A STUDY ON THE METHOD TO PREDICT PERIPHERAL ARTERIAL DISEASE (PAD) BY USING FINGER-TOE INDEX (FTI)

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ABSTRACT
In this paper, the purpose is to propose a new and a simpler parameter than the previous method which uses an ordinary blood pressure cuff and a Doppler ultrasound blood flow detector in order to predict the severity of PAD (Peripheral arterial disease). For the simpler system, we developed 4 channels of PPG (photoplethysmography) and proposed a new analysis parameter: finger-toe index (FTI).

In order to verify the usefulness of the developed system and the new analysis parameter, the experiments were performed on 43 normal subjects. The new analysis parameter: FTI was compared with ABI (ankle-brachial index) using regression analysis method.

There are two main findings of this study: first, the proposed parameter, FTI is more strongly correlated with age than ABI. The correlation coefficient between each parameter, FTI & ABI, and age was observed to be 0.642 and 0.271 respectively. The regression coefficient between the parameters, FTI & PTT, and ABI & PTT was observed to be 0.60 and 0.10 respectively. Secondly, the proposed parameter is a more quantitative index. For the same subject group (n=43), the result of ABI showed that all subjects are in a single state group but the results of FTI classified the subjects into three state group.

KEY WORDS
peripheral arterial disease (PAD), finger-toe index (FTI), ankle brachial index (ABI), upstroke time (UT), Blood pressure, photoplethysmography (PPG)

1. Introduction
Peripheral arterial disease (PAD) is a common circulatory problem that includes a group of diseases in which venous and/or arterial vessels become occluded or partially occluded in the periphery. PAD is nearly inevitable with the onset of aging. Aging, hypertension, and other risk factors such as diabetes, hyperlipidemia, and smoking can alter the structural and functional properties of the arterial wall [1].

PAD can be identified noninvasively before clinical manifestation. X-ray of the extremities can detect arterial calcification that is indicative of arterial disease with or without an occlusive component. Ultrasound with duplex scanning can also detect occlusive PAD noninvasively, while angiography remains the gold standard for identification and diagnosis of PAD [2, 3].

The ankle brachial index (ABI) test is a popular tool for the noninvasive assessment of PAD. ABI is the ratio of the systolic pressure at the ankle compared with the brachial artery pressure [4].

The aim of this study is to propose new noninvasive method which is simple and fast to evaluate the arterial disease. For the simplicity of system and operation, we developed the four channels PPG system which can measure the PPG signal on the four arterial channels (finger tip and toe tip of right and left side) simultaneously. We use PPG signal instead of the blood pressure because the measurement of PPG signal is simple. The upstroke time (UT) of PPG signal was chosen as new analysis parameter which corresponds to the blood pressure. In this study, we propose the new finger-toe index (FTI) method to evaluate the presence or absence of arterial disease. The FTI is the ratio of the UT of PPG in the toe tips to the UT of PPG in the finger tips.

2. Methods
Fig.1 shows the experimental set-up of the system implemented for this research. The system consists of single four channels of PPG pulse acquisition unit, a 12 bit A/D converter and software. PPG pulse acquisition units were outfitted with transducers and analogue signal-
processing units. Commercial off-the-shelf blood pressure monitors (HEM-78, Omron Healthcare Inc., Japan) were used to measure blood pressure.

Commercial off-the-shelf PPG transducers made by Pico Med Inc. were attached to four sites within human body (the right and the left second finger and toe tips) in order to acquire PPG signals. The signal processing unit consists of a pre-amplifier, a high pass filter and a low pass filter. The pre-amplifier is used to amplify the voltage signal obtained post-signal processing from the current signal output of a photo diode sensor. The high pass filter is used to remove DC signals unrelated to pulsating current. The low pass filter is used to eliminate the high frequency signals such as noises from other devices or power source.

The ABI is the ratio of the blood pressure in the lower legs to the blood pressure in the arms. The examiner should make all arm and leg blood pressure measurements. The systolic blood pressure is determined in both arms and the ankle systolic blood pressure is determined for the right and left posterior tibial (PT) and dorsal pedis (DP) arteries. In a person with normal arterial circulation, the ankle pressures should be equal or greater than the brachial pressures. Therefore, the normal ABI value is one or higher. Any patient with an ABI < 0.9 has lower extremity arterial occlusive disease. The ABI is calculated by dividing the systolic blood pressure in the arteries at the ankle and foot by the higher of the two systolic blood pressures in the arms. The ABI is determined by dividing the maximum ankle systolic pressure by the maximum brachial systolic pressure [5, 6].

PPG is a non-invasive circulatory signal related to the pulsatile volume of blood in tissue. It is known that PPG has a strong correlation with arterial blood pressure waveform. The height of pulsatile component of the PPG signal, the upstroke time (UT), is proportional to the pulse pressure, the difference between the systolic and diastolic pressure in the arteries [7].

In this paper, we use PPG signal instead of the blood pressure because the measurement of PPG signal is simple. The UT of PPG signal was chosen as analysis parameter which corresponds to the blood pressure.

Fig. 2 shows the typical PPG signal. UT is defined as the time from valley point to peak point in the PPG. From the values of PPG signal obtained, each peak and valley was detected. The equation (1) is the calculation algorithm of UT [8].

![Fig. 2 Typical PPG waveform.](image)

Here in the figure, UT is time from point S to the maximum point P.

$$UT_{\text{mean}} = \frac{\sum (P_n - S_n)}{f_s}$$  \hspace{1cm} (1)

$P_n$: Array of detected peak point index
$S_n$: Array of detected valley point index
$n$: Number of detection
$f_s$: Sampling rate

As in ABI, FTI is defined as the ratio of longest UT at finger tip to the longest UT at toe tip using obtained UT of PPG at four sites, left and right finger tip and toe.

$$FTI = \frac{UT_{\text{finger}}}{UT_{\text{toe}}}$$ \hspace{1cm} (2)

$UT_{\text{finger}}$: Longest UT at left and right finger tip
$UT_{\text{toe}}$: Longest UT at left and right toe

3. Experiments and Results

3.1 Experiments

In order to verify the usefulness of the proposed parameter, an experiment was performed to observe the change in UT and pulse transit time (PTT) when the systolic blood pressure is changed. PTT has been widely used for noninvasive examination of the arterial properties, such as elasticity, compliance and stiffness of vessel walls. PTT has also been proposed as an indicator of blood pressure. Therefore, PTT was chosen as reference parameter for verification of the proposed parameter, UT.

The experiment was conducted repetitively on two healthy male subjects, one in twenties and the other in fifties. A method was selected to increase the blood pressure according to exercise load which subjects were running on a treadmill [9].
The PTT measurement method used in this study is to measure PPG on four measuring points of four arterial channels simultaneously. PTT is defined as the time between the pulse propagation times on the finger tip and on the toe tip, from the heart [8]. Fig. 4 shows the definition of PTT which used in this study: PTT1 and PTT2 are the measurements of left and right side respectively.

Fig. 3 Definition of pulse transit time (PTT).

PTT1 is pulse transit time from left finger tip to left toe tip and PTT2 is pulse transit time from right finger tip to right toe tip.

Experiment was performed on a total of 43 healthy volunteers (aged: 12-81 years) using the following 4 steps:

Step 1: after set up experimentation system, subject have rest supine position for 5min. on the bed.
Step 2: measure the blood pressure on four sites, left and right arm and ankle.
Step 3: immediately after step 2, measure simultaneous PPG on four sites, left and right finger tip and toe for 100 second.
Step 4: immediately after step 3, measure blood pressure one more time.

The analysis and evaluation of data for total of 43 healthy subjects was performed to compare FTI to the ABI.

3.2 Results

3.2.1 Relation between Age and FTI, ABI

The result of relation of FTI, as proposed analysis parameter and ABI, as selected reference parameter, with age is showed in Fig. 4. This figure is a distribution of FTI and ABI according to age. For FTI the correlation coefficient is 0.600 and for ABI the correlation coefficient is 0.271. Through these results, the association of age with FTI is better than ABI, is confirmed.

3.2.2 Relation between PTT and FTI, ABI

Fig. 5 indicates the results of linear regressive analysis for relation of FTI, as proposed parameter, and ABI, as reference parameter, with PTT1. PTT1 is the left pulse transit time. For FTI the correlation coefficient is 0.718 and for ABI the correlation coefficient is 0.107.

Fig. 6 shows the distortion and results of linear regressive analysis for relation of FTI as proposed parameter, and ABI, as reference parameter, with PTT2. PTT1 is the left pulse transit time. For FTI, the correlation coefficient is 0.718 and for ABI the correlation coefficient is -0.107. From Fig. 5 and Fig. 6, the stronger association of left and right PTT with FTI than with ABI is confirmed.
3.2.3 Relation between FTI and ABI

Fig. 7 indicates the results of linear regressive analysis calculated for FTI and ABI for all the 43 healthy subjects, to verify relation between FTI and ABI as reference parameter.

From the result, the subject with no relation has correlation coefficient of 0.137. This result is considered because UT has very strong relation with blood pressure for an individual case, but UT has no relation with blood pressure for all subject cases.

Even though blood pressure of any two subjects could be similar yet still the UT of those two subjects could be quite different.

![Fig. 7 The correlation relation between FTI and ABI.](image)

In this study, we proposed FTI to analyze for character of vessels as parameter obtained information similar to ABI by using PPG, analyzed and confirmed relation between various parameters to confirm usefulness of proposed parameter.

Fig. 8 indicates the histogram of FTI and ABI results for all 43 subjects. Conclusions reached after histogram analysis and basic experiments are as follows.

1) ABI result shows the distribution from 0.9 to 1.4 and FTI result shows a distribution from 0.6 to 1.6. The result indicates FTI has a wider distribution than ABI.

2) FTI has no correlation with ABI. FTI has a better relationship with subject age than ABI as an analysis of relation with age reveals. Also FTI is closely related to PTT, the parameter that indicates vessel state, more than ABI.

![Fig. 8 Histogram of FTI (a) and ABI (b) for all subject.](image)

The correlation coefficient between ABI and FTI is 0.130, which means there is no relation between the two parameters, but the effect and validity of the proposed parameter confirmed through analysis of the relation between other parameters and the following example.

For example, one subject, aged 81 years old, was classified in the normal domain as ABI was 0.12. But the subject currently is taking medicine drug to lower blood pressure artificially as the subject has high blood pressure. Considering that, the result of FTI analysis for the same subject was 0.66. When this subject’s ABI is compared with one young subject, there is no difference between the two subjects for ABI. Whereas there is considerable difference for PTT. PTT for the old subject is 0.034[s] and for the young subject is 0.130[s]. These results explain that the blood vessel elasticity of an old subject is very lower than that of a young subject’s blood vessel. Thus, we think that the proposed parameter can be used to make a more accurate and detailed decision about occlusion of a blood vessel.

Thus there is a close relation between FTI and PTT. The parameters also have a strong relationship to age and elasticity. Also we think the easily measureable system that analyzes character of the arterial only using PPG without additional devices is better than existing system.

Also we think the reason that ABI have no correlation with other parameters because blood pressure measure by using domestic sphygmomanometers which is an observation error is large.

4. Conclusion

One of the purpose of this study is to investigate the comparison between FTI and ABI. The result of the regression analysis for the comparison showed that the proposed parameter, FTI provides a more quantitative analysis index for arterial aging or stiffness than ABI.

In conclusion, we believe that the proposed parameter FTI will provide a valuable quantitative index for screening of arterial aging or stiffness in clinic. We believe that FTI will be a more simple method and will provide more accurate information than ABI for the analysis of arterial vessel characteristics such as PAD.

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References


