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Blood Pressure Measurement by Pulse Oxymetric Method and Comparison with Conventional Technique

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Background: **Measurement of systolic arterial blood pressure using a pulse oxymeter involves the evaluation of plethysmographic waveform during inflation and/or deflation of a blood pressure cuff. The purpose of this study was to determine that during slow inflation and deflation of cuff, which one of the pulse oxymetry-based readings of blood pressure is in best agreement with the value obtained by conventional method.**

Methods: **Blood pressure was measured in a sample of 50 healthy adult volunteers with conventional and pulse oxymetric methods. The degree of agreement between two methods was calculated.**

Results: **The mean difference between systolic blood pressure and pulse oximetric blood pressure during inflation of the cuff was 0.06 ± 1.75 mmHg which was not different from zero. The highest correlation was also between these two pressures (0.988).**

Conclusions: **This study shows that the best agreement is between systolic blood pressure and pulse oxymetric blood pressure during inflation. We conclude that for accurate measurement of blood pressure by pulse oxymetric method it is necessary to inflate the blood pressure cuff at a slow speed for the pulse oxymeter to have enough time to reach equilibrium state.**

Key words: *Blood pressure determination. Oxymetry. Human.*

Indirect blood pressure measurement is performed using a variety of techniques and equipments, the most common of which relies on the inflation of a bladder cuff rounding the upper arm to occlude arterial blood flow and then deflation of the cuff to detect the reappearance of arterial pulse wave by either simple palpation of radial artery or listening to the so called Korotkoff sounds with a stethoscope. The later has been the standard practice for blood pressure measurement in different clinical setting for many decades.[1] Pulse oxymetry has been invented primarily as a monitoring means for arterial blood saturation and soon it has become a standard equipment for anesthetic care.[2] It also can be used in combination with a blood pressure cuff to detect arterial pulse and thereby estimating blood pressure.[3-5] The plethysmographic waveform of the pulse oxymeter can be utilized to measure systolic blood pressure. In a previous study the cuff pressures at disappearance of plethysmogram during inflation (BP_{inf}) and reappearance during deflation (BP_{def}) were evaluated, and a good agreement was found between conventionally measured systolic blood pressure and the average of BP_{inf} and BP_{def} (BP_{av}).[6] Since ordinary pulse oxymeters cannot reach rapidly to an equilibrium state following changes in the blood flow to the finger, real disappearance and reappearance of plethysmogram does not occur immediately after occlusion and reopening of the artery respectively. In fact flow changes cause an initial irregularity in the displayed plethysmographic waveform, which may be confused with disappearance of display. If however we wait for a period of 2 second the real display (either flat or normal depending on the presence of blood flow) would appear. Therefore a significant hysteresis may oc-

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cur between BP_{inf} and BP_{def} if the inflation and deflation processes do not take place slowly enough for the pulse oxymeter to accommodate. This may be the reason why the previous study suggested the use of BP_{av} as a better estimator for systolic blood pressure. Therefore it is not clear that during slow inflation and deflation of cuff, which one of the pulse oxymetry-based readings of blood pressure is in best agreement with the value obtained by conventional method. The pulse oxymetry method may be valuable in certain clinical conditions where the conventional blood pressure measurement is difficult or has low accuracy (obese patients, burning, low perfusion states, Takayasu's syndrome), but before evaluating its usefulness in these abnormal clinical settings it is necessary to prove its accuracy in normal subjects. This study was designed in a sample of healthy adult volunteers to determine during slow inflation and deflation of cuff which one of the pulse oxymetry-based readings of blood pressure is in best agreement with the reading obtained by conventional method.

Materials and Methods

After institutional approval and subject informed consent this study was conducted in fifty healthy adult volunteers (22 men, 28 women). The required sample size was calculated after a pilot study on ten individuals which yielded a correlation coefficient of 0.85 between BP_{inf} and systolic blood pressure. This was tested against a minimum value of 0.95 at a significance level of 0.05 considering a power of 95% (Type I and II error both equal 0.05). The difference between Fisher Z transformations ($Z = 0.5 \times \log e\ [(1 + r)/(1 - r)]$) of these values (i.e. 0.85, 0.95) yielded an effect size (q) of 0.8.

Using the following formula (7):

$$N = (N_{.10} - 3)/(100 \times q^2) + 3 \quad \{N_{.10} = 2167,\ q = 0.8\}$$

gave a sample size of 37. $N_{.10}$ is the necessary sample size for $\alpha = 0.05$ and a power of 95% at $q = 0.10$ ($N_{.10}$ = 2167). To increase the accuracy a sample size of fifty was selected.

Individuals with a history of hypertension, diabetes mellitus, peripheral vascular disease, and renal disease were excluded from the study.

The blood pressure was measured using an appropriate-sized blood pressure cuff by two methods: with conventional method of blood pressure measurement (Based on Korotkoff's sounds) as the standard method, and using the same blood pressure cuff attached to a sphygmomanometer combined with the plethysmographic waveform of the pulse oxymeter (Datex Cardiocap II). The blood pressure was measured in the right arm for each volunteer in the sitting position after a resting period of 20 minutes. Measurements were performed 5 min apart to ensure adequate blood flow after each recording.

The probe of the pulse oxymeter was attached to the index finger of the right hand, after which the plethysmographic waveform, pulse rate, and oxygen saturation were displayed. Once the displayed waveform became regular and smooth, and the displayed pulse rate and saturation values stabilized, the plethysmography was assumed to be reliable. After recording the displayed values for the pulse rate (PR) and the arterial oxygen saturation (SpO_2) the blood pressure cuff was inflated rapidly to 60 mmHg, after which it was inflated slowly in 2.5 mmHg increments each approximately 2 second apart for the display to reach equilibrium until the plethysmographic waveform disappeared. The cuff pressure at this point was recorded as blood pressure at inflation (BP_{inf}). After this the cuff was inflated rapidly up to a 30 mmHg higher pressure and then deflated in 2.5 mmHg decrements until the plethysmographic waveform reappeared. The 2.5 mmHg steps were chosen for the sake of easiness because they are the half of the major divisions of mercury and also aneroid gauges. This was recorded as blood pressure at deflation (BP_{def}). Total duration of blood pressure measurement was recorded in seconds.

Five min after measurement of BP_{inf} and BP_{def} the systolic and diastolic arterial blood pressure were measured in the same arm using Korotkoff's method of blood pressure measurement and the displayed values were recorded as BP_{sys} and BP_{dias} respectively. The cuff was inflated rapidly to a pressure of 30 mmHg higher than the point of pulse disappearance and then deflated in steps of 2.5 mmHg. Auscultation of the brachial artery at elbow was used to detect the Korotkoff sounds between steps of cuff pressure decrement. The BP_{sys} was defined at the appearance of the first Korotkoff sound. The point of muffling or total disappearance of Korotkoff sound (whichever happened earlier) was regarded as diastolic pressure.

This measurement was performed by a person who was unaware of the pulse oximetric blood pressure readings. The mean arterial blood pressure was calculated based on systolic and diastolic pressures as BP_{mean} ($[2 \times BP_{dias} + BP_{sys}]/3$).

To determine the degree of correlation between different blood pressure values a correlation matrix was produced together with multiple regression analysis to estimate the coefficient of equation for calculation of arterial blood pressure based on pulse oxymetric method. Multiple regression analysis was performed with the BP_{sys} as the dependent and all other variables as independent variables (Method = Stepwise). The Kolmogorov-Smirnov Z test was performed to check the assumption of normal distribution prior to multiple regression analysis.

To determine the degree of agreement between the two methods of blood pressure measurement, the technique proposed by Bland and Altman[8] was used. Statistical analysis was done using SPSS 10.0 software.

Results

A total of 50 volunteers participated in the study (age 20 – 45 yr). All variables that were recorded in this study were normally distributed. No statistically significant differences were found between men and women concerning various blood pressure readings in this study. Mean duration of blood pressure measurement was comparable between two groups (47 ± 9 seconds [M ± SD] by pulse oximetric method *vs.* 46 ± 8 seconds by conventional method).

The correlation coefficients between the blood pressure estimated by the two methods are shown in table 1. Maximum correlation was between BP_{sys} and BP_{inf} (Table 1). Statistics on differences between pulse oxymetric and conventional methods of blood pressure measurement are summarized in table 2. Only the difference between BP_{inf} and BP_{sys} was as often positive as negative, and the mean difference was close to zero (95% CI, –0.44 ~ –0.56). Other mean differences were significantly different from zero. The BP_{inf} may be 4.5 mmHg below or 4 mmHg above the BP_{sys} (P = 0.02, Fig. 1).

Table 1. Correlation Coefficients between the Two Methods of Blood Pressure Measurement

	BP_{inf}	BP_{def}	BP_{av}
BP_{sys}	0.988	0.970*	0.985
BP_{dias}	0.518	0.493	0.509
BP_{mean}	0.724	0.705	0.720

BP_{sys} = Systolic Blood Pressure, BP_{dias} = Diastolic Blood Pressure, BP_{mean} = Mean Blood Pressure, BP_{inf} = Pulse Oxymetric Blood Pressure during Inflation, BP_{def} = Pulse Oxymetric Blood Pressure during deflation.
All coorelations were highly significant (P = 0.000).
*$P < 0.01$ compared to correlation between BP_{sys} and BP_{inf} (0.988).

The regression of BP_{sys} on BP_{inf} through the origin yielded a regression coefficient very close to 1 (0.9997 *vs.* 1.0195 and 1.01 for BP_{def} and BP_{av} respectively, Fig. 2). Systolic blood pressure was significantly correlated with BP_{inf}, BP_{def}, and BP_{av} (Table 1). Two tailed comparison of these correlations (BP_{sys} with BP_{inf}, BP_{def}, and BP_{av}) showed that only the correlation of BP_{sys} with BP_{inf} was significantly different from that of the BP_{sys} with BP_{def} (0.988 *vs.* 0.97 respectively, $P < 0.05$). Multiple regression analysis between BP_{sys} as dependent variable and the others as independent variables determined the BP_{inf} as the only significant variable in the analysis. The regression accounted for 98% of variance (Adjusted R^2 = 0.98) and was significant at the 0.000 level (F = 1879). No significant effects due to other variables were detected. The prediction equation based on this analysis was:

$$BP_{sys} = 1.02 \quad BP_{inf} - 2.6$$

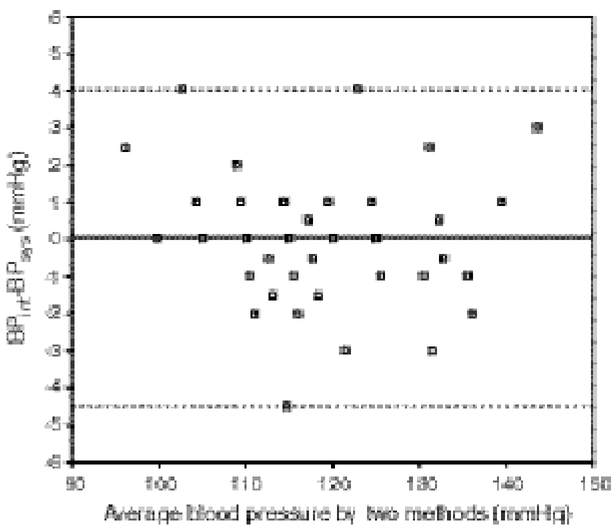

Fig. 1. Difference of systolic Blood Pressure (BP_{sys}) and Pulse Oxymetric Blood Pressure during inflation (BP_{inf}) against their average. The solid line is nearly horizontal which shows a complete agreement between BP_{sys} and BP_{inf}. The dotted line are 95% confidence intervals.

Table 2. Statistics on Differences between Two Methods of Blood Pressure Measurement

Differences	n (+, 0, –)	Mean difference ± SD	Minimum	Maximum
$BP_{inf} - BP_{sys}$	(21, 6, 23)	0.06 ± 1.75	–4.5	4
$BP_{def} - BP_{sys}$ [a]	(9, 2, 39)	–2.24 ± 2.79	–9	2.5
$BP_{av} - BP_{sys}$ [b]	(13, 1, 36)	–1.09 ± 1.98	–5.75	2.75

BP_{inf} = Blood Pressure at cuff inflation by pulse oxymetric method, BP_{sys} = Systolic Blood Pressure, BP_{def} = Blood Pressure at deflation of cuff by pulse oxymetric method, BP_{av} = average of BP_{inf} and BP_{def}, + = positive, – = negative. [a]Highly significant difference from zero (P = 0.000), [b]significant difference from zero (P = 0.022).

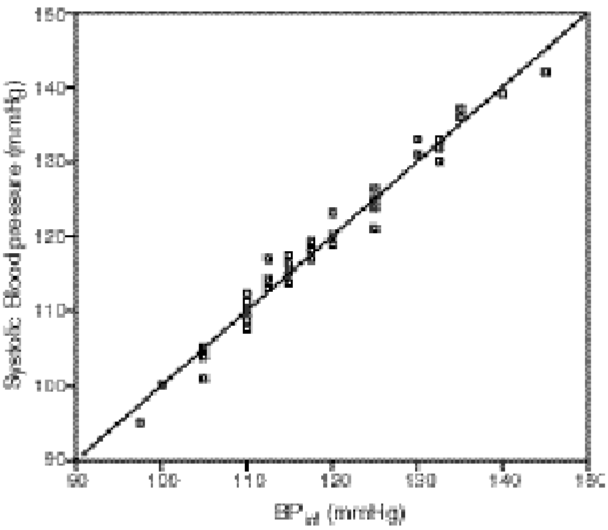

Fig. 2. Relationship of Pulse Oxymetric Blood Pressure during inflation (BP_{inf}) to Systolic Blood Pressure (BP_{sys}) ($P = 0.000$).

Discussion

This study shows that during slow inflation of cuff, BP_{inf} is in best agreement with systolic blood pressure obtained by conventional method. Specifically the regression of BP_{sys} on BP_{inf} when forced through the origin yields a regression coefficient of 1 and also the plotting of the difference between BP_{sys} and BP_{inf} against their average as porposed by Bland and Altman[8] is a horizontal line indicating a nearly complete agreement between these two blood pressure. In fact by applying the prediction equation we can estimate the BP_{sys} accurately using the BP_{inf} as the predictor. Chawla *et al.*[6] reported that the BP_{av} (but not the BP_{inf}) is in best agreement with systolic blood pressure measured by conventional methods. This may be due to different and possibly inadequate time period spent on inflation and deflation of blood pressure cuff. In this study we used inflation increments and deflation decrements of 2.5 mmHg with a pause period of 2 second after each increment or decrement to observe the plethysmographic display. Using this maneuver the obtained BP_{inf} is as accurate as BP_{av} for estimation of BP_{sys}. This 2-second pause is necessary because immediately after each increment or decrement the plethysmographic display temporarily perturbs, which may be confused with obliteration of pulse waveform. A pause period of about 2 second brings a normal pattern of waveform or in the case of complete occlusion a flat trace.

The reference systolic blood pressure was measured in this study using the standard Korotkoff method, which implies detecting Korotkof sounds during deflation. The equivalent of this systolic blood pressure may be BP_{def} which is also measured during deflation but in this study BP_{def} was lower than systolic blood pressure. In other words pulse wave (as detected by plethysmography) may reappear after Korotkof sound. Whether this phenomenon is due to a biological hysteresis in pulse wave propagation or an inherent bias of the pulse oxymeter instrument is not within the scope of the present study.

The subjects of this study were normal adult volunteers. Although the results can not be readily generalized to patient populations with abnormal cardiovascular physiology (e.g. low perfusion states), it is however necessary as a basis for future investigations to search for a correct understanding of the normal relationship between the conventional blood pressure measurement and the pulse oxymetric method.

Estimation of systolic blood pressure by the knowledge of BPinf provides a tool that can be used in a variety of clinical conditions where the ordinary methods of indirect blood pressure measurement cannot be applied easily or accurately,[3,4,9-11] namely obesity, burning lesions of extremities, low perfusion states, and Takayasu's syndrome.

In conclusion the result of this study shows that with only one measurement during cuff inflation the systolic blood pressure can be estimated with reasonable accuracy and its measurement may be easier than measurement of BP_{av} which needs averaging of BP_{inf} and BP_{def}.

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