Age-Related Changes in Specific Harmonic Indices of Pressure Pulse Waveform

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Abstract — **The central elastic arteries and the peripheral muscular arteries are different in their responses to aging. Aorta stiffens in much larger extent with age than peripheral arteries do. Peripheral blood pressure indices such as pulse pressure (PP) or augmentation index (AI) were preferred as surrogates in assessing arterial stiffness for clinical convenience. AI and PP both increase progressively with age.**

In this study, we present a harmonic based pulse waveform analysis method which may give similar result about central pressure as augmentation index. This method avoids the extra but necessary manipulations such as flow measuring, 4^{th} derivative of pressure wave in determining the inflection point, the second systolic peak for augmentation index calculating, all these manipulations can introduce error. The non-invasive peripheral pulse waveforms copied from published reports for several ageing studies were analyzed. The mean pulse height *A0* and the harmonic proportion of the 1^{st} harmonic *C1* increased but the harmonic proportion of the 3^{rd} harmonic *C3* and the harmonic proportion of the 4^{th} harmonic *C4* decreased with ageing. Aging had no significant effect on the harmonic proportion of the 2^{nd} harmonic *C2*. Among all these harmonic indices, *A0*, the mean pulse pressure increased dramatically since the 6th decade.

These results suggest that A0 is related to aorta stiffen or PP sensitive. The gradual increasing of C1 and gradual decreasing of C3 and C4 by ageing suggest that C1, C3 and C4 could be similar to AI; it corresponds to the pressure pulse waveform affected from ageing.

The harmonic indices could be clinically useful in non-invasive cardio risk assessing for the elderly patients.

Keywords — **Ageing, Augmentation Index, Harmonic Analysis, Blood Pressure Pulse Waveform, Biosignal Processing**

I. INTRODUCTION

With the advancement of health care the average age of death is increased every year. The issue of gerontology is more and more important with the ageing population. It has been noted that aorta stiffens in much larger extent with age than peripheral arteries [1] [2]. It is convenient to assess arterial stiffness in clinic by peripheral blood pressure indices such as pulse pressure (PP) or augmentation index (AI) which both increase progressively with age [3].

However to calculate AI value needs to measure pressure and flow velocity at the same time [4] or 4^{th} derivative of the measured pressure wave [5] [6] to determine the second systolic peak or the inflection point. The previous method needs extra flow measuring; and the latter one may give erroneous results sometimes [7] [8].

In this study, we analyze the pulse waveform from the published report of ageing effect. The pulse waveform was described by the harmonic proportions together with the mean pulse height where the harmonic proportions equal the amplitude of each harmonic divided by mean pulse height [9] [10]. The change of harmonics with ageing is expected.

II. METHOD

A. The data source

The data source is scanned from the report of Kelly et al. 1989 as shown in figure 1 [5]. Radial pulse waveforms were collected from 420 normal subjects who were 2-91 years old (207 men and 213 women) of whom 82 were smokers. Each pulse waveform is average of 40-70 individual pulse. Amplitude is showed in uncalibrated voltage (mV) units which can be translated into pressure unit (mm Hg) from the Millar preamplifier box as 1 mV to 1 mm Hg.

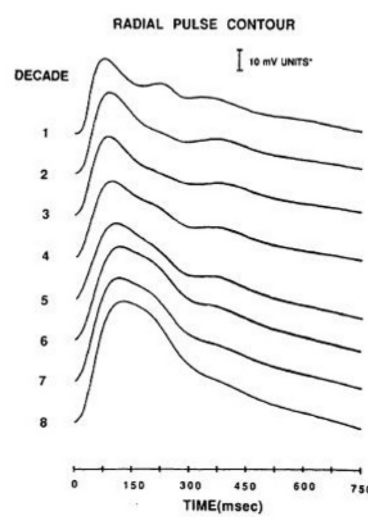

Fig. 1 Pulse waveform of 1 to 8 decades from 420 subjects

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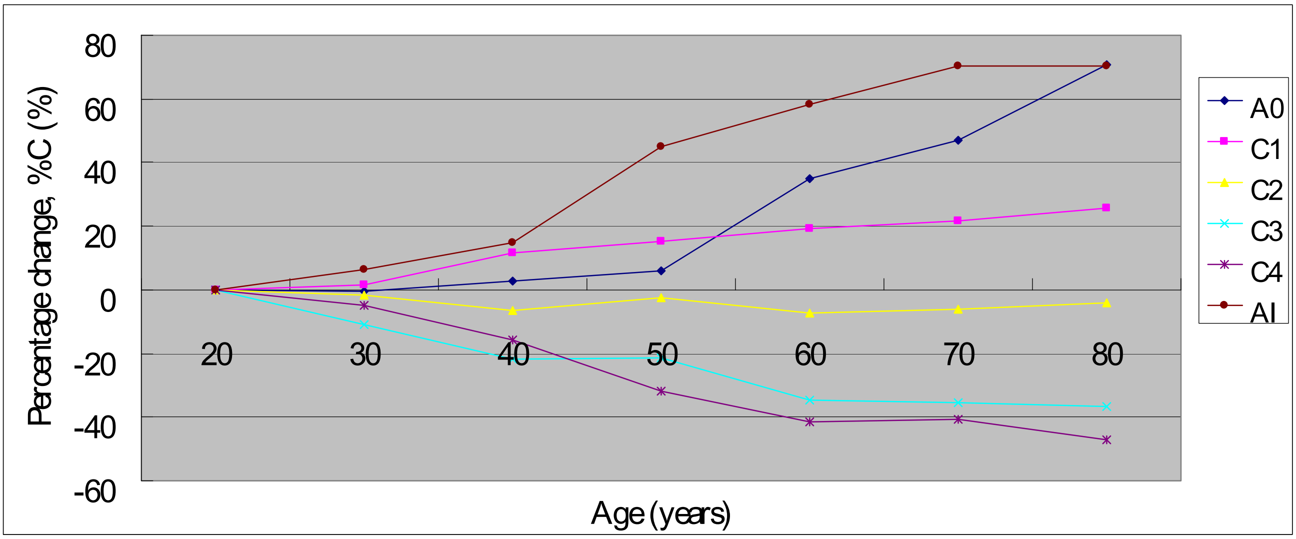

Fig. 2 Percent changes of pressure pulse harmonic proportions and AI with ageing

B. Digitalization and Analysis

Each pulse is scanned form the data source and is digitalized into 1068 points on the same time interval by the program "MATLAB". The digitalized pulse waveform was adjusted with the slope to make the start and the end point at the same height. The adjusted data are Fourier transformed into frequency domain. In this study, we only focused on the change in the first four harmonics and compute the harmonic proportion *Cn* as a pattern instead of the amplitude *An* of the n^{th} harmonic. *Cn* was defined as *Cn = An/A0*, where *A0* is the mean value of pulse pressure.

The pulse waveform of the 2^{nd} decade of age was used as control. The other ages such as 3^{rd}, 4^{th}, 5^{rh}, 6^{th}, 7^{th} and 8^{th} decade were presented as the percentage changes $\%C^{Cn}$ in the harmonic proportion of the n^{th} harmonic between the spectrums of each decade of age and control,

$$(\%C^{Cn}) = 100 \times \frac{Cn,test - Cn,cont}{Cn,cont}, \qquad (1)$$

where Cn,cont is the harmonic proportion of the n^{th} harmonic of the control, Cn,test is the harmonic proportion of the n^{th} harmonic of the testing pulse waveform under aging.

The percent change $\%C^{A0}$ of the mean pulse pressure was presented as

$$(\%C^{A0}) = 100 \times \frac{A0,test - A0,cont}{A0,cont}, \qquad (2)$$

where A0,cont is the mean pulse pressure of the control, A0,test is the mean pulse pressure of the testing pulse wave form under aging.

The percent change $\%C^{AI}$ of the augmentation index was presented as

$$(\%C^{AI}) = 100 \times \frac{AI,test - AI,cont}{AI,cont}, \qquad (3)$$

where AI,cont is the augmentation index of the control, AI,test is the augmentation index of the testing pulse waveform under aging which was intercepted from the data source directly.

III. Result

The calculated data of the 2^{nd} decade of age as the control is showed on table 1. The testing data is based on the control.

Figure 2 is the result of the testing harmonic proportion of 3^{rd} to 8^{th} decade of age which is compared with that of the control. The mean pulse pressure *A0* and the harmonic proportion of the 1^{st} harmonic *C1* increased with ageing. The harmonic proportion of the 3^{rd} harmonic *C3* and the

Table 1 data of 2^{nd} decade of age (the control)

A0 (mm Hg)	C1	C2	C3	C4	AI (%)
14.3	77.8	52.1	38.1	21.5	3

Table 2 Averaged percent changes of %C and AI on 3rd- 4th, 5rh- 6th and 7th -8th decade

Age (yr)	% C^{A0} (%)	$\%C^{C1}$ (%)	$\%C^{C2}$ (%)	$\%C^{C3}$ (%)	$\%C^{C4}$ (%)	$\%C^{AI}$ (%)
30-40	1.25	6.46	-4.02	-16.5	-12.3	10.5
50-60	20.5	17.1	-4.80	-28.1	-47.7	51.7
70-80	58.9	23.7	-5.12	-36.1	-46.8	70.3

harmonic proportion of the 4th harmonic *C4* decreased but no significant change on the harmonic proportion of the 2nd harmonic *C2* with ageing. Among all these harmonic indices *A0* increased conspicuously at the 6th decade.

Table 2 averaged the percent change of AI, *A0* and harmonic proportions of harmonic 1 to 4 into three age groups. Averaged *A0* on age group between the 7th to 8th decades is about 2.8 times of the value on age group between the 5th and 6th decades. But the percent changes of C1, C2, C3, C4 and AI on age group between the 7th to 8th decades are only 1 to 1.4 times of the value on age range between the 5th and 6th decades. Averaged *A0* on age group between the 5th to 6th decades is about 16 times of the value on age group between the 3rd and 4th decades. But the percent changes of C1, C2, C3, C4 and AI on age group between the 5td to 6th decades are only 1 to 4 times of the value on age group between the 3rd and 4th decades.

IV. Discussion

From the results of this study, the mean pulse pressure, A0, is changed noticeably with ageing. Ageing could cause the increase of aorta stiffen and the pulse pressure. A0 may be an index that related to aorta stiffen or PP sensitive. The gradual increasing of C1 and gradual decreasing of C3 and C4 by ageing suggest that C1, C3 and C4 could be similar to AI which corresponds to the pressure pulse waveform affected from ageing. These harmonic indexes all have high correlation coefficient to augmentation index (C1: R=0.96; C3: R=-0.93; C4: R=-0.92) but use an easier algorithm. Only we need to do is to get the pulse waveform from the subject non-invasively and use Fourier transform for these pulse waveform. This analysis leaves out the measurement of blood flow and avoids the errors caused by the determination of the shoulder of pressure pulse. We could easily estimate the change of pulse waveform by harmonic analysis method. The harmonic indices could be clinically useful in not only geriatric hypertension research but also cardiovascular drugs development.

V. Conclusions

In this study we present an assessment of the change on the pulse waveform by harmonic analysis method. The harmonic index provides the similar result as augmentation index without the measurement of blood flow. The harmonic indices could be clinically useful in non-invasive cardio risk assessing for the elderly patients.

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