Difference between Blood Pressure Measurement during Cuff Inflation and Deflation in the Oscillometric method

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***Abstract**:*
The majority of automatic blood pressure (BP) measurement devices use the oscillometric method made during cuff inflation. However, there is currently little information available concerning the measurements during cuff inflation. This study aimed to provide this information. To achieve this goal, an oscillometic blood pressure device was developed with the ability to drive out the cuff pressure signal and the oscillometric waveforms. The both signals were recorded and processed simultaneously by a specific algorithm to get blood pressure measurements during cuff inflation and deflation.
From 9 normotensive cases, the relationship between diastolic blood pressure (DBP), mean blood pressure (MBP) and systolic blood pressure (SBP) measurements during cuff inflation and deflation was compared. The results found confirm a positive linear regression found with a very strong correlation coefficient ($R^2 = 0.97$) in the case of MBP. Also, a strong one ($R^2 = 0.81$) is found in the case of DBP. However, a moderate R^2 is found in the case of SBP ($R^2 = 0.60$).

These results confirm the feasibility of blood pressure measurement during cuff inflation particularly in the estimation of MBP and DBP, which can considerably reduce the duration of measurement from 1 or 2 minute to a few seconds.

***Keywords**: Oscillometric blood pressure measurement, Inflation pahse, Deflation phase, Systolic blood pressure, diastolic blood pressure, Mean blood pressure.*

I. Introduction

Blood pressure (BP) is one of most important vital sign of health care. Generally, it is given with two values systolic blood pressure (SBP) and diastolic blood pressure (DBP). The SBP is the peak pressure in the arteries when the blood flows from the ventricles to the arteries during ventricular systole, and DBP is the minimum pressure in the arteries in the ventricular diastole. Given in mmHg, the BP can be measured both invasively and non-invasively, using or not using cuff, non-continuously and continuously.

In general, the non-invasive measurement technic using cuff are the most popular in the majority of health practitioner. With this technic, two methods can be used: the auscultatory method and the oscillometric method. The auscultatory method, coming first, it is regarded as the 'gold standard' for office blood pressure measurement, it is based on the detection of Korotkoff sounds issued from the acoustic transudcer signal. Its main advantages are (1) similarities with usual clinical measurement of BP; and (2) accurate detection of systolic and diastolic pressures on the appearance and disappearance of sounds. The main disadvantages of this method are (1) artefacts due to movements; and (2) difficulties in signal analysis due to physiological variations of the Korotkoff sound patterns or poor signals [1].

With the oscillometric method, the pressure variation in the cuff are detected during deflation. The maximum oscillation is related to the mean arterial pressure. The systolic and diastolic BP are determined by an algorithmic interpretation of the shape of oscillometric amplitudes as well as the heart rate. The main advantages are (1) the measurement of the mean arterial BP; (2) no need of a microphonic sensor, and (3) possibility of BP measurement in the cases when the Korotkoff signal is poor. The main disadvantages are (1) some oscillometric curves are difficult to read accurately; (2) oscillometry is very sensitive to movements, so the arm must be immobile; and (3) the accuracy of the systolic and diastolic BP depends on the algorithm used [1]. This technic is the most used in the automatic blood pressure measurement devices. Usually, BP values are determined during cuff deflation. There are also some devices that automatically determine BP values during cuff inflation to reduce the measurement time [2]. However, the different mechanical behavior of the artery during cuff inflation and deflation may influence the BP values. Zheng et al [3] has reported that the measured systolic blood pressure (SBP) from cuff inflation were lower than that from cuff deflation, and the measured diastolic blood pressure (DBP) were significantly higher. Tardy et al [4] studied the diameter change of the brachial artery during cuff inflation and deflation using an ultrasound technique. The results found from the animal tests also showed a different on arterial mechanical responses between cuff inflation and deflation [5].

In reality, there is a little information available on the feature analysis and comparison of the oscillometric pulse waveform between cuff inflation and deflation. For a better understanding of the the oscillometric method, this study aimed to investigate the shape differences of the oscillometric pulse waveform and the difference on BP measurement between standard cuff inflation and deflation.

II. Methodology

To study the difference between blood pressure measurement during cuff Inflation and deflation in the oscillometric method, a BP measurement device was developed. The device controls automatically the cuff inflation and deflation, and records simultaneously the oscillometric pulse waveform with the cuff pressure signal. In this study, a database containing these recording is done on 9 subjects male and female with different body height and weight is done. All the subjects signed an agreement to voluntary participate to this study.

Figure 1 presents the diagram bloc of the developed system. In the last, three part can be distinguished: (1) signal conditioning circuit, (2) control circuit, and (3) data acquisition.

II.1 Signal conditioning circuit

The signal conditioning circuit is developed according to [6]. Where, an instrumentation amplifier is used with a bande-pass filtred [0.5 - 40 Hz] for a best detection of pulse oscillations (AC component). The pressure level (DC component) is taken directly from the output of the instrumentation amplifier.

II.2 Control circuit

The cuff inflation\deflation control is realised around a microcontroller circuit of ARDUINO system. Where, a push button can activate the inflation pump, the closing of the electro-valve and the reading of the pressure level coming from the output of the instrumentation amplifier simultaneously. If the pressure level in the cuff achieve 180mmHg, the control circuit stop the pumping, take a pause for 5sec and open the electro-valve. The last is adjusted at a small opening for getting a progressive deflation at a rate of 4 -5 mmHg/s.

II.3 Data acquisition

The AC/DC components are recorded by PowerLab acquisition system (15T, ADInstruments, Australia).

The signals are recorded simultaneously with a sampling frequency of 1khz from the beginning of inflation until the end of deflation.

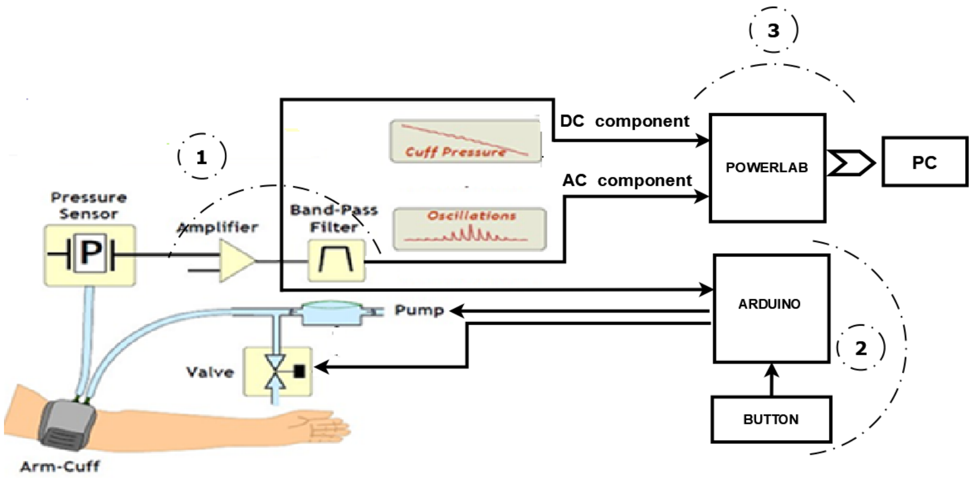


Figure 1: Diagram bloc of the oscillometric blood presure measurement

II.4 SBP, DBP and MBP Measurement

The SBP, DBP and MBP are estimated by the algorithm proposed by Lim et al [7]. The process starts by the envelop detection of the oscillometric pulse signal, from which, the location of the envelop peak corresponds directly to the MBP in the DC component signal. The SBP and DBP are corresponding to the pressure of 0.5 times and 0.8 times of oscillometric peak, as shown in Figure 2. This algorithm is used during the inflation phase, in the deflation phase, a similar algorithm is employed with a permutation between SBP and DBP.

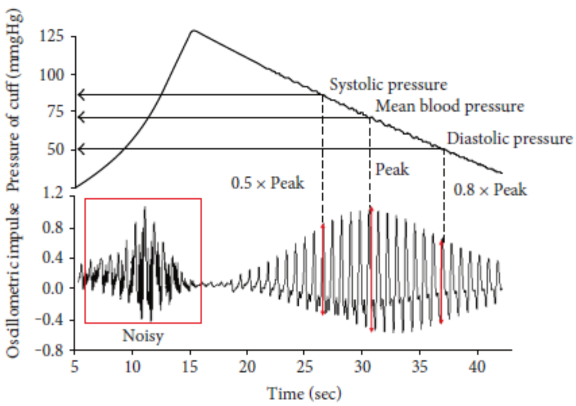


Figure 2 : SBP/DBP measurement technique in the Oscillometric methode.

II.5 Statistical analysis

All data are expressed as the mean±SD or percentage. The differences in SBP, DBP, and MBP measured for the same subject are compared using absolute error. The relationship between the measurement of SBP, DBP and MBP during inflation and deflation is assessed by the R^2 correlation coefficient. All statistical analysis is performed using OriginLab v8.

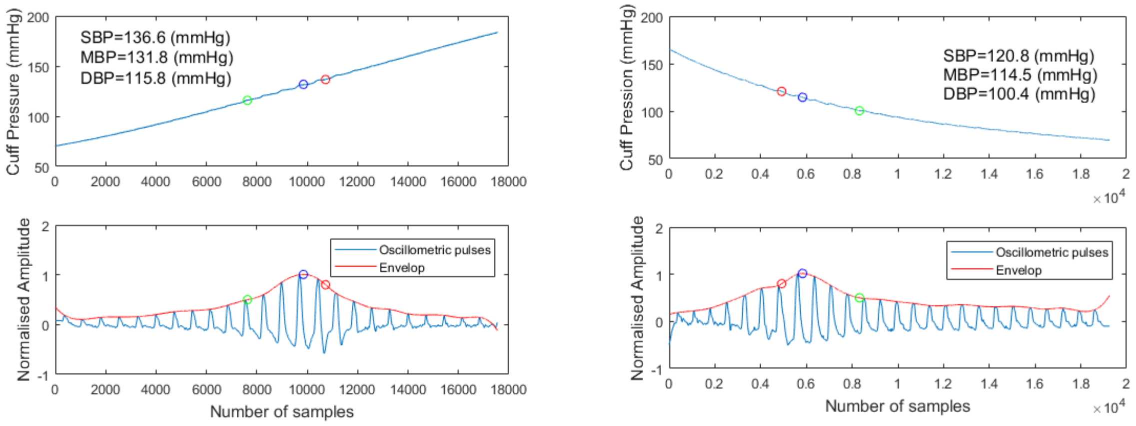
III. Results

Nine normotensive subjects (3 male and 6 females; age from 23 to 45 years; systolic blood pressure (SBP)<140 mmHg) were studied. The detailed subject demographic information including age, height, weight and BPs values are summarised in Table 1.

Table 1: Demographic data for the subjects studied. Their number (No.) or means standard deviations (SDs) are presented.

Parameters	Values
N°	9
Age (Years)	30±5
Height (cm)	170±8
Weight (kg)	70±5
Systolic blood pressure, SBP (mmHg)	118±6
Diastolic blood pressure, DBP (mmHg)	73±8

Figure 3 shows an example of the obtained signals from the cuff pressure and the oscillometric pulses for both cases, inflation and deflation. Figure 3 (a), illustrates the AC/DC components obtained during cuff inflation. In the AC components, the red curve indicates the envelop detected from the oscillometric pulses. The peak of the envelop locates the MBP position (blue circle). The real value of the last is determined directly by the projection of this position on the DC component. Consequently, the SBP and DBP are deduced and displayed by a red and a green circle, respectively. The same processing is done in the case of deflation, figure 3 (b).



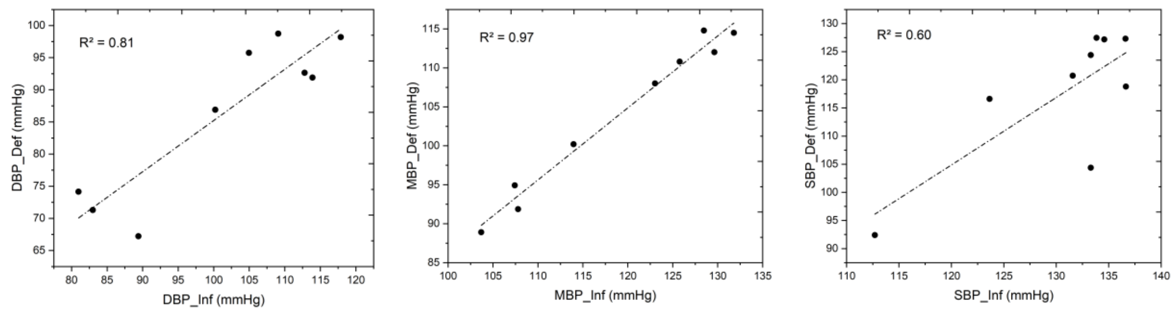
(a) (b)

Figure 3: DC and AC signals and measurement of blood pressures found during cuff inflation and deflation. (a) during cuff inflation, (b) during cuff deflation

The overall measurement results of SBP, DBP and MBP obtained during cuff inflation and deflation are resumed in table 2. From the last, we observe that the values found in the case of inflation phase are significantly higher than those of the deflation phase. Where the mean average error found for all measurements is 14.53 mmHg. However, we observe also a significant correlation between the measurement during inflation and deflation, particularly in the cases of MBP (Fig.4 b) where a very strong linear relationship is found with a correlation coefficient equal to $R^2 = 0.97$. Also, another strong linear relationship is observed between the measurements of DBP (Fig.4 a) found with $R^2 = 0.81$. However, in the case of SBP measurements (Fig.4 c), a moderate linear relationship is observed with a coefficient correlation equal to 0.6.

Table 2: The overall results of blood pressure found during cuff inflation and deflation

	BPs (mmHg)	Inflation phase	Deflation phase	Absolute error
Subject 1	SBP	112,70	92,39	20,31
	MBP	103,70	88,90	14,80
	DBP	83,00	71,30	11,70
Subject 2	SBP	123,64	116,60	7,04
	MBP	113,96	100,20	13,76
	DBP	100,22	86,90	13,32
Subject 3	SBP	133,30	124,40	8,90
	MBP	107,80	91,86	15,94
	DBP	89,40	67,22	22,18
Subject 4	SBP	133,30	104,36	28,94
	MBP	107,43	94,92	12,51
	DBP	80,98	74,14	6,84
Subject 5	SBP	134,58	127,17	7,41
	MBP	129,63	112,01	17,62
	DBP	117,88	98,19	19,69
Subject 6	SBP	131,58	120,72	10,86
	MBP	123,03	108,01	15,02
	DBP	109,09	98,73	10,36
Subject 7	SBP	136,65	118,79	17,86
	MBP	128,47	114,79	13,68
	DBP	104,97	95,76	9,21
Subject 8	SBP	133,85	127,46	6,39
	MBP	125,77	110,80	14,97
	DBP	112,80	92,65	20,15
Subject 9	SBP	136,60	127,30	9,30
	MBP	131,80	114,50	17,30
	DBP	113,90	91,90	22,00
			MAE =	**14,53±7,88 mmHg**



(a) (b) (c)

Figure 4: the correlation between the blood pressure measurements during cuff inflation and deflation. (a) The correlation found in DBP measurements, (b) The correlation found is MBP measurements, (c) the correlation found in SBP measurements.

IV. Discussion and conclusion

In this paper, a comparative study was elaborated between the oscillometric measurements of blood pressure during cuff inflation and deflation. In fact, a blood pressure measurement device was developed with the ability of recording of both signals, cuff pressure and oscillometric pulses simultaneously from the start of cuff inflation until the end of cuff deflation.

The comparative study was elaborated around 9 recordings, where it has been reported that the measurement of blood pressure during cuff inflation were considerably higher than those found during cuff deflation found with a MAE±STD = 14.53±7.88 mmHg, but strongly correlated particularly in the case of MBP (R^2 = 0.97) and DBP (R^2 = 0.81).

This finding confirms the feasibility of blood pressure measurement during cuff inflation. Furthermore, because the oscillometric pulse amplitude and shape are related to the arterial compliance, any factors, including ageing and cardiovascular diseases, associated with the changes of arterial compliance can also influence the amplitude and shape of the oscillometric waveform envelope.

To further understand the oscillometric waveform shape features between cuff inflation and deflation, a large number of physiological and pathological oscillometric waveforms need to be investigated. This may eventually improve the oscillometric technique for automatical BP measurement.

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