# A COMPARATIVE STUDY IN THE USE OF BRACHIAL PHOTOPLETHYSMOGRAPHY AND THE QRS COMPLEX AS TIMING REFERENCES IN DETERMINATION OF PULSE TRANSIT TIME

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*Abstrac*t- **For more than a century, there has been interest in pulse wave velocity and pulse transit time as a possible metric for blood pressure and other cardiovascular parameters. The most common approach in noninvasive measurement of these metrics has been to measure the time delay between the QRS complex on the electrocardiograph and the detection of the finger photoplethysmograph. This paper introduces a new technique for measuring the brachial photoplethysmograph and argues that this forms a better timing reference than the QRS complex.**

*Keywords* - **Pulse wave velocity, pulse transit time, photoplethysmograph, blood pressure, arterial compliance, ECG.**

## I. INTRODUCTION

Pulse wave velocity and blood pressure are in a quasi-linear relationship, as determined experimentally. A model, demonstrating the mathematical basis for this relationship was proposed by Moens and Korteweg in 1878. More recently artificial neural network models have been realised to account for the relationship between PWV and systolic and diastolic blood pressure and heart rate [1]. We propose to measure PWV in a completely novel fashion.

Current noninvasive methods rely on the time lag between features on the electrocardiogram (ECG) and features on the photoplethysmograph[1] (PPG) taken at the finger. It has been shown that using such metrics yields inaccurate measures of blood pressure [2] and indeed since the path length is not known then in fact these measures only really yield pulse transit time (PTT) measures. This makes blood pressure determination from such measures somewhat difficult.

Our method relies on the determination of the PPG at two points along the same artery as shown in Fig. 1. A conventional finger PPG (transmissive) is taken at site 2
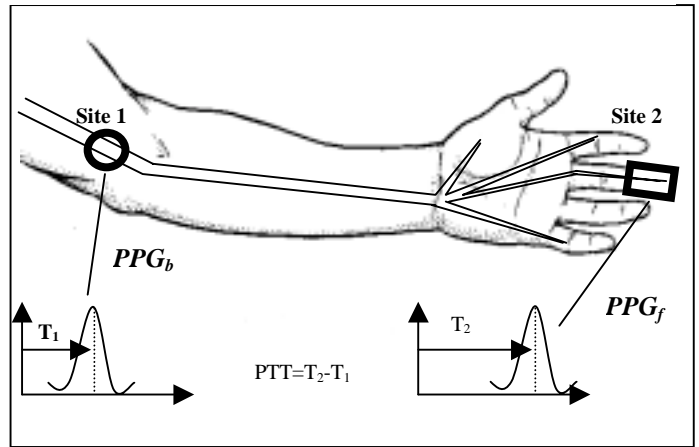


Fig. 1    Diagram of the arm showing the PPG sites

along with a reflective PPG at a point on the brachial artery at the inside elbow (site 1). This allows an accurate measure of blood PTT and since it is easy to measure the path length between these two sites then the quotient of these two figures yields an accurate measure of average PWV over that path length. This has undoubted clinical significance.
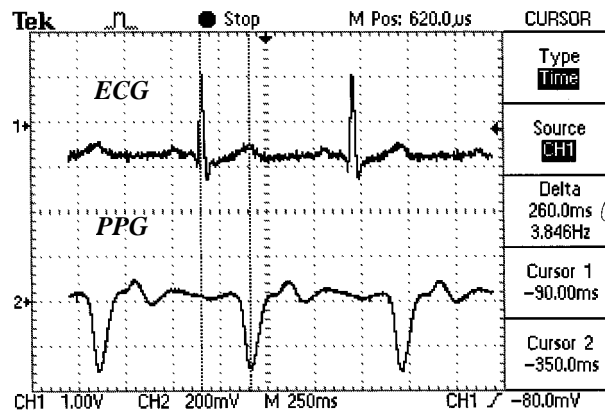


Fig. 2    Measurement of PTT using the QRS complex

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[1] The PPG signal is acquired by bathing an area of tissue with infrared light and measuring in the case of transmissive PPG the transmitted light and in the case of reflective PPG the reflected light picked up by a proximal photo sensor. This signal strongly reflects the changes in volume of the blood vessels that modify the absorption, reflection and scattering of the light.

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**Abstract**

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In Fig.2 the traditional method of calculating PWV changes by measuring the PTT between the QRS wave and systole is shown. Maximum absorbency and consequently the minimum point of the characteristic indicate systole. It is interesting to contemplate why such an approach was adopted initially, from our literature review it appears that many of the researchers working in this area have relied on using "off-the-shelf" PPG devices, which are made for very specific functions at specific sites on the body. As a result of this, current and past research has merely used PPG sensors at conventional sites such as the finger, earlobe or toes [5]. As we have developed from first principles, our own PPG devices we are able to tailor their performance for the particular conditions that exist at various sites of the human body and therefore can acquire PPG signals at a variety of novel sites. It is this ability that allows more direct measure of PTT.

In this paper then we report on the results of an experiment to record and compare PTT results (and hence a measure of PWV) as determined using each of the two techniques.

## II. METHODOLOGY

### A. Apparatus

An apparatus was designed comprising a means of sampling up to six channels of data and logging them. Transmissive and reflective probes were designed to detect the finger and brachial plethysmograph. It was necessary to develop minimal analogue gain and coupling circuitry to link the probes with the data logger.

The data logger recorded 35 seconds of high-resolution data. Table I lists the channel and the measured parameter. The sample rate was 500Hz. The resulting signals were processed and the correlation co-efficient was calculated to assess the data. The correlation function is calculated from equations:

$$r_{x,y} = \mathrm{Cov}\,(x,y)/\sigma_x.\sigma_y \qquad (1)$$

$$-1 < \sigma_{xy} > 1 \qquad (2)$$

$$\mathrm{Cov}\,(x,y) = 1/n \sum_{i=1}^{n} (x_i - \mu_x)(y_i - \mu_y) \qquad (3)$$

where $\mu_x$, $\mu_y$, $\sigma_x$, $\sigma_y$ represent the mean and variance of the data distributions.

TABLE I

| Channel | Parameter |
|---|---|
| 1 | Finger PPG |
| 2 | Brachial PPG |
| 3 | Three lead ECG |
| 4 | Systolic blood pressure |
| 5 | Diastolic blood |
| 6 | Marker |

The ECG amplifier was designed around a Burr-Browne application [3] and is detailed in a previous publication [4].

### B. Procedure

The subjects were each fitted, on their right hand side, with a finger PPG probe and a brachial PPG probe. Additionally, each was fitted with a three lead ECG. The right arm was splinted in each case to keep the brachial archery prominent. The probes were connected with flexible cable to the data acquisition unit. The subject was fitted with a Portapres © system for the purposes of observing continuous blood pressure. Variation in blood pressure causes variation in the PWV the variable under examination in this study. A wide variation in blood pressure allows a wider range of PWV data to be collected.

The subjects were weighed and measured. The subjects lay for a period of ten minutes on an examination couch and were encouraged to close their eyes. When a resting blood pressure was reached a sample of data was taken. The subject then stood up, lowering their blood pressure temporarily. A sample of data was taken during the stand. Lastly, as the body regulates the blood pressure back to normal it tends to overshoot, providing a wide variation in blood pressure. A sample of data was taken during this period. A measurement of the distance from the detection point on the brachial archery to the detection site on the forefinger was measured and recorded.

## III. RESULTS

The traditional method of calculating PTT has been to use the QRS complex of the ECG as a timing reference. Our results demonstrate that this may not be the optimum reference to use. The QRS complex is an electrically recorded depolarisation event that is taken to represent the point at which blood is expelled from the left ventricle. It is our contention that there may be variations of the isovolumetric contraction period of the left ventricle [5], rendering it unsuitable as a timing reference. Our results plot the PTT measured from the brachial site to the finger site against the PTT measured from the QRS complex to the finger site. These simultaneous measurements should demonstrate a very high correlation, if not fall along a line of equality, as they are measures of the same phenomenon [7]. Clearly the measurement taken from the ECG reference will register a longer PTT than that of the brachial site, this will only affect the slope of the line and have no impact on the correlation co-efficient of the two data sets.

Referring to Fig. 3 there is a correlation co-efficient of 0.7 associated with the two data sets. In the case of Fig. 4, the co-efficient is 0.6305. A co-efficient greater than 0.5 indicates that there is moderately strong relationship between the data sets. The scatter in each case must result from variations in one of the timing references
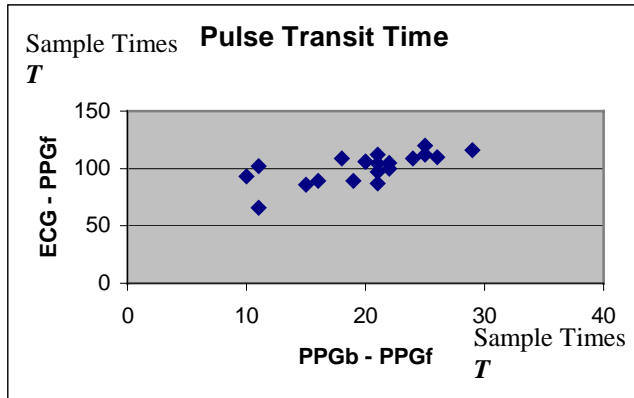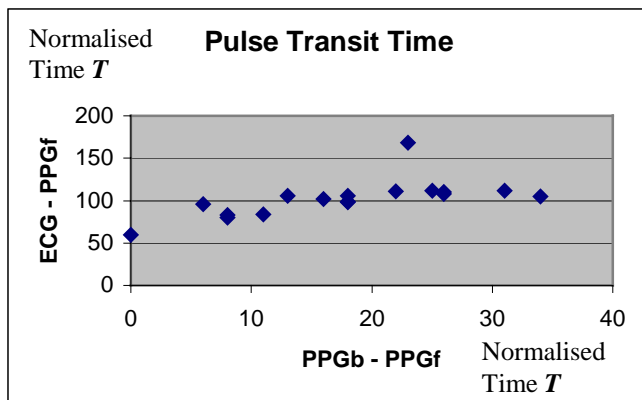
Fig. 3 Subject MM    r=0.7000



Fig.4  Subject SH        r=0.6305

## IV. DISCUSSION

The results of this experiment clearly show a discrepancy between the two methods in terms of pulse transit times. We argue that as our technique is based on a direct measurement of blood flow using a the double site PPG then the results from this method should be considered definitive as a measure of PTT. Therefore, the PTT as determined using the ECG as a timing reference must be erroneous to some extent.

Our initial research in this area was concerned with finding a method to measure PWV directly and non-invasively. It is well established [2] that there is a linear relationship between PWV and blood pressure. In each paper exploring this relationship non-invasively, PWV was inferred from PTT. This is because it is not possible to accurately measure the arterial distance between the heart and the finger site. Some experimentation with reflective oximetry probes led to the development of a reflective PPG probe. This probe was positioned on the brachial archery, at the elbow, and produced a strong, if elusive, plethysmograph. The wider focus of this work is to explore a means for non-invasive continuous blood pressure measurement. This technique offers exciting possibilities for direct measurement of PWV. As pulse wave velocity is a function of blood pressure, arterial compliance and cardiac output [8][9], a method

capable of non-invasively measuring PWV could form the basis of a diagnostic tool for arterial disease.

Future work on this subject will include taking another reference point for direct reflective measurement along the archery and correlating this with the brachial PPG reference and the ECG reference.    It is also hoped to do a more thorough statistical analysis such as Bland Altman [7,10].

## V. CONCLUSION

The brachial to finger PPG is a true measure of the pulse wave passing through one point and arriving at another. It is a direct measurement using similar probes whose position do not change over the duration of the experiment. The ECG to finger PPG is an inferred measurement where we depend on a relatively slowly changing physiological indicator to mark the emergence of a systolic wave that we duly detect at the finger. If this reference was constant and true, we should expect a very high correlation between the recorded data sets. Instead, we find a moderately strong relationship, in both cases that indicate a degree of variability in the measured PTT as between the two methods. This manifests itself, graphically, as a scatter. It is our conclusion that there is variability in the isovolumetric contraction period of the left ventricle and that consequently, measurement of PTT using a brachial PPG site is superior to the use of the QRS complex as a timing reference.

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