Patterns of digital volume pulse waveform and pulse transit time in young and older individuals

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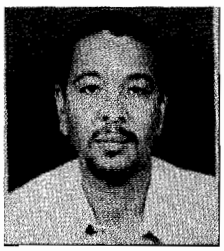
Abstract:

Introduction: Arterial wall changes underlie many disorders of aging and the complications of diseases like hypertension and diabetes mellitus. Analyzing the pulse wave is an easy, noninvasive method used to assess vessel wall stiffness and pulse changes. In this study the digital volume pulse wave and the pulse transit time of the thumb and big toe were analyzed in young and older subjects some of whom were hypertensive. We aimed to study the components and patterns of the pulse waveform and the pulse transit time and how they might change.



Material and Methods: Seventy volunteers were drawn from the students and employees of the University of Khartoum. A Powerlab system, ECG leads and a Pulse Mechanotranducer were used. SPSS programme was used for analysis.

Results: Young subjects had two main patterns of digital volume pulse waveform in the thumb and two patterns in big toe. The older subjects showed significant decrease in prominence of the diastolic pulse flow waves in both thumb and toe. There was a significant decrease in pulse transit time with advancing age.

Discussion: The prominence of systolic deflections combined with decrease in diastolic deflections in the digital waveform in older subjects indicated shift in blood flow towards systole. Changes of pulse waveforms are more prominent in the feet than in the hands. The decreased pulse transit time could explain some, but not all of the observed changes especially in the feet. Digital volume waveform analysis can be developed into a bedside test.

Keywords: arterial stiffness, digital volume pulse, pulse transit time, hypertension

Introduction

Arterial wall changes like arteriosclerosis and atherosclerosis are involved in the pathogenesis of age associated disorders and the various complications of diseases like arterial hypertension, diabetes mellitus and hyperlipidaemia. Arteriosclerosis which is characterized by generalized increase in arterial wall stiffness is commonly seen with advancing age and in patients with hypertension[1]. The stiffness of arterial walls results in decreased compliance, and an increase in the speed of transmission of the pulse wave. This increase in pulse wave velocity (PWV) is the cause of early return of reflected waves that lead to high aortic pressure which is detrimental to the left ventricle[2]. Arterial wall changes, therefore, have two main detrimental effects: ischaemia of various tissues due to noncompliant thickened vessels and increased afterload on the heart due to early wave reflections.

Assessment of the condition of arterial walls should be considered a prognostic parameter in cardiovascular diseases, in addition to measurement of blood pressure and blood lipids[3]. Efforts are now directed towards determining which parameters of arterial wall changes are of prognostic value. Several researchers have addressed the issues concerning the various methods used to assess arterial stiffness and their clinical applications and were discussed[4].

It is possible to study the structural changes of the arterial tree using various imaging processes like arteriography, ultrasound and MRI. However, we are mainly concerned with structural changes that affect the functions of arteries: the conduit function and the cushioning function[5]. That is why researchers have concentrated on methodologies that analyze the pulse: the speed of its transmission (PWV), the shape of its waveform and the pressure changes during a pulse. However, most attention has been directed to PWV and peripheral pulse pressure and how these can be used to predict central arterial pressure changes. Not much attention has been directed towards assessing the prognostic value in arterial disease of changes in the pulse waveform.

One simple method is to study the pulse waveform of a digit to record the digital volume pulse (DVP). Fingers are often used. Researchers have recorded DVP using photoplethysmography and compared it to direct measurements of arterial pulse pressure using applanation tonometry. There is a simple linear relation between the shape DVP and that of the pulse pressure[6].

Assessing the speed of transmission of the pulse wave can be done by measuring the time needed for a pulse to travel from the heart to a peripheral site like a digit. This is the pulse transit time (PTT). The investigator needs to perform simultaneous recording of the ECG and the pulse

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wave. PTT is equal to the time interval between the peak of the R wave in the ECG and the beginning of the pulse wave. As the PWV increases, the PTT will decrease[7, 8].

In this study we used a pulse mechanotranducer and a Powerlab system, aiming to determine the pattern of the DVP waveform and PTT of the thumb and big toe, in young healthy individuals and compare that to older subjects some of whom were hypertensive.

Methods

Subjects: Two main groups of volunteers were selected randomly. Those fulfilling the requirements for inclusion were enrolled until we reached the planned sample size. The subjects were enrolled into two groups: those <40 years of age and those >40 years. Both groups were equally divided into males and females. The first group comprised forty healthy young volunteers (20 males and 20 females) age range 18-28 yrs. The second group comprised thirty older volunteers (15 males and 15 females) age range 40 – 65yrs. Ten individuals of this group of older subjects have controlled hypertension. The remaining twenty were healthy subjects who had no history of chronic disease and were normotensive at the time of the study. The hypertensive patients were on antihypertensive therapy.

Materials: Data collection was done by a Powerlab system connected to a computer running the Chart V5.0.2 4310 software (ADInstruments/Australia). Piezo-electric MP100 pulse transducer (ADInstruments) was used to record the digital volume pulse. It is applied to a digit and held in place by a Velcro strap. ECG was recorded using adhesive MLA1010 ECG electrodes (ADInstruments). Arterial blood pressure was measured by the electronic sphygmomanometer KBM-21 digital blood pressure monitor.

Test procedure: This study was carried out in the period June to September 2005. The study was conducted in a laboratory in which the temperature was kept at about 25^{O} C. All the steps were carried out by the same doctor throughout the study. Initially, a questionnaire regarding the subject's personal and health details was filled by directly questioning the subject. After 5 minutes of bed rest, the blood pressure was measured. The pulse transducers and ECG leads were then applied with the patient lying supine on a couch. ECG limb leads were used. One pulse transducer was applied to the left thumb and the second one to the left big toe. The subject was asked to stay still during recording. Real time recording appeared on the computer screen. The digital pulse waves from the thumb and toe were recorded simultaneously with the ECG on the same time scale and in the same chart.

The pulse transducers were disconnected and reapplied three times and each time a 12 seconds recording was obtained so that each subject provided three recordings at the same session. The 12-second period was selected to insure a whole respiratory cycle recording.

Determination of systolic and diastolic events: ECG was used to determine whether an event was systolic or diastolic. Systole starts at the R wave and diastole at the end of the T wave of the ECG[9]. For each cardiac cycle the peak of the R wave is considered "zero time". For other sites of the circulation the pulse transit time should be added i.e. a diastolic event at the thumb occurs after a time interval equal to the sum of the time at the end of T plus the pulse transit time for the thumb.

Statistical analysis: For each subject in the study, the mean and standard deviation were calculated from ten pulse waves for each of the variables (pulse wave components and time intervals) using the Excel program and SPSS 13.0. The frequency of each pulse wave component was expressed as a percentage of the total subjects in each group. T-test was used to determine the significance of differences between groups.

Results

The thumb pulse wave of young subjects:

The thumb waveform showed five deflections that had been labeled **a**, **b**, **c**, **d**, and **e** (fig 1A). The deflections "**b**" and "**d**" are downward deflections. Deflection "**e**" is diastolic while the others are systolic. This pattern (thumb pattern 1) was seen in 63% of the young subjects in the study. The remaining 37% showed a pattern (thumb pattern 2) in which the "**b**" and "**c**" deflections seemed to have been incorporated into a broadened "**a**" deflection, and "**e**" is low relative to "**a**" (Fig 2A).

Deflections "**a**" and "**e**" were constant and were present in 100% of the young subjects of the study. Deflection "**d**" was absent in 16% of the young subjects. The patterns appeared the same for both male and female subjects.

The big toe pulse wave of young subjects:

The waveform of the big toe in young subjects showed two deflections; an upward "**a**" deflection followed by a downward "**b**" deflection (Fig. 2B). Both "**a**" and "**b**" were systolic. This

Figure 1: thumb and big toe pulse waveforms in young adults.

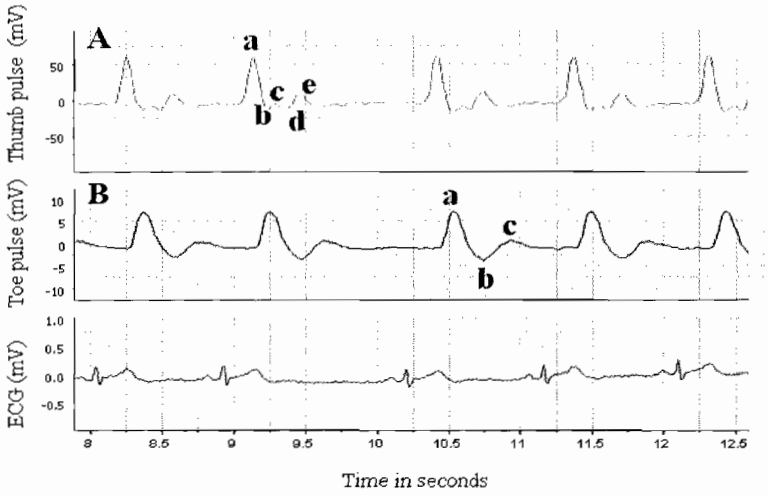


Figure 2: thumb and big toe pulse waveform in young adults

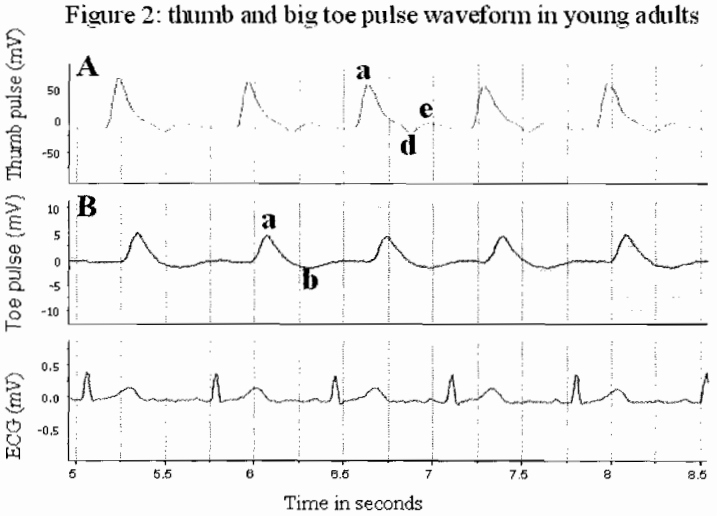
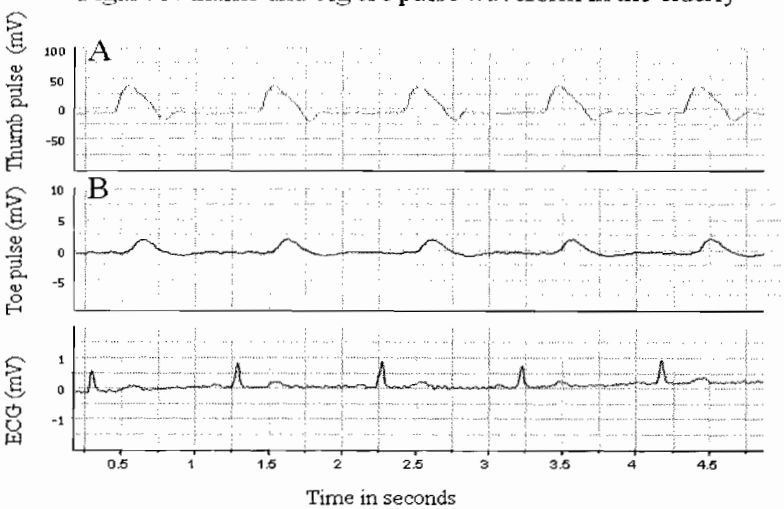


Figure 3: thumb and big toe pulse waveform in the elderly



pattern (toe pattern 1) was seen in 67% of the young subjects. 33% of the young subjects showed an additional upward diastolic deflection; the **c** deflection (Fig 1B). This is "toe pattern 2". The patterns appeared the same for both male and female subjects.

The pulse waveform of older subjects:

The thumb pulse waveform in subjects who were >40 yrs showed a broad "**a**" deflection and a low "**e**" deflection (Fig.3 A), similar to "thumb pattern 2" of young subjects. Their toe pulse waveform (Fig.3 B) was similar to "toe pattern 1" of the young subjects which did not have a diastolic deflection.

The pulse waveform of hypertensive older subjects:

The thumb waveform of hypertensive older subjects was characterized by a broad "**a**" deflection and a low "**e**" deflection (Fig. 4A), as in nonhypertensive older subjects. The big toe waveform of 60% of hypertensive subjects was toe pattern 1 of young subjects although the "**b**" deflection appeared shallower. However, in 40% of hypertensive subjects the toe pulse was made of one upward systolic deflection; the "**a**" deflection (Fig. 4B).

The duration of the pulse wave of the thumb:

There was no marked difference in the duration of the pulse wave from the beginning of "**a**" deflection to the end of "**e**" deflection between the different groups in the study. However, the "**a**" wave clearly got broader with advancing age (Table 1) and was significantly different between the young and the normotensive older subjects (P=0.003) and hypertensive older subjects (P=0.001). There was no difference between normotensive and hypertensive older subjects.

The PTT of the thumb:

Table 2 shows that the PTT of the thumb got shorter with age and was significantly different between the young and both the normotensive older subjects (P=0.0001) and hypertensive older subjects (P=0.0001). The PTT of the thumb was not different between the normotensive and hypertensive older subjects.

The PTT of the big toe:

Table 3 shows that the PTT of the big toe decreased from 0.24 ±0.02 seconds in the young to 0.2 ±0.03 seconds in normotensive older subjects, and to 0.17 ±0.03 seconds in hypertensive older subjects. The mean PTT of young subjects differed significantly from that of older normotensive subjects (P=0.0001) and that of hypertensive older subjects (P=0.0001). The mean toe PTT of normotensive and hypertensive older subjects was not different.

Discussion

During our review of the literature, we noticed that much of the research about arterial disorders in hypertension, diabetes mellitus, and hypercholesterolaemia relied on evaluation of the central blood pressure in the aorta, because it is of good predictive value for complications. Consequently, measurements of PWV, peripheral arterial pulse wave and digital volume pulse were routinely processed by formulas to calculate the augmentation index for central blood pressure[10]. This seems to us to be no more than measuring blood pressure by other means, and then continue using it as the major prognostic indicator.

In this preliminary study, we aimed to investigate the patterns of peripheral pulse waveforms whether they show predictable changes that can make them potential indicators of arterial wall disorders and disorders of blood flow. We analyzed the waves resulting from the cyclic fluctuation in the volume of the digits, caused by fluctuation in digital blood flow during the cardiac cycle[5]. Our results demonstrated that there was a pattern of the wave of the digital volume pulse that changed significantly with advancing age in both normotensive and hypertensive individuals. Young adults showed two patterns of the thumb volume pulse wave. Pattern 1, the commoner of the two, was characterized by fluctuating systolic blood flow (several waves in Fig.1A), whereas pattern 2 showed a longer period of flow during systole (broad "**a**" deflection in Fig. 2A). It is not clear to us what factors result in healthy young individuals having different patterns of digital blood flow. We found no evidence that these patterns are related to gender. Figures 3A and 4A show that in the older group systolic thumb blood flow is increased, with less diastolic flow (wide "**a**" deflection and diminished "**e**" deflection). However, it is clear in all our figures that the "**e**" deflection represents the early part of diastole and we can not, therefore, conclude that total diastolic flow was diminished. It is worth noting that there was no significant difference between the study groups in the length of the pulse wave cycle (start of "**a**" to end of "**e**" in Table 1) of the thumb, but it was the configuration of the component deflections that changed, indicating shifts in flow between systole and diastole. Our results demonstrated that flow to the digits shifted towards systole in older subjects, both normotensive and hypertensive.

The toes also showed various patterns of volume pulse waveforms. However, there is a notable difference between the thumb and big toe

Figure 4: thumb and big toe pulse waveform in hypertensives.

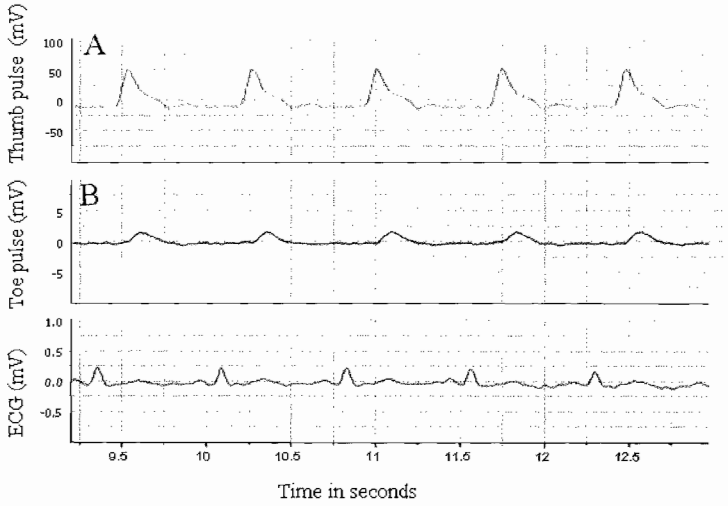


Table 1: Duration of thumb pulse wave cycle and duration of "**a**" deflection.

Group	Duration of "**a**" deflection in seconds	Duration from start of "**a**" to end of "**e**" deflections in seconds
Young males (n=20)	0.168 ±0.018	0.518 ±0.026
Young female (n=20)	0.183 ±0.033	0.523 ±0.037
Older males (n=10)	0.257 ±0.039	0.517 ±0.048
Older females (n=10)	0.271 ±0.038	0.537 ±0.047
Hypertensive males (n=5)	0.266 ±0.063	0.511 ±0.049
Hypertensive females (n=5)	0.281 ±0.015	0.516 ±0.042

Table 2: Mean and standard deviation for thumb PTT.

Group	Mean thumb PTT and SD in seconds
Young male (n=20)	0.143 ± 0.019
Young female (n=20)	0.134 ±0 .013
Older males (n=10)	0.118 ± 0.022
Older females (n=10)	0.114 ± 0.017
Hypertensive males (n=5)	0.110 ± 0.014
Hypertensive females (n=5)	0.116 ± 0.020

regarding the changes that occur in older subjects. Thumb pulse flow shifted towards systole (see above) whereas toe pulse flow was reduced in both systole and diastole, as demonstrated by the diminished size of the "**a**" and "**b**" deflections (compared to the young) and the complete absence of the "**c**" deflection (Fig. 3B and 4B).

The changes seen in the thumb volume pulse of the older individuals could be explained by the short PTT, which led to early wave reflection causing a rise in central systolic pressure and a decrease in diastolic pressure[1,2,7]. However, the changes seen in the big toes of the same group - where there was a decrease in the volume pulse in both systole and diastole- indicate that factors other than PWV/PTT and central pressure are involved. This gives credibility to our argument that the pulse waveform should be evaluated independently in arterial disorders. We would also argue for assessment of peripheral pulse waveforms at different sites and not to rely only on fingers because apparently different sites show different changes. Clinicians are aware that ischaemia affects the feet more than the hands.

The hypertensive subgroup of older subjects in this study was controlled by antihypertensive treatment and they fell in the same age group as the nonhypertensive older subjects. Their thumb volume pulse waves were not different. However, there was a difference in toe volume pulse waves between the two groups. The difference was the absence of the "**b**" deflection in 60% of hypertensive individuals. Again, toes seem to show circulatory changes earlier than fingers.

Pulse wave analysis is simple and noninvasive. It has the potential to be developed into a simple bedside technique. We recommend more detailed studies of the pattern of pulse waveforms and their possible use as diagnostic/prognostic indicators of arterial disorders. Large scale surveys of different age groups, male and female of both healthy individuals and patients with various cardiovascular diseases are needed.

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