Original Article

A Statistical Model to Predict Instantaneous Blood Pressure Using Velocity Measurements in the Radial Arteries.

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ABSTRACT

Background: Ambulatory BP monitoring (ABPM) provides a more reliable measure of a patient's BP than isolated clinic measures for continuous monitoring and rigorous control of hypertension. Regular users of ABPM hesitate to wear it because of aesthetic considerations and pain during inflation and deflation of the cuff. **Methods:** A statistical model is suggested from this study to aid in the development of wearable ABPM on the wrist which would aesthetical be acceptable and without pain. The model uses Blood flow velocities of the left and right radial arteries and their wall thickness to predict the Blood pressure at the right arm. Blood flow velocities (Peak systolic velocity- PSV and End diastolic velocity - EDV in cms/sec) and vessel wall thickness (in mm) were measured using B mode ultrasound and Doppler of 99 healthy persons. **Results:** The blood pressure of the right arm was measured using a mercury sphygmomanometer prior to the measurement of the Blood flow velocities. Systolic BP = 1.183 (LRA PSV) + 38.903 (LWT) +72.193, Diastolic BP = 5.211 (LRA EDV) + 56.071 (LWT) + 26.231, Systolic BP = 1.753 (RRA PSV) + 40.060 (RWT) +59.659, Diastolic BP = 4.302 (RRA EDV) + 28.378 (RWT) + 42.795. **Conclusion:** This statistical model needs further refinement and can be only used as an initial step in the modeling of Blood pressure based on the Blood flow velocities in the development of wrist- wearable ABPM instruments.

Keywords: Diastolic BP, Predicting, Systolic BP.

INTRODUCTION

According to World Health Organization the World Health Statistics of 2012 29.2 percent of men and 24.8 percent of women have high blood pressure.[1] Hypertension is universally-recognized as a predictor of cardiovascular, circulatory and cerebrovascular disease events where early treatment and control of blood pressure is required. Ambulatory blood pressure monitoring (ABPM) at regular intervals for 24 hours sense some blood pressure behaviors that are correlated with disease risk.[2] It has been very useful in identifying dippers from non-dipper blood pressure pattern during sleep which is reported as a predictor of cardiovascular and cerebrovascular risk. ABPM is also very useful in evaluating the effectiveness of oral antihypertensive medication. ABPM uses Sphygmomanometer. Daily users of ABPM hesitate to wear it because of pain during inflation and deflation of the cuff which could potentially damage tissue and because of the noises from cuff, and its appearance. Simpler instruments should be developed to monitor blood pressure during ambulation without the difficulties of wearing a cuff. An ambulatory blood pressure monitor attached to the wrist may be attractive aesthetically for users. This study will test the hypothesis that Blood pressure at the arm can be predicted using Peak blood flow velocities in the Radial arteries. The results could be used in the development ABPM instrument which is user friendly, wearable sensing system at the wrist and aesthetically acceptable.

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MATERIALS AND METHODS

Both male and female who visited the master health clinics were included in this study. A total of 99 subjects took part in this study of which 60 (61%) were males and 39 (39%) were females. Subjects with major illnesses including cardiovascular illness and on antihypertensive medications were excluded. Sonographic examination of the abdomen is a routine examination for these subjects during which blood flow velocities in radial arteries were additionally determined sonongraphically. Supine

Blood pressure was measured on the right arm by mercury sphygmomanometer before the time of determination of blood flow velocities at the radial arteries.

Gray scale B mode ultrasound and doppler study was done using high frequency linear probe (10 – 12 MHz) of GE VolusonP8 and E8 Expert ultrasound machines. Vessel Wall thickness, calcification and plaques were measured in distal radial artery at the wrist in both upper limbs. On spectral Doppler, angle corrected Peak Systolic Velocity (PSV) and End Diastolic Velocity (EDV) was measured by placing the sampling gate at the center of the lumen.

RESULTS

Table 1: Demographic characteristics of the study subjects.

Demographic characteristics	Frequency (n)	Percent (%) **
Sex		
Male	60	61
Female	39	39
Age group		
Below 30	7	7
31-40	17	17
41-50	32	33
51-60	20	20
Above 60	23	23

**Rounded off

[Table 1] presents the demographic characteristics of the study subjects. From the findings, it is observed that the majority of the subjects are male (61%) whereas the females are only 39 percent. When the age groups of the subjects are considered, around 33 percent of the subjects aged between 41 and 50 years which are followed by, 23 percent aged more than 60 years age group, 20 percent aged 51-60 years and a minimum number of subjects are below 30 years age group.

Table 2: Descriptive statistics for the blood pressure parameters.

Parameters	Min.	Max.	Mean	SD
Systolic BP	100.0	190.0	127.27	15.64
Diastolic BP	60.0	110.0	79.70	11.91
RRA PSV	21.0	55.0	30.66	6.58
RRA EDV	2.0	12.0	6.29	1.94
LRA PSV	17.0	60.0	34.88	10.39
LRA EDV	2.0	11.0	6.43	1.43
RWT	0.3	0.6	0.35	0.06
LWT	0.3	0.5	0.36	0.06

RRA PSV – Right Radial Artery Peak Systolic Velocity (cms/sec)
RRA EDV - Right Radial Artery End Diastolic Velocity (cms/sec)
LRA PSV – Left Radial Artery Peak Systolic Velocity (cms/sec)
LRA EDV - Left Radial Artery End Diastolic Velocity (cms/sec)
RWT – Right Wall Thickness (mm)
LWT – Left Wall Thickness (mm)

[Table 2] shows the summary statistics like minimum, maximum and mean of the study parameters. On an average, the subjects have 127.27±15.64 mmHg systolic BP, 79.70±11.91 mmHg diastolic BP, 30.66±6.58 cms/sec RRA PSV, 6.29±1.94 cms/sec RRA EDV, 34.88±10.39 cms/sec LRA PSV, 6.43±1.43 cms/sec LRA EDV, 0.35±0.06 mm RWT and 0.36±0.06 mm LWT.

Hypothesis (H1): LRA PSV and LWT are positive relationship with systolic BP.

Table 3: Predicting systolic BP with the assistance of LRA PSV and LWT.

Predictors	Unstandardized Coefficients		Adjusted R-square	t-value	p-value
	Beta (β)	SE			
(Constant)	72.193	4.929		14.645	0.000
LRA PSV	1.183	0.087	0.740	13.571	0.001**
LWT	38.903	15.274		2.547	0.012**

Dependent Variable: Systolic BP   **p<0.01

[Table 3] shows the regression model. In the model, LWT and LRAPSV are considered as independent variables while systolic blood pressure is considered as the dependent variable. The systolic blood pressure of the subjects depends on the LWT and LRA PSV as the statistical significance values are below 5 percent level (both p values<0.05). Also, LWT and LRA PSV explain around 74 percent variations in the systolic blood pressure (Adjusted R-square=0.740). Finally, the beta coefficient of LWT reveals that for every unit increase in LWT, 38.903 unit increases in systolic blood pressure is predicted. Similarly, for every unit increase in LRA PSV, 1.183 unit would increase in systolic blood pressure. Hence, the hypothesis '(H1): LRA PSV and LWT are positive relationship with systolic BP' is Valid.

The statistical model is given below:

Systolic BP = 1.183 (LRA PSV) + 38.903 (LWT) +72.193.

Hypothesis (H2): RRA PSV and RWT are positive relationship with systolic BP.

Table 4: Predicting systolic BP with the assistance of RRA PSV and RWT.

Predictors	Unstandardized Coefficients		Adjusted R-square	t-value	p-value
	Beta (β)	SE			
(Constant)	59.659	5.330		11.194	0.000
RRA PSV	1.753	0.157	0.684	11.198	0.001**
RWT	40.060	16.411		2.441	0.016*

Dependent Variable: Systolic BP   **p<0.01, *p<0.05

Association between systolic blood pressure, RRA PSV and RWT is shown in [Table 4]. In the statistical model, systolic blood pressure is defined as a dependent variable while RWT and RRA PSV are defined as independent variables. From the statistical significance (p- values<0.05), it is inferred that systolic blood pressure depends on the RRA PSV and RWT. In addition, the independent

variables explain around 68 percent variation in the value of systolic blood pressure (Adjusted R-square: 0.684). Hence, the hypothesis '(H2): RRA PSV and RWT are positive relationship with systolic BP' is Valid.

On the basis of the beta coefficients, the statistical model can be created in the following manner:

Systolic BP = 1.753 (RRA PSV) + 40.060 (RWT) +59.659.

Hypothesis (H3): LRA EDV and LWT are positive relationship with diastolic BP.

Table 5: Predicting diastolic BP with the assistance of LRA EDV and LWT.

Predictors	Unstandardized Coefficients		Adjusted R-square	t-value	p-value
	Beta (β)	SE			
(Constant)	26.231	5.864		4.473	0.000
LRA EDV	5.211	.592	0.519	8.804	0.001**
LWT	56.071	14.275		3.928	0.001**

Dependent Variable: Diastolic BP; **p<0.01

From the [Table 5], it is noticed that LWT and LRA EDV do the significant influence on the diastolic blood pressure. Since, the statistical significance values are below 5 percent level (both p values<0.05). As per the coefficient of determination (Adjusted R-square=0.519), LWT and LRA EDV explain around 52 percent variations in the diastolic blood pressure. Finally, the beta coefficient of LWT depicts that for every unit increase in LWT, 56.071 unit increase in diastolic blood pressure is predicted. Similarly, for every unit increase in LRA EDV, 5.211 unit will increase in diastolic blood pressure. Hence, the hypothesis '(H3): LRA EDV and LWT are positive relationship with diastolic BP' is Valid.

The statistical model is given below:

Diastolic BP = 5.211 (LRA EDV) + 56.071 (LWT) + 26.231.

Hypothesis (H4): RRA EDV and RWT are positive relationship with diastolic BP.

Table 6: Predicting diastolic BP with the assistance of RRA EDV and RWT

Predictors	Unstandardized Coefficients		Adjusted R-square	t-value	p-value
	Beta (β)	SE			
(Constant)	42.795	4.523		9.463	0.000
RRA EDV	4.302	0.427	0.579	10.080	0.001**
RWT	28.378	13.217		2.147	0.034*

Dependent Variable: Diastolic BP; **p<0.01, *p<0.05

Association between diastolic blood pressure, RRA EDV and RWT is shown in [Table 6]. In the statistical model, diastolic blood pressure is defined as a dependent variable while RWT and RRA EDV are defined as independent variables. From the statistical significance (p- values<0.05), it is inferred that diastolic blood pressure depends on the RRA

EDV and RWT. Also, the independent variables such as RRA EDV and RWT explain around 58 percent variation in the value of diastolic blood pressure (Adjusted R-square: 0.579). Therefore, the hypothesis '(H4): RRA EDV and RWT are positive relationship with diastolic BP' is valid. On the basis of the beta coefficients, the statistical model can be writtenin the following manner:

Diastolic BP = 4.302 (RRA EDV) + 28.378 (RWT) + 42.795.

DISCUSSION

Ambulatory BP monitoring provides a more reliable measure of a patient's BP than isolated clinic measures and is useful for monitoring BP in patients with labile hypertension, poor control despite using appropriate antihypertensive therapy;[6,7] worsening end-organ damage, in patients where rigorous control of blood pressure is essential, and in cases of suspected syncope or orthostatic hypotension, in patients with symptoms or evidence of episodic hypertension and to detect 'white-coat effect.[3-4]

According to Tolonen et al.[11] several factors affect BP measurement such as environmental factors, vigorous physical activity, heavy meal or smoking before measurement, cuff size, calibration error, left vs. right arm, supine vs. sitting, and these results in variations from 1–2 mmHg up to 20–50 mmHg in individual measurements.

While clinic measurement of BP is useful for screening, and in the management of suspected and true hypertension, ambulatory BP and home BP measurements add considerably to the accurate diagnosis of hypertension and the provision of optimal care. The Newer measurement techniques use different algorithms to measure the Blood pressure and work on the principles of Auscultation (Korotk off sounds), Cuff oscillometry, which relies on detection of cuff pressure oscillations and volumetric oscillometry using detection of volume pulsations under a cuff.[8] All these techniques use the vascular phenomenon of wave form transmission to detect blood pressure.

In a study on new born infants Blood flow velocity in the major cerebral and renal arteries was related to blood pressure.[9] Another study found that there was a significant relationship between Dental pulp blood flow velocity and systolic blood pressure.[10] We hypothesized that if blood pressure influences blood flow velocity then it should be possible to predict Blood pressure based on the Blood flow velocity provided the factors influencing pressure and flow velocity remain constant. We have not used vessel diameter in this model because at any given instance the diameter remains same. However, blood pressure may be influenced by the pliability of the vessel wall for the same diameter in different individuals at a given instance hence the thickness of the wall was included.

Systolic BP = 1.183 (LRA PSV) + 38.903 (LWT) +72.193

Systolic BP = 1.753 (RRA PSV) + 40.060 (RWT) +59.659

Diastolic BP = 4.302 (RRA EDV) + 28.378 (RWT) + 42.795

Diastolic BP = 5.211 (LRA EDV) + 56.071 (LWT) + 26.231

This statistical model allows for the study of both normal and pathological variations of blood pressure at the right arm. It may be also used to monitor rapid changes in blood pressure dynamics resulting from ventilatory or pharmacological manipulation, or from clinical deterioration.

The new clinical guideline for hypertension from the National Institute for Health and Clinical Excellence considers an interarm difference of less than 10 mm Hg to be normal and attributes a difference of more than 20 mm Hg to underlying vascular disease. Although there is inter-arm variability accommodated within this statistical model it cannot be used to predict inter-arm variability of blood pressure. The reason being that the blood flow velocities of the right radial artery and the blood flow velocities in the left radial artery both predict only the blood pressure at the right arm. This is an inherent weakness in this model. However this statistical model could be used as an early step in modeling blood pressure from Blood flow velocities in the development of ambulatory blood pressure monitors.

CONCLUSION

In summary, the statistical model developed from our study indicate the possibility of modeling and predicting blood pressure on the right arm using the blood flow velocities measured at the right radial artery and the left radial artery with their respective vessel wall thickness. Although there is inherent weakness in the predictability of interarm blood pressure variation yet it is encouraging to have a working statistical model as an initial step in predicting blood pressure using blood flow velocities in the development of ambulatory blood pressure monitors.

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