$$

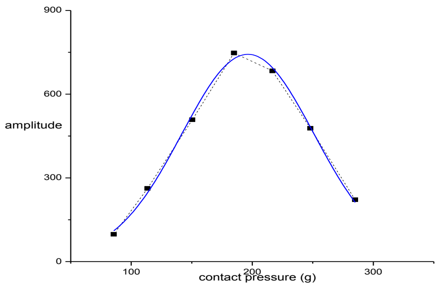


Figure 7. The relationship between contact pressure and pulse amplitude: the x-axis is the contact pressure and the y-axis is the accordingly pulse amplitude. The blue line is the fitted Gauss curve to the actual black points.

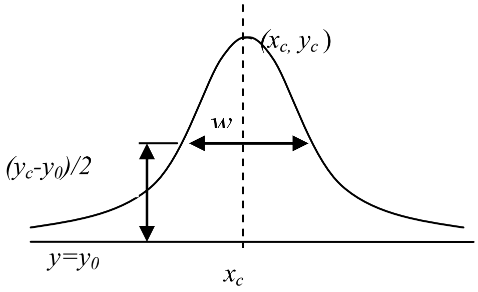
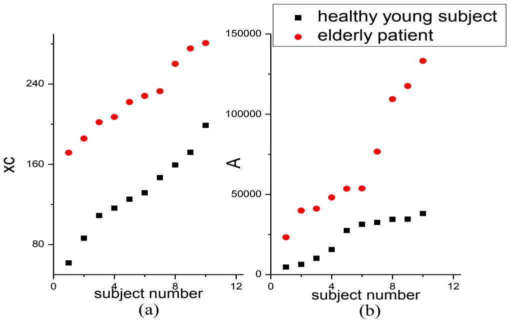


Figure 8. The illustration of Gauss fit.

In addition, a comparison between Gauss curve parameters of the groups of youth and elderly patients is conducted through Independent-Samples T-test, with SPSS (as shown in Fig. 9). The results show that: the difference of the parameters of x_c and A between the groups are significant (P<0.01), and the difference of the parameters w is close to the edge of the significant difference (P=0.51).



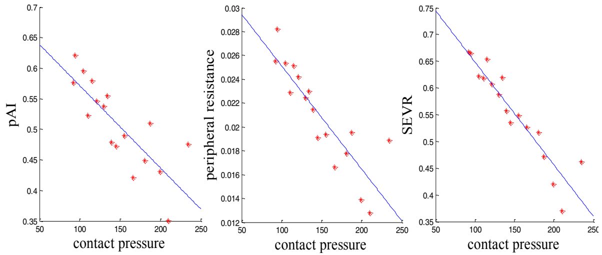
(a) (b)

Figure 9. The comparison of Gauss parameters xc and A between the subject groups of young people and elderly patients.

B. *Variation of pAI and peripheral resistance*

By comparing pulses in the different contact pressure, it can be found that when contact pressure changes, the contour of the pulses do not change apparently, and there is a similarity between them. However, as when calculating the parameters such as pAI, SEVR and using Windkessel model, the normalization of the pulses need to be done. After normalization, the difference occurs between the feature points in different contact pressure. As all the pulses were normalized to the blood pressure level, the maximum and minimum values of the pulses are same. However, their other feature points, such as tidal wave peak are different. This results in the different of pAI. In Fig. 10(a), we can see the relationship between contact pressure and the according pAI. It can be found that when contact pressure rises, the pAI is in a decreasing trend. The fluctuation in the high pressure part may be resulted by the high-frequency interference, because of the effect of tissue around radial artery became more obvious when the external force is higher.

Moreover, as shown in Fig. 10(b), the peripheral resistance calculated from Windkessel model has the similar variation trend. This is also resulted by the variation of pulse contour. There is also difference between the parameters of SEVR and peripheral compliance as shown in Fig. 10(c).



(a) (b) (c)

Figure 10. The difference of pAI, peripheral resistance and SEVR between different pulses in contact pressure.

IV. CONCLUSION

This paper analyzed the difference between the contour of the pulse signals measured under the different contact pressures. It is found that the variation trends of pulse amplitude of subjects with different healthy condition are not the same, and there exists a significant difference between the parameters of xc of young healthy people and elder patients. Moreover, the morphologies of the pulses waves at different contact pressures various after the pulses are normalized to the blood pressure level. The heights of tidal wave and dicrotic wave decrease with the rising of contact pressure, therefore the pAI also decreased with the height of tidal wave. The variation of pulse wave contour also results in the drop of the value of the peripheral resistance. In addition, the calculation results of SEVR and compliance also changes when the contact pressures varies, however the changing trends are not obvious.

To conclude, it is necessary for the measurement of pulse signal to be operated in the condition that the transmural pressure is zero. As at this condition, the detected pulse wave has the largest amplitude and the interference from the tissue is small. Moreover, the variation trend of the parameters are different between subject groups, therefore the trend might be a kind of indicator for identifying the condition of cardiovascular system.

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