Engineering, 2013, 5, 176-180
http://dx.doi.org/10.4236/eng.2013.510B038 Published Online October 2013 (http://www.scirp.org/journal/eng)

Scientific Research

Cardiovascular Diseases Detecting via Pulse Analysis

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Received May 2013

ABSTRACT

In this research, we have performed pulse analysis on the data of 127 subjects collected from Department of Cardiology at Shandong Provincial Hospital in China. By taking the first and third derivatives of an entire pulse wave, we have firstly identified the locations of wave foot, systolic peak, and reflected point. Then we calculated Reverse Shoulder Index (RSI) and Ratio of Distance of the evaluated subjects, and correlated them to age, the history of hypertension, and different cardiovascular diseases of the subjects.

Keywords: Pulse Wave Analysis; Wave Reflections; RSI; Cardiovascular Diseases Detection

1. Introduction

In the year of 1872, the father of pulse wave analysis, Mahomed, wrote the following statement in his research [1], "Since the information that the pulse affords is of so great importance, and so often consulted, surely it must be to our advantage to appreciate fully all it tells us, and to draw from it every detail that it is capable of imparting". Since then more and more scientists put lots of efforts to discover the important points from pulse wave and connected them to age and different kinds of diseases, especially cardiovascular diseases, for instance, hypertension, acute myocardial infarction and coronary heart disease.

In 19th century, pulse wave was recorded invasively from the aortic ascending artery. Therefore, during that period, pulse wave analysis is mainly concentrated in ascending aorta. The invasive method has lots of short comings. It is greatly inconvenient to be obtained and hard to keep consistency of wave form. Later on, scientists developed noninvasively methods for obtaining pulse wave. Furthermore, not only the pulse wave of aortic central artery, but also waves of peripheral arterial, carotid, brachial and femoral arteries can be recorded. In our study, pulse waves were recorded noninvasively from index finger using a finger clip with infra-red sensor.

The noninvasively method of recording pulse wave does make a great contribution to the process of pulse analysis. Among all related research of pulse wave, the study of reflection of the primary pressure pulse along the human arterial tree has important significance in medical research. In 1890, Murgo *et al*. pointed out that wave reflection was highly associated with age [2]. Both Mitchell *et al*. in 2004 [3] and O'Rourke, Nichols and in 2005 [4] proved there was inextricable link between wave reflection and age. Furthermore, Eshan *et al*. [5] correlated wave reflection with cardiovascular risks. They emphasized that it may be a useful measure of assessing overall rick for coronary artery disease. Certainly wave reflection is a momentous aspect for pulse analysis, and it is a different issue between central aortic pulse pressure and peripheral arterial pulse pressure. For central aortic pressure, augmentation index is used as an incidence of reflected waves among total pulse pressure, as mentioned in [6]. For peripheral arterial pressure, another index would be adopted, which is RSI (Reverse Shoulder Index). Due to all of the pulse waves for our study are recorded from peripheral artery, we applied the method discussed in [7]. According to [7], we verified the wave foot by the first derivative form and located the reflected point and systolic peak via the third derivative curve. RSI (Reverse Shoulder Index) and Ratio of Distance were calculated using those two points. In the following part, we will introduce the details of the method. Finally, we associated those two parameters with age, hypertension, coronary artery disease and chest pain. Results will be shown in the following statement.

2. Subjects and Device

We evaluated 127 subjects from August, 2008 to August, 2010 in Department of Cardiology at Shandong Provincial Hospital in China. All the pulse waves were recorded noninvasively by finger clip with infra-red senor. The device is made by Anhui Huake Electronic Technical Research Institute in China, and the model of the device is HKG-07C, shown as **Figure 1**. The data were col-

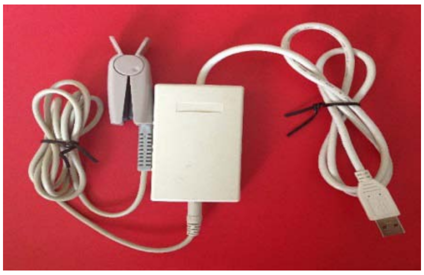

Figure 1. Finger clip and infra-red sensor.

lected when each subject felt comfortable and peaceful. The infra-red sensor was applied to the right index finger, and it could detect the blood pressure and track the strength of it. Only stable and appropriate pulse wave will be recorded. The sampling rate is 200 Hz.

Figure 2 shows a sequence of pulse waves recorded from one subject by the infra-red sensor.

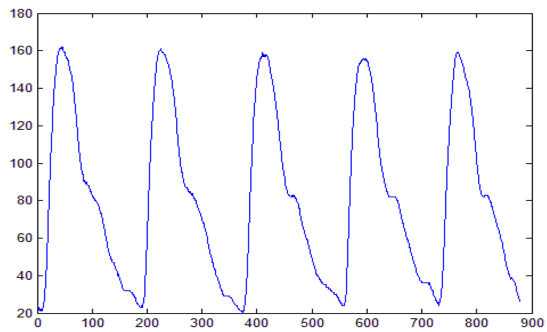

Figure 2. Pulse waves.

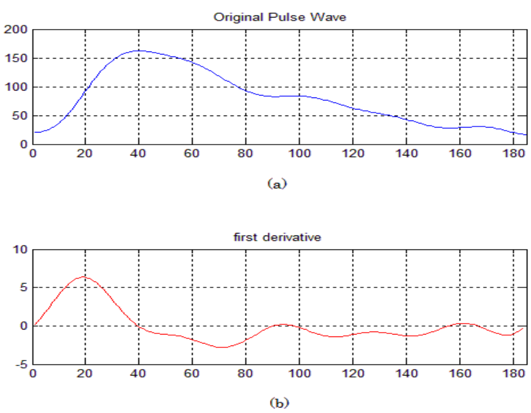

Figure 3. Original pulse wave and its first derivative curve.

3. Methodology

3.1. Dynamic Curve Fitting

When a serial of pulse signals are collected, firstly, we need to perform dynamic curve fitting on the data. It is an iterative process that may converge to find a best fitting of trigonometric function. Among all of the experimental tasks carried out, we found that the sum of sine function with eight terms provides the optimal results. This fitted function is expressed in Equation (1).

$$f(x) = a_1\sin(b_1x+c_1) + a_2\sin(b_2x+c_2) + a_3\sin(b_3x+c_3) + a_4\sin(b_4x+c_4) + a_5\sin(b_5x+c_5) + a_6\sin(b_6x+c_6) + a_7\sin(b_7x+c_7) + a_8\sin(b_8x+c_8) \quad (1)$$

where a, b, and c are coefficients for determining the best fit of original pulse waves. Finding the best fitted function is an iterative process, which starts with a guess at the coefficients and keeps modifying the coefficients until the best fit is reached. The purpose of doing curve fitting is to calculate the first and third derivatives of pulse waves.

3.2. Identify the Foot of Pulse Wave

The pulse signal recorded by device from each subject is a series of continuous cycles of pulse waves.

In our study, however, all the analyses are based on one entire cycle of pulse wave. Therefore, it is necessary to identify the wave foot in order to conduct our research. The wave foot is corresponding to the first negative to positive zero crossing point on the first derivative curve, which is calculated based on the fitted function discussed previously.

Figures 3(a) and **(b)** show an entire cycle of pulse wave and its first derivative curve, respectively. Once the foot of pulse wave is located, we can obtain one entire waveform from the original continuous cycles of pulse waves.

3.3. Verify the First and Second Shoulders

Within an entire pulse wave cycle, the first and second shoulders indicate the reflected point and systolic peak. In our study, we classified two types of subjects according to these two points. The differences between two types are illustrated by **Table 1** and **Figure 4**.

Refer to both **Table 1** and **Figure 4**, the pulse wave of Type 1 has systolic peak occurs before reflected point. In contrast, systolic peak occurs behind reflected point in the pulse wave of Type 2.

To classify two different types of pulse waves, we performed the third derivative of the fitted function and labeled the relative maximum point of the third derivate with ‘Max3rd’, as shown in **Figure 5(b)** and **Figure 6(b)**. When ‘Max3rd’ locates at or nearby the location which of the systolic peak in time domain and before the location which of the diastolic peak, this pulse wave is regarded as Type 1. Type 2 is which ‘Max3rd’ occurs in front of systolic peak but within 60 milliseconds.

Besides the contours of two different types of pulse waves are distinct, the methods of verifying two shoulders are different for Type 1 and Type 2 as well. According to Type 1, the first shoulder is the point refers to

Table 1. Difference between Type 1 and Type 2.

	First shoulder	Second shoulder
Type 1	Systolic peak	Reflected point
Type 2	Reflected point	Systolic peak

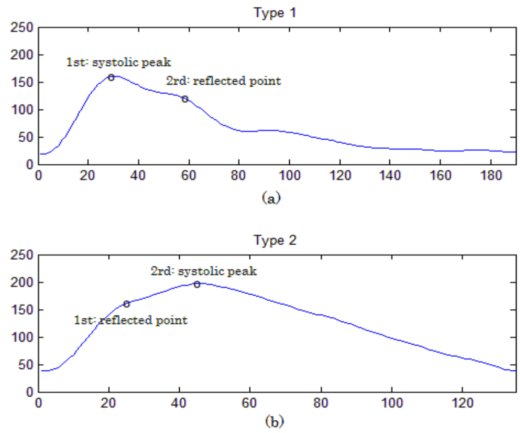

Figure 4. Illustration of Type 1 and Type 2.

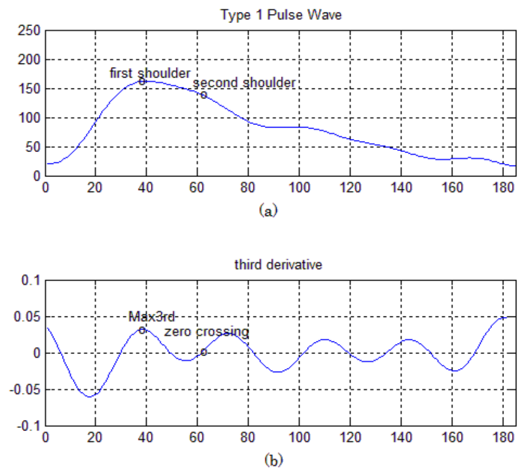

Figure 5. Type 1 with two shoulders.

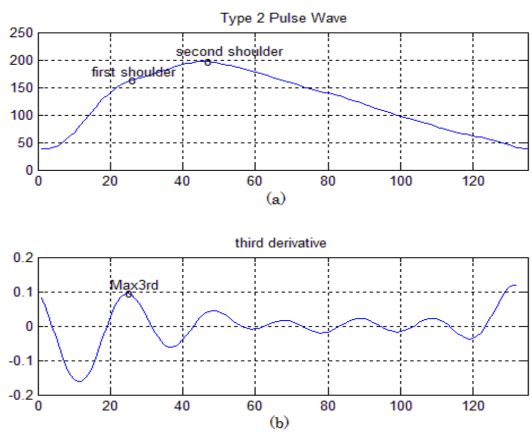

Figure 6. Type 2 with two shoulders.

the maximum point of the original pulse wave, known as systolic peak as well. Thereafter, the second shoulder is determined by discovering the first negative to positive zero crossing of the third derivative curve, labeled as 'zero crossing' in **Figure 5(b)**.

For Type 2, we labeled systolic peak as the second shoulder. Thus, as shown in **Figure 6**, the first shoulder is the point "Max3rd" at the location of the reflected point.

After types classifying and two shoulders being discovered, we would mark down both of the positions and pressure values of two shoulders for further calculation and analysis.

3.4. Calculate RSI and Ratio of Distance

As illustrated by **Figure 7**, RSI, Reverse Shoulder Index, is generated by dividing the pressure at the second shoulder minus the pressure at the wave foot, P_1, by the pressure at the first shoulder minus the pressure at the foot of wave, P_2, which is expressed by Equation (2).

$$RSI = \frac{P_2}{P_1} \times 100 \quad (2)$$

Since the heart rates of each subject are different, the lengths of pulse wave of each subject are uneven. In order to be more precise, in this study, we calculate the ratio of distance, as expressed in Equation (3), which is divided the distance between two shoulders by the length of whole pulse wave, as shown in **Figure 8**.

$$\text{Ratio\_of\_Distance} = \frac{d}{D} \times 100 \quad (3)$$

4. Experimental Results

Among all of 127 evaluated subjects, 106 of them were

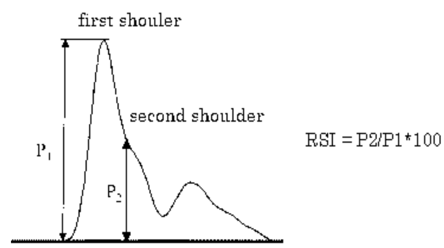

Figure 7. Illustration of RSI.

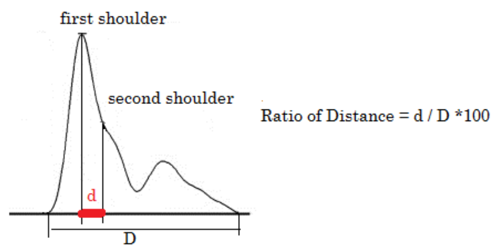

Figure 8. Illustration of ratio of distance.

regarded as Type1, whose first shoulder is systolic peak and second shoulder is reflected point, and 21 subjects were labeled as Type 2, whose first shoulder occurs before systolic peak.

First, we correlated RSI and Ratio of Distance with the ages of subjects. **Table 2** shows RSI and Ratio of Distance of subjects of Type 1, whose ages are ranged from 50 to 90. There are 88 subjects in this category. Since the numbers of subjects aged from 0 to 49 is small and the distribution of age is uneven, we did not take them into consideration.

From **Table 2**, it can be observed that when ages increase, RSI and Ratio of Distance of the subjects would increase as well. The higher the RSI value is, the larger the absolute amplitude between two shoulders is. And a high Ratio of Distance implies the longer distance between two shoulders.

Then we compared RSI and Ratio of Distance from different genders for both Type 1 and Type 2. The results shown in **Table 3** indicate that RSI of female are significantly higher than that of male for both types. While the age ranges and mean ages of female and male in both types are similar, RSI of female goes up to 77.33 and 118.33 for Type 1 and Type 2, respectively. Although the Ratio of Distances for female and male are almost the same in Type 1, female have a higher value in Type 2, which means that the reflected point occur earlier.

In this research, we have also focused on the relationship between pulse wave and cardiovascular diseases, such as hypertension, coronary heart disease, and chest pain.

Table 4 shows RSI and Ratio of Distance of subjects who have history of hypertension. It is obvious that for the subjects who have longer history of hypertension, the value of RSI goes higher and that of Ratio of Distance becomes less.

Table 5 illustrates the values of RSI and Ratio of Distance collected from the subjects with coronary heart disease only, both of hypertension and coronary heart disease, and subjects without any of these two diseases.

For Type 1, the subjects who have both diseases have the highest RSI, while the subjects without any of these two diseases have the lowest RSI. The Ratio of Distance is only slightly changed for the subjects from all of three groups. For Type 2, while the subjects without any of these two diseases still have the lowest RSI and highest Ratio of Distance, the subjects with coronary heart disease have higher RSI values than those who have both diseases and Ratios of Distance are close. In general, subjects who have coronary heart disease have higher RSI than those who have not.

Close to 50% of evaluated subjects, 64 out of 127, complained chest pain. The RSI and Ratio of Distance values of the chest pain complainers are shown in **Table 6**. Compared with the values illustrated in **Table 5**, we can observe that the subjects with chest pain have higher RSI and lower Ratio of Distance. It indicates that cardiovascular function of subjects with chest pain is considerably worse.

5. Conclusions

In this study, we have conducted the research on pulse waves collected from 127 subjects who have different types of cardiovascular diseases. The dynamic curve fitting is applied to the pulse waves of each subject in order to obtain the fitted function. Based on an entire cycle of pulse wave, we calculated the first derivative of the pulse

Table 2. RSI and ratio of distance related to age (Type 1).

age	RSI	Ratio of Distance	Numbers of subjects
≥50, <70	72.15	13.38	40
≥70, ≤90	76.85	12.24	48

Table 3. RSI and ratio of distance related to gender.

	Gender	RSI	Ratio of Distance	Numbers of subjects
Type 1	Female	77.33	12.83	47
	Male	72.98	12.92	59
Type 2	Female	118.33	10.19	10
	Male	107.31	8.08	11

Table 4. RSI and ratio of distance for subjects of Type 1 have history of hypertension.

History of Hypertension (years)	RSI	Ratio of Distance	Numbers of subjects
≥1, <10	77.05	12.38	20
≥10, <20	79.64	11.86	10

Table 5. RSI and ratio of distance related to coronary heart disease and hypertension.

	Have coronary heart disease	Have hypertension	RSI	Ratio of Distance	Numbers of subjects
Type 1	No	No	73.81	13.67	31
	Yes	No	75.37	12.55	75
	Yes	Yes	76.39	12.53	47
Type 2	No	No	106.51	10.74	8
	Yes	No	116.28	8.07	13
	Yes	Yes	111.87	8.81	7

Table 6. RSI and ratio of distance related to chest pain.

	RSI	Ratio of Distance	Numbers of subjects
Type 1	79.17	11.50	53
Type 2	118.51	8.71	11

wave, classified two types of waveform associated with different positions of the first and second shoulders using the third derivative curve. The analyses of RSI and Ratio of Distance are conducted. By correlating RSI and Ratio of Distance with evaluated subjects' ages, genders, and cardiovascular diseases, such as hypertension, coronary heart disease, and chest pain, we have reported some results.

Firstly, when subjects' ages increase, the RSI and Ratio of Distance increase as well. Secondly, RSI of female subjects are considerably higher than that of male. Thirdly, for the subjects with longer history of hypertension, their values of RSI are higher and those of Ratio of Distance are less. Fourthly, subjects with both hypertension and coronary heart diseases generally have the higher RSI values than those who do not have any of these diseases. Finally, subjects who complain chest pain have significantly higher RSI values.

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