SYSTOLIC BLOOD PRESSURE ACCURACY ENHANCEMENT IN THE ELECTRONIC PALPATION METHOD USING PULSE WAVEFORM

H. S. S. Sorvoja[1], R. A. Myllylä[1], S. M. Nissilä[2], P. M. Kärjä-Koskenkari[3], J. K. Koskenkari[4], M. K. Lilja[3], Y A. Kesäniemi[3]
[1]Dept. of Electrical Engineering, University of Oulu, Oulu, Finland.
[2]Polar Electro Oy, Kempele, Finland
[3]Dept. of Internal Medicine and Biocenter Oulu, University of Oulu, Oulu, Finland.
[4]Dept. of Anesthesiology, University Hospital of Oulu, Oulu, Finland.

Abstract-**This paper presents and evaluates some methods to improve the accuracy of systolic blood pressure measurements based on pulse waveform. A set of measurement was carried out with elderly cardiac surgery patients. The experiments comprised two to five measurements per patient, each including a one-minute follow-up, after which the cuff was slowly inflated over the systolic blood pressure. Systolic pressure errors were defined and correlations with other specific values, like pressure rise time, pulse wave velocity, systolic pressure, augmentation, arm circumference and body mass index were calculated. These indices may be affected by arterial stiffness, a common source of errors in blood pressure measurements. With a value of –0.52, the character which correlated best with systolic error was found to be the peak level of the first derivative of the pressure signal. Also rise time (10%…90%) exhibits a moderate correlation, +0.49. On the other hand, pulse wave velocity, body mass index, cardiac output, peripheral and intra-arterial temperature do not seem to correlate with systolic blood pressure error. It is also noteworthy that indices describing the rising edge of the pressure pulse correlated better with systolic pressure error than those describing the falling part. Using the first derivative peak level method, accuracy improved slightly.**

Keywords - **Electronic palpation method, systolic blood pressure, accuracy**

I. INTRODUCTION

The noninvasive electronic palpation method for measuring blood pressure was introduced in 1998 [1]. In this method, a cuff is attached over the brachial artery and a multi-element transducer array is used to sense pulsations in the artery. The measurement can be made either during the inflation or deflation of the cuff, but the inflation mode was found to be more stable. Diastolic blood pressure is determined by the point where the blood pressure pulse amplitude starts to decrease or in the place where the pulse transit time starts to be delayed [2]. The last pulse detected determines the systolic blood pressure. This method is briefly illustrated in Fig. 1.

Some measurements overvalue both systolic and diastolic pressure values. The overestimation is caused by factors such as arm circumference and obesity, but also by the stiffness of the brachial artery. In atherosclerosis, arterial rigidity prevents the vessel from collapsing, when cuff pressure exceeds blood pressure. This stiffness can be described by terms like distensibility, compliance and elastic modulus, which are difficult to measure directly. Indirect measures of arterial stiffness include pulse wave velocity and characteristic impedance [3].

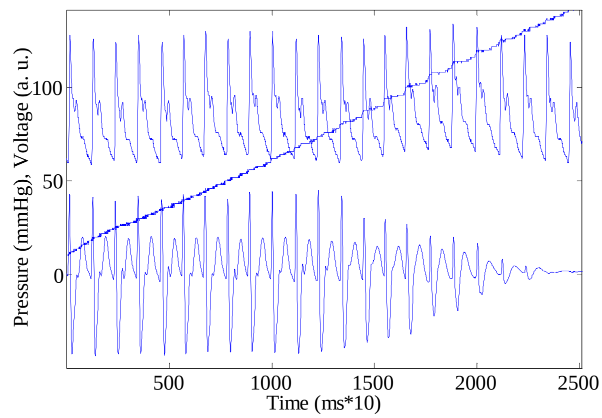


Fig. 1. From top to bottom: intra-arterial blood pressure, rising cuff pressure and electronically palpated signals presented as a function of time.

One approach is to measure the augmentation of the central arterial pressure wave, which is a manifestation of early wave reflection, and can be expressed as a percentage of pulse pressure. This augmentation can be measured noninvasively on the radial artery on the wrist. When special indices are known, arterial stiffness can be assumed and blood pressure readings refined correspondingly.

II. METHODOLOGY

A set of measurements was carried out in the intensive care unit at the Oulu University Hospital. The test subjects were patients, 66 years in average, who had undergone cardiac surgery (either bypass or valve operation, or both) during the day the measurements were made. It was presumed that most of the patients suffered from atherosclerosis. The study was approved by the Ethical Committee of the University of Oulu.

A laptop PC with a National Instruments data acquisition card (DAQCard™ 700) was used to acquire signals produced by the 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 the 100

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Systolic Blood Pressure Accuracy Enhancement in the Electronic Palpation Method Using Pulse Waveform	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Department of Electrical Engineering University of Oulu Oulu, Finland	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
4

Hz frequency. The transducer array is based on electro thermo mechanical film [4, 5], and was specifically designed for detecting radial artery pulsations. Transducer signals are amplified and band-pass filtered. The amplifier unit is used to amplify and band-pass filter cuff pressure signals.

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

The medical staff of the hospital department contributed to the measurements. The patients (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 next morning, when they were awake and less affected by medication.

Measurements were analyzed by Matlab™-software. Pressure pulse wave shapes were investigated and classified using a set of indices developed to ease specifying the level of augmentation. The problem is that augmentation depends on systolic pressure level and appears and disappears with pressure fluctuations. Fig. 2 presents a typical waveform for an augmented pressure pulse. Systolic pressure is boosted some 20% over the original value, due to reflections from the periphery. The manifestation of this augmentation is easily tested by measuring the rising time from 10% to 90% of the pulse pressure (Trise), or the time from the 50% level to the top level (T2) or the pulse at the 80% level.

The original systolic pressure can be defined by the "systolic turning point" of the first derivative signal after the peak (Fig. 3). Unfortunately, the signals are often weakened by noise. The second derivative can also be calculated, but subsequent signals are too noisy. It was established that the percentage of the first derivative peak of the pulse pressure is well suited to describing arterial stiffness. Hence, if the pressure slope is highest shortly after the foot of the pulse (diastolic value), the patient is likely to suffer from stiff arteries. In young and healthy persons, however, this level is near the 50% level of the pulse pressure. Another way of describing the waveform is the percentage of the mean pressure level of the pulse pressure, which can be easily calculated.

Also pressure pulse transit time was defined, followed by a calculation of pulse wave velocity (PWV). Normally, PWV is noninvasively measured using pressure pulses between the carotid and femoral artery, followed by a determination of the distance between the measuring points. In this study, time was determined from the ECG's R-spike to the end of diastole, when the pressure is just about to rise again. Distance from the heart to the wrist was defined afterwards by multiplying the patients' height by the coefficient 0.43, an empirically established mean value for normal young people. This value shows an individual variation of about ±10%, producing a corresponding error in the determination of PWV.

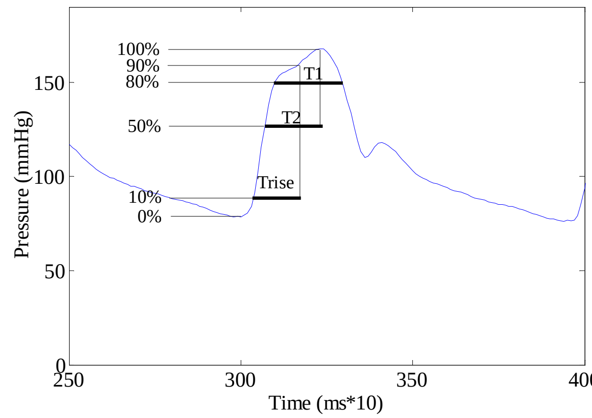


Fig. 2. Blood pressure signal and specific time values producing a numerical description of the signal.

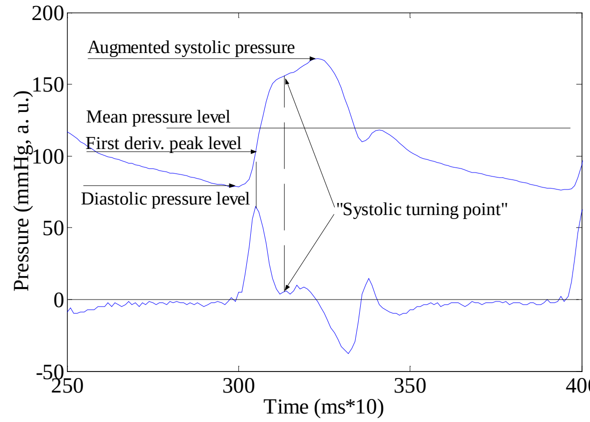


Fig. 3. Blood pressure signal (upper) and its first derivative multiplied by five (below).

Other factors were also tabulated, including the visually detected existence of augmentation, average of systolic mean and diastolic pressure, age, weight, height, cardiac output and peripheral and blood temperature.

III. RESULTS

First, systolic blood pressures were determined based on the visually detected last pulse of the electrically palpated signals. Then, systolic blood pressure errors were determined for every measurement by calculating the difference between the obtained pressure value and the average value of intra-arterial systolic pressure during the measurement. The average of the thus achieved accuracy was +4.4 mmHg ± 13.2 mmHg (mean ± standard deviation).

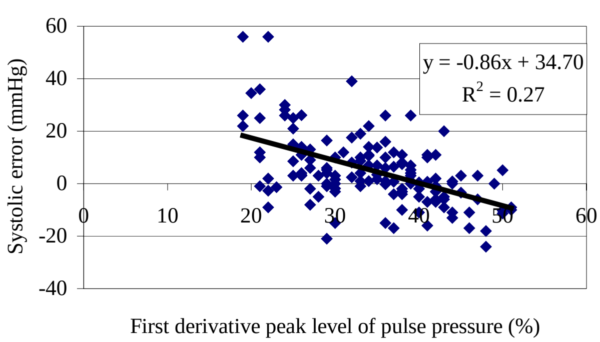
TABLE I presents the above-mentioned indices and the corresponding correlations between the obtained systolic blood pressure errors. The indices are shown in a descending order according to the correlation coefficient. It can be seen that features of the rising edge of the pressure pulse correlate better with the systolic error than those of the falling part. The first derivative peak level of each pulse pressure describes the pulse's highest rise rate.

TABLE I
CORRELATIONS BETWEEN SYSTOLIC BLOOD PRESSURE ERROR AND DIFFERENT INDICES OF PRESSURE PULSE WAVEFORM

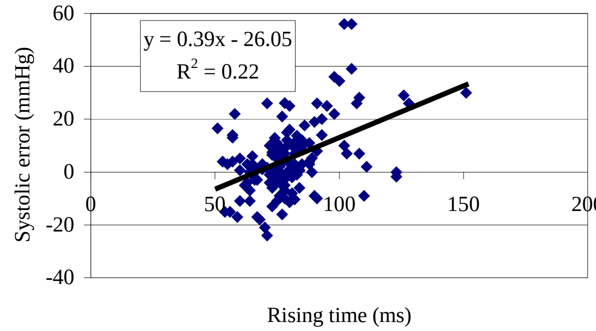
	Correlation coefficient R
First derivative peak level of pulse pressure	-0.52
Rising time (10%…90%)	0.49
Time from 50% of pulse pressure to the maximum	0.46
(MAP-DIAS)/(SYS-DIAS)*100%	0.44
Time from diastolic to systolic pressure (0%…100%)	0.40
Systolic pressure (last palpated pulse)	0.35
Arm circumference	0.32
Augmentation (visual)	0.32
SYS, Systolic pressure (intra-arterial)	-0.31
Pulse width at 80% level of pulse pressure	0.27
Electronically palpated amplitude	0.21
Weight	0.17
Age	0.16
MAP, Mean arterial pressure	-0.14
DIAS, Diastolic pressure (intra-arterial)	-0.13
Peripheral temperature	-0.12
BMI, Body mass index	0.11
Height	0.07
PCWP, Pulmonary capillary wedge pressure	-0.06
CO, Cardiac output	0.05
SpO2, Saturation of oxygen	0.04
PWV, Pulse wave velocity	0.03
Blood temperature	0.00

The table also indicates that many features have no correlation with systolic pressure error. If the absolute value of the correlation coefficient is less than 0.3, the correlation is considered negligible. Thus, there seems to be an insignificant correlation between systolic pressure error and factors like pulse wave velocity, oxygen saturation, cardiac output, body mass index, peripheral temperature, diastolic and mean pressure, age and weight.

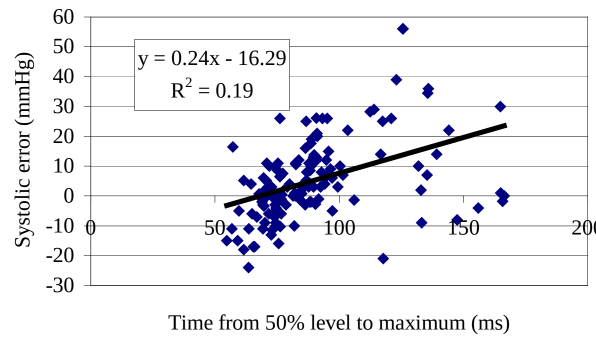
Figs. 4 a), b), c) and d) present systolic error as a function of the four features which are most correlating with it.



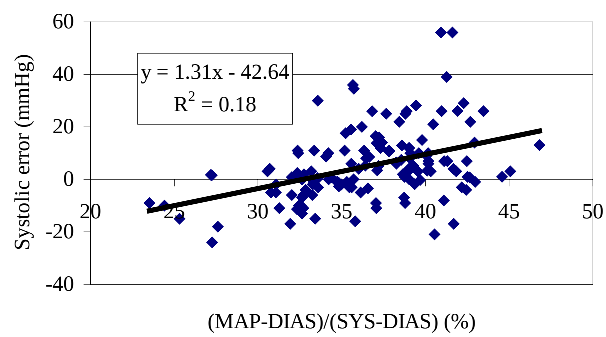
a)



b)



c)



d)

Fig. 4. Systolic pressure error in the electronic palpation method as the function of a) the first derivative peak level, b) rising time, c) time from 50% level to maximum and d) percentage of mean artery pressure minus diastolic pressure divided by pulse pressure.

TABLE II shows the systolic error after correction using linear regression coefficients and constants. Thus, the methods produce a mean error that equals zero. Standard deviations are slightly improved.

TABLE II
SYSTOLIC PRESSURE ERRORS WITH AND WITHOUT CORRECTION

Systolic BP correction	Standard deviation (mmHg)
First derivative peak level of pulse pressure	11.52
Rising time	11.90
Time from 50% level to maximum	12.13
(MAP-DIAS)/(SYS-DIAS)*100%	12.23
Time from diastolic to systolic pressure	12.52

Without correction, the linear regression equation is y = 0.79x + 29.05 and the correlation coefficient R^2 = 0.61. Fig. 5 displays the first derivative peak level of the pulse pressure method, a corrected scatter gram, the equation and the coefficient, which have all improved. The palpated signal can be corrected likewise: if the measuring bandwidth is, say 0.2-15 Hz, the palpated signal is not distorted and the waveform closely resembles that of the intra-arterial pressure pulse. Hence, this accuracy enhancement method can be easily adapted to the noninvasive electronic palpation method.

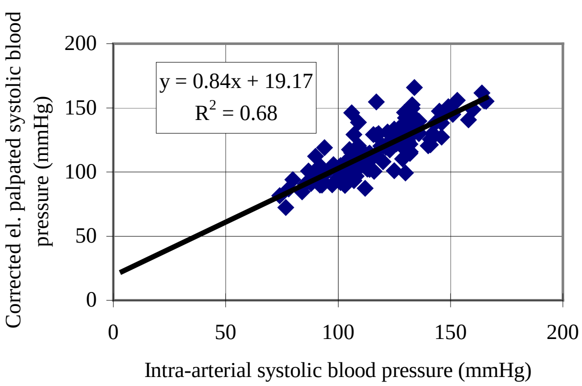


Fig. 5. Corrected systolic blood pressure values by electronic palpation method as a function of intra-arterial systolic blood pressure.

IV DISCUSSION

Most of the patients were under medication during the measurements, which may have affected the results. Several patients were given vasoconstrictive (dopamine, noradrenalin or adrenalin) or vasodilating (Nipride or Nitromex) medicines. Also painkillers and anesthetics (Oxanest, Diprivan, Fentanyl and Rapifen) may have affected the measurements. It is hard to distinguish the effects of medication and assess their relation to blood pressure errors and pulse shapes.

Surprisingly, PWV correlated weakly with systolic blood pressure errors. Numerous papers have noted that PWV correlates well with arterial stiffness. However, those studies usually measured PWV between the carotid and femoral artery, while the present study determined PWV from the ECG's R-spike to the wrist. Also the subsequently determined distance may have affected the results. The average value for PWV was 5.03 m/s (± 0.93 m/s), which is much less than the usual value quoted. However, higher values (7.93 ± 2.17 m/s), approximating the usual values, can be obtained, assuming that the R-spike is followed by a delay of about 50 ms before diastole begins in aortic arc.

It was also found that the aorta and the brachial artery differ in one aspect [6]: with age, the distensibility of the aorta decreased to the same extent in both sexes, whereas the distensibility of the brachial artery did not change significantly. This means that increased PWV aptly describes deformations in the aorta, but not in the brachial artery.

V CONCLUSION

During this study, 51 cardiac operated patients were measured to define the effects of arterial stiffening on the accuracy of the electronic palpation method. Systolic blood pressures were determined by the last pressure pulse detected in the wrist, with inflating cuff pressure. Accuracies were defined relative to the intra-arterial blood pressure in the other wrist. Correlation coefficients were determined for accuracies between various measurement characters. Of these, the peak of the first derivative of the pulse pressure provided the best description of the error. This correction method produced a slight improvement in accuracy.

REFERENCES

[1] S. Nissilä, M. Sorvisto, H. Sorvoja, E. Vieri-Gashi, R. Myllylä, “Non-invasive blood pressure measurement based on the electronic palpation method,” *Engineering in Medicine and Biology Society, Proceedings of the 20th Annual International Conference of the IEEE*, Vol. 4, pp. 1723 -1726, 1998.

[2] H. S. S. Sorvoja, R. A. Myllylä, S. M. Nissilä, P. M. Kärjä-Koskenkari, J. K. Koskenkari, M. K. Lilja, Y A. Kesäniemi, ”A method to determine diastolic blood pressure based on pressure pulse propagation in the electronic palpation method”, Submitted to *23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Istanbul, Turkey, Oct. 2001.*

[3] M. F. O’Rourke, G. Mancia, “Arterial stiffness”, *Journal of Hypertension*, vol 17 No 1, 4 p., 1999.

[4] Kirjavainen K. “Electomechanical film and procedure for manufacturing same”. *US Patent 4,654,546*, March 1987 [9 p.].

[5] M. Ficher, K. Kirjavainen, P. Vainikainen, E. Nyfors: Sensor for the measurement of pressure. *Proceedings of 20th European microwave conference*, Budapest, Hungary, Sept. 1990 [pp. 985-989].

[6] J. J. van der Heijden-Spek, J. A. Staessen, R. H. Fagard, A. P. Hoeks, H. A. Struijker Boudier, L. M. Van Bortel, “Effect of age on brachial artery wall properties differs from the aorta and is gender dependent”, *Hypertension* 2000;35:637.