A METHOD TO DETERMINE DIASTOLIC BLOOD PRESSURE BASED ON PRESSURE PULSE PROPAGATION IN THE ELECTRONIC PALPATION METHOD

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Abstract-**This paper evaluates the accuracy of the pulse transit time method for determining diastolic blood pressure using intra-arterial blood pressure as a reference. First, the paper describes the method. Then it discusses two sets of measurements which were carried out to determine the accuracy of the method with cardiac operated patients and healthy young volunteers. The thus obtained accuracies were +0.7 mmHg ± 10.7 mmHg for the cardiac patients and -6.6 mmHg ± 10.5 mmHg for the young volunteers, respectively.**

Keywords - **Electronic palpation method, blood pressure, pulse transit time**

I. INTRODUCTION

In 1998, we introduced a noninvasive electronic palpation method for measuring blood pressure [1]. In this method, a cuff is attached over the brachial artery and a multi-element transducer array is employed to sense pulsations in the radial artery. Diastolic blood pressure is defined as the point where the blood pressure pulse amplitude starts to decrease, while systolic blood pressure is defined as the last pulse detected.

To test the method, measurements were carried out on healthy volunteers and some cardiac patients. With the healthy volunteers, the achieved accuracy was –0.8 mmHg ± 4.6 mmHg for diastolic and –1.5 mmHg ± 5.0 mmHg for systolic blood pressure. The measurements were made during cuff inflation, as it provides more stable readings than deflation.

As mentioned previously, blood pressure was determined on the basis of changes in pressure pulsation amplitude. Blood pressure amplitude is slightly higher in the radial artery than in the brachial artery, due to reflections from the peripheral arteries and arterioles. The amplitude discrepancy varies depending on individual vascular properties (vasoconstriction/vasodilation), thereby complicating the determination of diastolic blood pressure.

However, cuff pressure affects not only amplitude, but also transit time. As the increasing cuff pressure level approaches the pressure in the brachial artery, the pulse transit time from the aorta to the radial artery is correspondingly delayed. This effect is illustrated by Fig. 1. In the ideal model, the time elapses continue to rise until the systolic pressure level is achieved. Thus, the maximum transit time change equals the time a blood pressure pulse takes from the diastolic to the systolic pressure point, i.e., from the bottom to the top level

This method has been reported in papers published by Šantić, Šaban and Lacković [2, 3] and Kerola, Kontra and Sepponen [4]. The first two papers deal with diastolic blood pressure determination in a finger, while the third paper describes both diastolic and systolic blood pressure measurements in the brachial artery. The main problem in finger measurements is that blood pressure in a finger is not identical to that in the brachial artery, which is the standard measuring point. The third study [4], on the other hand, is impaired by the fact that the distance between the two sensors under the cuff was short. Thus, when cuff pressure exceeds diastolic pressure, thumbing blood volume on the upper side of the cuff results in rocking, which may lead to noisy sensor signals.

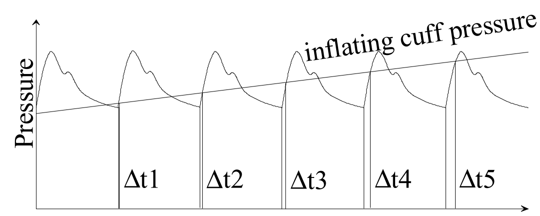

Fig. 1. Time elapses caused by cuff pressure exceeding diastolic arterial pressure.

In the electronic palpation method, a transducer is positioned on the radial artery at some distance from the cuff. Consequently, the sensor records only pulsations in the artery.

II. METHODOLOGY

A set of measurements was carried out in the intensive care unit at the Oulu University Hospital during the winter 1998/99. The test subjects were patients who had undergone cardiac surgery (either bypass or valve operation, or both) during the day the measurements were made. The study was approved by the Ethical Committee of the University of Oulu. It was presumed that most of the patients suffered from atherosclerosis.

A laptop PC with a National Instruments data acquisition card (DAQCard^{TM} 700) was used to acquire signals produced

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by a DATEX™ patient monitoring system and a blood pressure measurement device. The device consists of a standard 13 cm cuff, a wristwatch-type four-channel pressure transducer array, an amplifier/connection unit, an automatic pressure controlling unit and a microprocessor unit for determining blood pressure. Signals were sampled at 100 Hz. The transducer array was based on electro thermo mechanical film [5, 6], and was specifically designed to detect radial artery pulsations. Signals produced by the transducer were amplified and band-pass filtered. Cuff pressure signals were amplified and band-pass filtered by an amplifier unit.

A connection from the DATEX™ device gave an ECG signal and the patients' radial and pulmonary artery blood pressure. The automatic pressure-controlling unit started cuff pressure inflation and telemetrically sent pressure data to the processor unit.

The medical staff of the hospital department contributed to the measurements. The patients (totaling 51) were measured 2 - 5 times depending on their artifacts and post-operational shivering. All told, 152 measurements qualified for later analysis. Most patients were measured in the afternoon shortly after their operation and again in the morning, when they were awake and less affected by medication.

Fig. 2 presents the original and filtered pulse transit time, intra-arterial blood pressure (IAP), cuff pressure, the electronically palpated signal and the ECG signal as a function of time in a typical measurement. The pulse transit time was measured from the ECG's R-spike to the top of the electronically palpated pulse. This particular patient seems to have arrhythmia, and, because of that, oscillometric blood pressure methods may give erroneous results. The figure shows that a large variation in pulse amplitude has a negligible influence on pulse transit time. However, owing to weak sampling resolution (10 ms), the transit time signal must be filtered before further analysis. For this purpose, five point moving median filtering followed by five point moving average filtering were found to be adequate (the upper curve in Fig. 2).

Diastolic pressure can be defined as the point where the pulse transit time begins to increase. This turning point can be accurately determined by using "triangle conversion". In this method, all time values are recalculated in order to get an isosceles triangle, and line fitting is used to get the accurate turning point.

Firstly, time values have to be inverted to obtain decreasing time values. Then, the equation used in the method based on decreasing palpation amplitude (the second signal from the bottom in Fig. 2) is applied to obtain new values:

$$T_{new}(i) = T_{old}(i) - \frac{\left(T_{old}(1) - T_{old}(n)\right) * (i-1)}{n-1} - T_{old}(n) \, , \quad (1)$$

where $T_{new}(i)$ is a new time value for index (i), $T_{old}(i)$ the old time value for index (i) and (n) is the index value for the last measured pulse. This triangle is not yet isosceles, so it has to be truncated and converted. Three successive conversions are sufficient for an accurate determination of diastolic pressure. Fig. 3 presents these three triangles, with the third triangle and line fittings printed in a thick line. The corresponding diastolic blood pressure is marked with a black square on the cuff pressure curve. Systolic pressure is determined by the last pulse detected (the black circle).

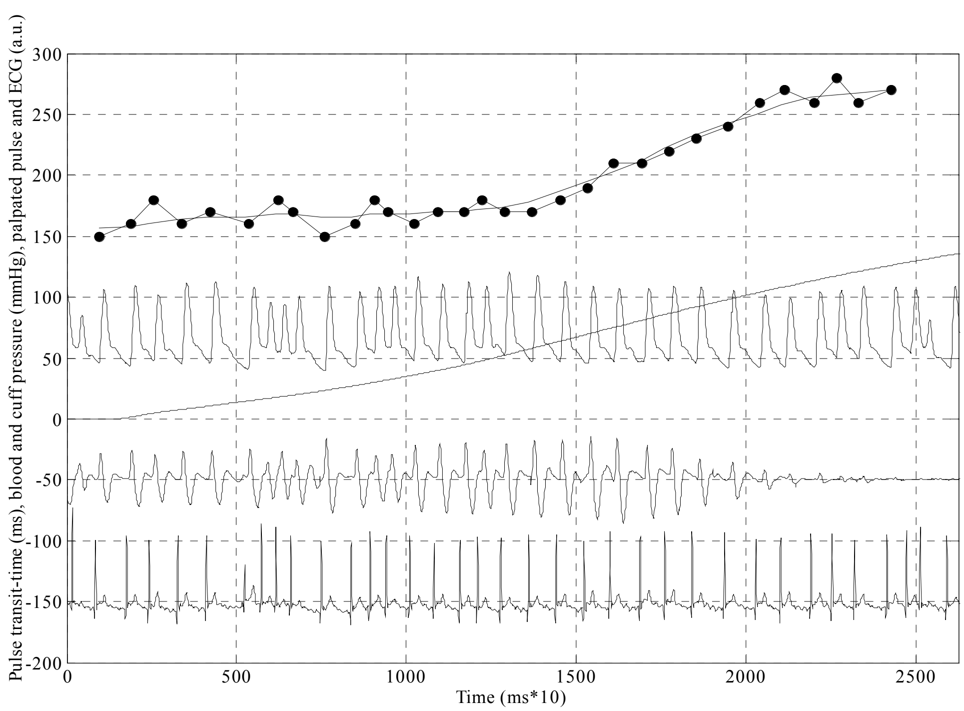

Fig. 2. From top to bottom: original and filtered pulse transit time, intra-arterial blood pressure and cuff pressure, electronically palpated signal on the radial artery and ECG signal.

The figure shows that if the triangle is not isosceles, the crossing point of the line fittings will shift the determined diastolic pressure slightly to a higher or a lower level.

Because the method records not only ECG, but also intra-arterial blood pressure, the transit time turning point can be measured from the diastolic point in the intra-arterial pressure wave to the top of the electronically palpated signal. In fact, diastolic blood pressure can be measured with a noninvasive transducer array on the radial artery in both wrists and the cuff on one arm.

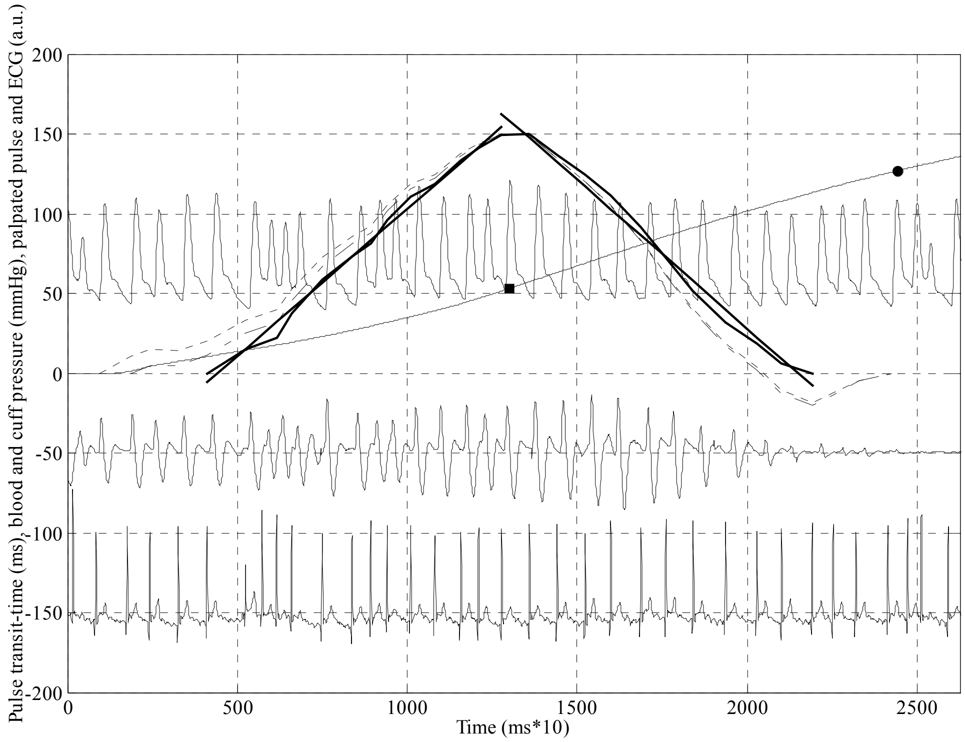

Fig. 3. Three triangle conversions for the transit times shown in the previous figure and line fittings for the isosceles triangle.

III. RESULTS

Firstly, blood pressure values from the electrically palpated signal's (second signal from the bottom in Fig. 2) amplitude were determined using the triangle conversion method described above. On average, the method offered an accuracy of +4.4 mmHg ± 13.2 mmHg for systolic and an accuracy of +10.0 mmHg ± 15.9 mmHg for diastolic blood pressure. The figures clearly overestimate both pressures for the seriously ill patient group.

The transit time method (using the diastolic point of IAP as a reference) achieved a better accuracy: the mean error for systolic blood pressure was +0.8 mmHg ± 9.4 mmHg. Relative to the electric palpation method, the figure is about 9 mmHg smaller. Also the standard deviation is much smaller, because variations in pressure amplitude do not have a great effect on transit time.

Fig. 4 presents these diastolic pressures as a function of intra-arterial pressure (IAP). The correlation coefficient R of these pressures is 0.68, and the line fitting coefficient (obtained by using the least square sum method) and constant are 0.89 and 7.4, respectively. These values are credible for old, seriously ill cardiac patients (66 years in average), who are assumed to have atherosclerosis.

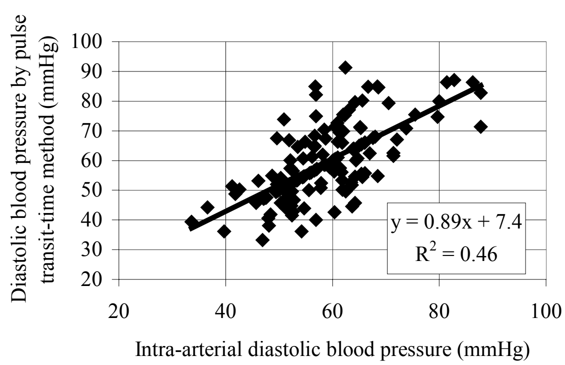

Fig. 4. Diastolic blood pressure measured by the pulse transit time method as a function of intra-arterial blood pressure (using the diastolic point of IAP as a timing reference).

In the measurement set conducted on healthy volunteers [1], the amplitude method produced a mean error and standard deviation of –0.8 mmHg ± 4.6 mmHg for diastolic blood pressure. The transit time method, on the other hand, fared worse: the error was -6.6 mmHg ± 10.5 mmHg. The result attests that the transit time method underestimates diastolic blood pressure. The explanation is that the transit time starts to be delayed even before cuff pressure reaches the diastolic level.

When using the R-spike of ECG signals as a timing reference, the average transit time without pressure in the cuff was 183 ms ± 33 ms. As cuff pressure increased, the maximal transit time change was 101ms ± 34 ms, on average. The rising time (10%…90%) for a blood pressure wave was 80 ms ± 15 ms, which constitutes approximately 80% of the transit time change. The obtained accuracy in the measurements was +0.7 mmHg ± 10.7 mmHg. At these pressures, the correlation coefficient R was 0.66, and the line fitting coefficient and constant were 0.98 and 2.2, respectively. The diastolic pressure data points are presented in Fig. 5.

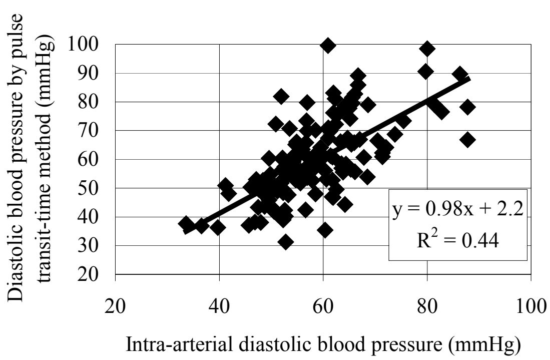

Fig. 5. Diastolic blood pressure obtained by the pulse transit time method as a function of intra-arterial blood pressure (using the R-spike as a timing reference).

With the cardiac operated patient group, the mean error was found to vary with the patients' obesity level and arm circumference. Consequently, both factors are assumed to have an effect on accuracy. Figs. 6 and 7 present these errors as a function of arm circumference and body mass index. As can be seen, diastolic pressure errors are independent of these parameters.

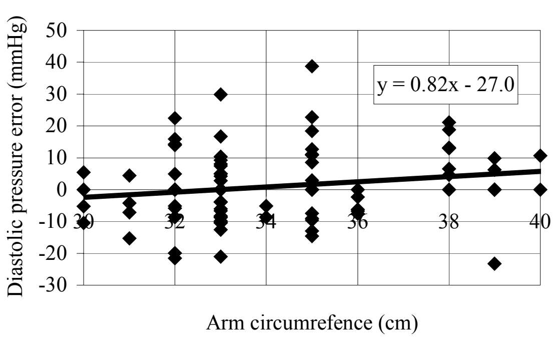

Fig. 6. Diastolic blood pressure errors as a function of arm circumference.

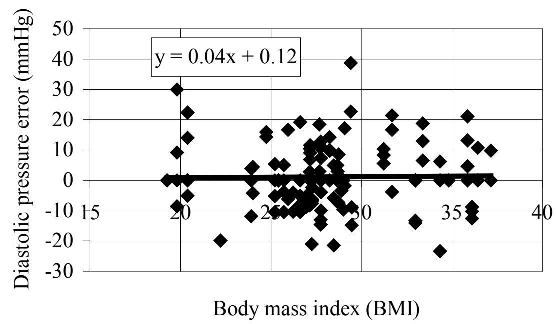

Fig. 7. Diastolic blood pressure errors as a function of body mass index.

IV. CONCLUSION

Diastolic pressure can be determined by the point when the transit time start to increase. The R-spike of ECG signals or the diastolic point in the other radial artery can be used as a time reference. Both methods give better accuracy than methods based on amplitude change. Diastolic pressure errors are not strongly dependent on arm circumference and body mass index.

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