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Surface Recording of Aortic Pressure Wave from Aortic Area of Auscultation in Women with Hypertension: A New Idea to Indirectly Monitor Aortic Pressure

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ABSTRACT

Objectives: Blood pressure recording from the peripheral artery is subject to variations. While blood pressure is said to a modifiable risk factor for many cardiovascular and neurological diseases, the diagnosis of hypertension using Sphygmomanometry must be complemented with other tests to find central blood pressures. A newer, non-invasive method to indirectly record the aortic pressures is required. Aim of the study is to record surface aortic pressure waves (SAP) from aortic area of auscultation during breath holding and to compare the wave characteristics in hypertensive and normotensive women at rest and after mild exercise.

Materials and Methods: 128 women were recruited in the study. Piezoelectric sensor placed in the aortic area was used for getting the SAP waves during breath holding for 30 seconds. ECG was taken to show temporal association of these waves to R waves. Mean arterial pressures from arm (map-a) and from SAP waves (map-s) were calculated. Powerlab 8/35 and Labchart Pro software by AD Instruments were used in the study.

Results: R waves were followed by the SAP waves by about 31±2.2 ms at rest and 11±2.4 ms after mild exercise in all subjects. In hypertensive women, the map-s values were significantly ($p < 0.05$) lower in magnitude than in normotensive women both at rest and after exercise. There was no significant correlation between the map-a and map-s in any of the groups at rest or after exercise.

Conclusion: This new method, with some refinement could prove as a better alternative to blood pressure recording.

Keywords: Aortic pressure, Aortic area, Hypertension

INTRODUCTION

Hypertension is one of the major modifiable risk factors for cardiovascular morbidity and mortality. Systolic blood pressure is a function of myocardial contractility which is dependent on, in turn, various other factors such as sympathetic activity and levels of sodium in the extracellular fluid, whereas diastolic blood pressure is a function of peripheral arterial resistance which is also affected by sympathetic stimulation. Hence, when there is high blood pressure, it needs to be understood that the heart is either contracting against a greater load, or the myocardial oxygen demand is more to maintain the high pressures in the circulation. The normal blood pressure range is <130/85 mmHg.[1,2] Risk factors for hypertension include – obesity, stress, over usage of nonsteroidal anti-inflammatory drugs, and chronic diseases such as diabetes and renal disorders.[3,4] The complications of hypertension include coronary heart disease, retinal hemorrhage, and renal impairment. Elevated blood pressure directly correlates with the risk of stroke. Other than these, complications such as heart failure, peripheral vascular diseases, and impairment of vision due to retinal hemorrhages can be caused due to hypertension.[5] Before menopause, females have little lower (4–6 mmHg) systolic blood pressure than males of corresponding age. After menopause, systolic blood pressure in females is little higher (4–6 mm Hg) than males of same age group. Higher prevalence of hypertension is noted in women of low- and middle-income countries as compared to those of high-income countries across all age groups.[6] To diagnose an individual as hypertensive, the clinician should be very keen in recording the blood pressure and correlating the recorded value with other signs and symptoms and confirming the altered pathophysiological state using various other diagnostic tests. While blood pressure is said to a modifiable risk factor for many cardiovascular and neurological diseases, the establishment of hypertension is equally a challenging task as there are many factors affecting the recording of blood pressure using conventional techniques. Especially in the developing countries like ours, where a traditional auscultatory method using manometric recording is being used to establish hypertension or pre-hypertension in an individual, one must be aware of the possible array of factors affecting the values. The oscillometric method of the estimation of blood pressure used in most of the digital apparatus must also need careful watch on the factors that could affect the reading. The following physiological and physical factors can produce fluctuations in recorded blood pressure – diurnal rhythms, dietary habits, salt intake, menstrual cycle in women, psychological state such as anxiety and others, and physical factors such as cuff size, arm size, muscle bulk, and audibility of sounds. On the other hand, other than physiological and physical factors, there is significant increase in the systolic and diastolic blood pressure levels with increasing age which also varies with social class.[7] Systolic and diastolic blood pressures are also related to weight and age in urban areas.[7] Coming to gender as a factor affecting blood pressure, only about 7% of males and 8% of females are aware that they have high blood pressures.[8]

While the research works are being carried on probing into the pathophysiology and drugs to control hypertension, it is equally important to carry out research in finding alternate methods of recording of blood pressure or alternate parameters which will supplement the diagnosis and showcase the associated risks of hypertension. Such alternate methods of the estimation of blood pressure would complement the traditional methods. Many derivatives using the mathematical and physical principles have been introduced recently into the array of tests such as aortic stiffness index, augmentation index, carotid-femoral pulse wave velocity (cfPWV), and color Doppler study of arteriosclerosis in blood vessels. Invasive methods will help to estimate the central aortic pressures rather than the usual sites of arm or forearm pressures and bring accuracy in the diagnosis of hypertension. However the question is, can a non invasive method be developed to record aortic pressure with precision? The following study tries to address this question.

If the circadian rhythm of BP is dysregulated, cardiovascular and cardiorenal mortality rates drastically increase.[9] The proposition of "hypertension is a myth" has garnered much debate and commentary. Contrary to this belief, it has been verified from data obtained from conventional brachial cuff sphygmomanometer, that hypertension is a major risk factor to cardiovascular morbidities. This technique has many inherent limitations. There is yet need for a suitable, universally accepted device that can replace the brachial cuff sphygmomanometer, which is practical and non-invasive and has a wide range of clinical application particularly to predict a future cardiovascular risk.[10]

The central aortic systolic blood pressure is lower than the corresponding brachial vessels. Recent studies make it evident that as compared to brachial pressure, the central systolic pressure has a better correlation to any future risks of cardiovascular diseases. Antihypertensive drugs exert different effects on central and brachial blood pressure. Thus, medication decisions based on central, rather than brachial pressure, are more likely to be effective. However, this paradigm shift will not be possible unless there is further direct evidence that targets central pressure and proves to be a better indicator than the brachial cuff sphygmomanometer.[11]

Abnormalities in elasticity of the arterial tree are the major cause to raise the blood pressure which, in turn, produces vascular damage. Hence, techniques to find the arterial wall stiffness, conduction velocity of pulse wave along the arterial tree, aortic stiffness index, and 2-D echocardiography to assess aortic flow rate have been introduced as monitoring tools and risk assessment measures in hypertensive.[12] These changes are even found to be expressed much earlier than the actual clinical measurements of high blood pressure are documented.[13] Therefore, regular monitoring has become essential in risk assessment and to take preventive measures in cases of hypertension. However, how far the hypertensive patients or those who are prone to hypertension are being subjected to these monitoring techniques in a routine basis is a question. Furthermore, the monitoring and diagnostic techniques such as estimation of cfPWV, arterial stiffness index, and carotid artery Doppler studies are not available with all clinical setups. Only few centers with advanced equipment can perform the above-mentioned studies.

Therefore, the present study tries to address the above issues and proposes an indirect, novel method of surface recording of aortic pressure wave from aortic area of auscultation during breath-holding as an alternative and indirect monitoring tool for hypertensive women.

MATERIALS AND METHODS

The study was commenced after obtaining approval from the Institutional Ethics Committee. The 128 females in the age group of 30–60 years visiting to endocrinology/ medicine OPD with hypertension were selected for the study. Controls were also chosen from same age group from general population using simple random sampling. An informed consent was taken from them.

Inclusion criteria

Women with hypertension with or without aortic valve disease, on medication, and age-matched normal healthy women were included as controls.

Exclusion criteria

Females having a history of coronary artery disease, uncontrolled diabetes mellitus, thyroid dysfunction, active lung disease, renal impairment, or any other chronic disease were excluded from the study. All COVID protocols were duly followed during the testing.

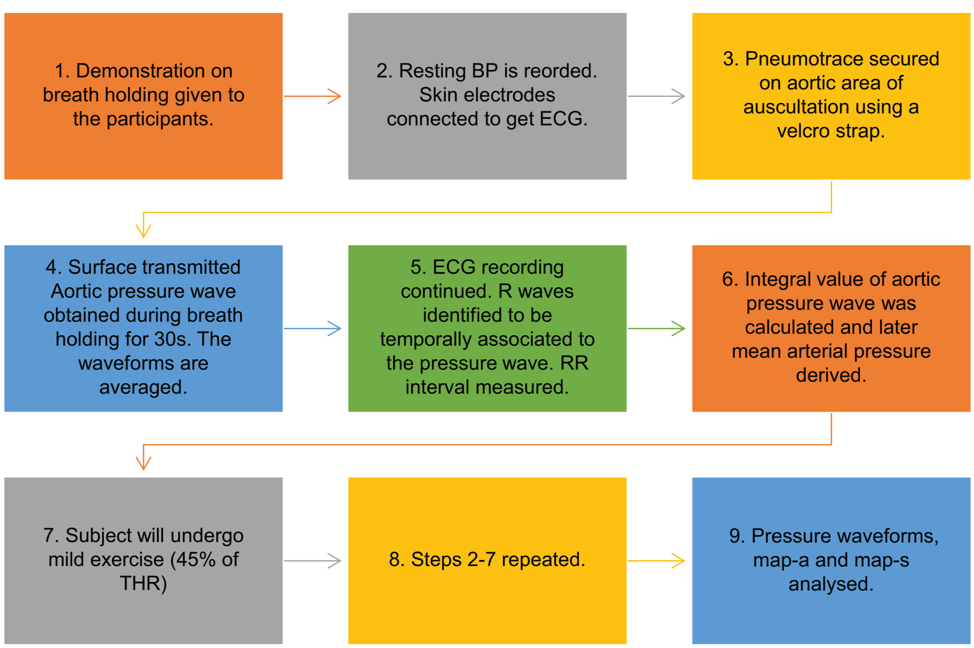
Method

A Pneumotrace with a piezoelectric sensor was used for getting the waveform from the aortic area of auscultation. Pneumotrace/ MLT1132/D respiratory belt transducer is a mechanical sensor with piezoelectric transducer material which is connected to PowerLab 8/35. This belt transducer was tied around the chest keeping the sensor exactly at the aortic area of auscultation (2nd right intercostal space, parasternal line) and securing it with Velcro strap. This sensor, once connected to the chest, will show the breath waves. Once during breath-holding, the sensor from the same location picks up the pressure waveforms from the aorta throughout the breath-holding time. These waveforms look like the experimental aortic pressure waveforms. They maintained and followed the same temporal relation with the R waves of electrocardiogram (ECG). Their amplitude will be measured by the software in mV. ECG was obtained from lead II using surface electrodes. A digital aneroid manometer was used to estimate the blood pressure from the arm. The cuff was tied to the arm keeping the arm at the level of heart. A cardiomicrophone was kept inside the cuff which records the Korotkoff sounds to estimate the blood pressure accurately. The blood pressure so recorded by the software will usually appear in the units of mV.

The subjects were explained and demonstrated on how to hold their breath for minimum 30 s, after a deep inspiration. After the rest state, they were instructed to perform mild exercise for about 5 min on a bicycle ergometer or normal walking. Mild exercise was standardized based on target heart rate fixed at 45% of maximum heart rate (calculated as 220 minus age) for all subjects. After exercise, the same method was followed to record the aortic pressure waveforms and the ECG. The data acquired on the LabChart Pro software were later analyzed. The analysis was done using GraphPad Prism software and Microsoft Excel. The method is summarized in the following flowchart.

RESULTS

Out of 128 women selected for the study, only 96 turned out for the study and gave consent. Out of 96 women, we discarded



Test methodology

Table 1: Distribution of age and Mean Arterial Pressures from brachial artery (map-a) in normotensive and hypertensive women at rest and after mild exercise expressed as mean±SD.

Group	Age (years)	map-a (in mmHg units)		map-a (in mV units)	
		Before exercise	After exercise	Before exercise	After exercise
Normotensive women (*n*=35)	41±8	90±8	94±9	4.51±0.4	4.69±0.5
Hypertensive women (*n*=26)	43±6	107±6	107±9	5.36±0.3	5.37±0.5

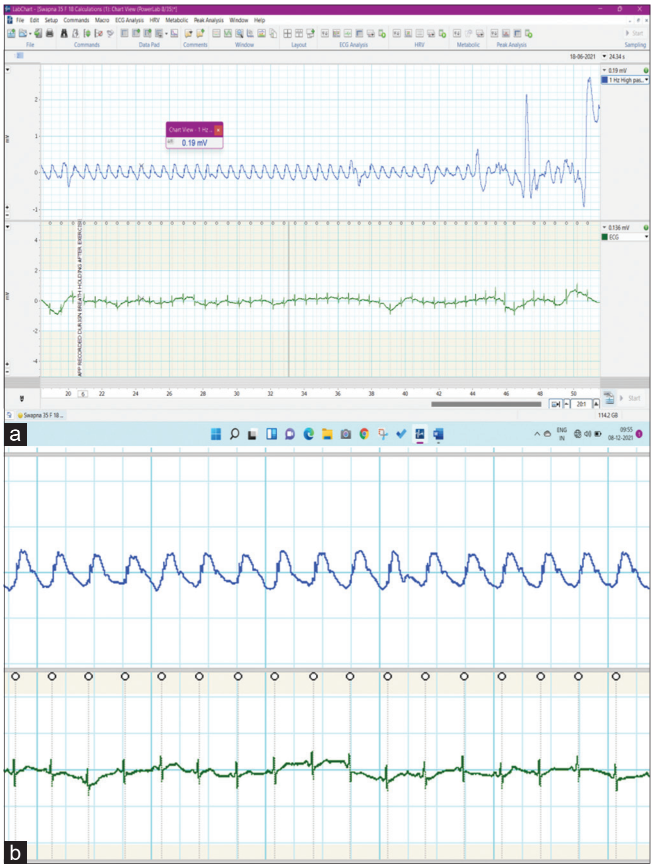


Figure 1: (a and b) Screenshot of the software chart view showing the derived aortic pressure waves in the upper channel and the ECG in the lower channel. (b) Is the closer view of the same.

the recordings from 35 women as they could not perform breath-holding properly and were apprehensive during the test. In the remaining 61 subjects, 35 were normotensives and 26 were hypertensive on regular treatment. There were no women with known aortic valve sclerosis or any other abnormalities of the valve. The hypertensive women were on regular medication. Three parameters were recorded from each subject. Three parameters were recorded. 1. Arm blood pressure, 2. Waveform from aortic area during breath holding, 3. ECG. The mean arterial blood pressure (DBP + 1/3 PP) from arm (map-a) was calculated before and after exercise and tabulated in the units of mV [Table 1]. During a period of about 30 s of breath-holding time in all subjects, the transmitted pressures from aorta to the surface of the chest appeared as waves in succession and maintained a good temporal association to the R waves [Figure 1a and b]. The obtained waveform characteristics were studied after averaging [Figure 2a and b]. R wave of each ECG is followed by the beginning of the pressure waves just like the experimental conditions [Figures 3 and 4] by a duration of about 31 ± 2.2 ms at rest and 11 ± 2.4 ms after mild exercise in all subjects. The RR intervals were calculated from the ECG. The mathematical formula of integration was applied to the pressure waves which give the area under the waveform. The area under the waveform, now called as integral max, is divided by the RR interval to get the mean arterial pressure (map-s) in mV units. In hypertensive women, the map-s values were significantly ($P < 0.05$) different from the normotensive women both at rest and after exercise [Table 2]. In hypertensive women, after a mild exercise, the map-a did not show much of a change [Table 1] but there is a significant change in the value of map-s [Table 2]. There was no significant correlation between the map-a and map-s in any of the groups at rest or after exercise.

DISCUSSION

Previous research suggests that the routine method of sphygmomanometry has its own drawbacks.[10,11] Hence, to understand the comprehensive health status of the individual and to investigate into the cause and extent of the cardiovascular disease in a person, the blood pressure recording is being complemented with other tests. The aortic pressure, which can usually be studied through invasive or mathematical methods, has been obtained in this study through an indirect method. Aortic area of auscultation is chosen to be the best area on chest wall to pick up this pressure energy in the form of surface aortic pressure waves. There were two challenges in this endeavor. One – whether the recorded waveform is an honest representation of the aortic pressure wave and two – how to eliminate the noise due to respiratory movements while extracting the signal. The fact that the R waves of the ECG were in good association with the recorded waves, a behavior more like an experimental recording of cardiac cycle events, explains that the waveform obtained is surely from the aorta, the character of this pressure wave, also suggesting the same. There were, however, subtle differences in the waveform character in all the subjects. This difference could possibly be due to the amount of tissue intervening the

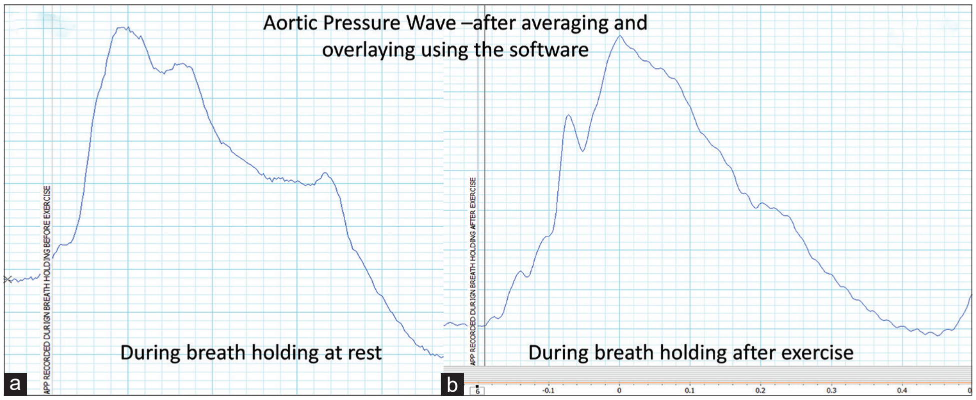


Figure 2: (a and b) Aortic pressure wave forms derived from the surface of chest.

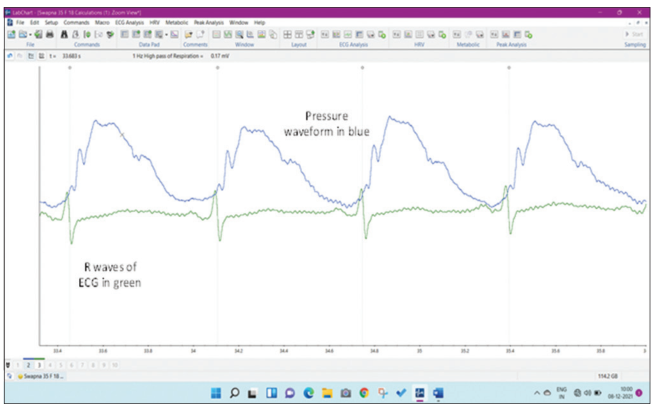


Figure 3: Screenshot of the software page showing the temporal association between the R waves of ECG and the derived aortic pressure waves.

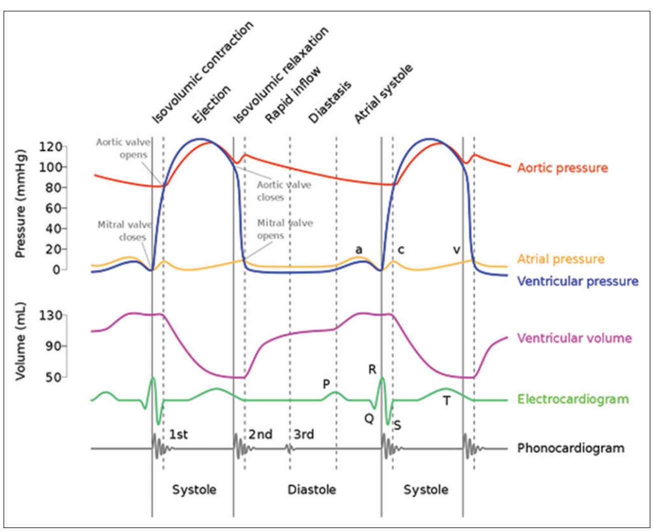


Figure 4: Wiggers diagram showing the temporal association between various electrical, physical, and mechanical events during cardiac cycle. Source: adh30 revised work by Daniel Chang MD who revised original work of DestinyQx; Redrawn as SVG by xavax-Wikimedia Commons: Wiggers Diagram.svg.

aorta and the surface, fat in the subcutaneous tissue, pressures *per se* in the aorta, or other minor factors such as skin texture, movements during the recording, and sweating. Adequate care has been taken to rule out such avoidable factors during the study. However, above all what seems to be an important factor affecting the character of this derived aortic pressure waveform is breath-holding. To eliminate the noise due to chest movements during breathing, the authors decided to make the subjects perform breath-holding to ensure elimination of noise and in fact this had worked very well. However, not all women were able to hold their breath.

The surface aortic pressure waves thus obtained were averaged and analyzed to calculate map-s in mV which were later compared to map-a values. The map-a values increased in both normotensive and hypertensive women after a mild exercise, as expected [Table 1]. However, the hypertensive women showed a little change in their map-a compared to normotensives. This could possibly be due to the drugs which are constantly present in their plasma which are counteracting the smaller raise in blood pressure after exercise. However, when the map-s values were compared at rest and after exercise in both the groups, two interesting points were observed. One – the map-s decreased after exercise compared to its value at rest in both groups. RR interval reduced after exercise in both groups, more fall (52 ms) in hypertensive women (745–693 ms) than a little reduction (30 ms) in normotensives (845–815 ms). If the map-s values were to be affected by the RR interval, the reduced RR after exercise should lead to increased map-s value (RR value being in denominator), but the observation is that map-s values reduced after exercise may be due to some hemodynamic factors in aorta. The second interesting point is that this decrease in map-s value is significantly lower in hypertensive women than normotensive women. When the map-s value reduced from 0.210 mV to 0.166 mV (−44 units) in normotensive women, they reduced from 0.114 mV to 0.108 mV (−6 units) in hypertensive women. The resting value of map-s as well as the degree of reduction both are lower in hypertensive women.

Table 2: Distribution of the characteristics of the transmitted aortic pressure wave recorded from the surface expressed as mean±SD.

Group	RR interval (s)		map-s (in mV units)	
	Before exercise	After exercise	Before exercise	After exercise
Normotensive women (*n*=35)	844±260	815±210	0.210±0.18	0.166±0.14
Hypertensive women (*n*=26)	745±210	693±220	0.114±0.09	0.108±0.16

Map-s waveform obtained from the surface of the chest is the miniature representative of the central aortic pressure, which is, in turn, dependent on the systolic pressure and the reflected pressure wave.[14] Studies done in the past showed that there is a tendency for the reduction in the central aortic pressure after exercise. This difference is basically due to the duration of cardiac cycle or, in other words, heart rate. Faster heart rates reduce the cardiac cycle duration and the effect of reflected waves on the systolic pressure wave in the aorta will be seen in the early part of cardiac cycle. After mild exercise, the reduction in RR interval will, therefore, affect the reflected waves and the hemodynamics at the aorta resulting in lower pressures. This observation has been confirmed in the past using many tools such as applanation tonometry and studying the parameters such as augmentation index. In our study, the same has been evident from the wave characteristics of the transmitted waveform. Furthermore, studying the characteristics of the surface transmitted waveforms will provide good insights into the actual central pressures.[14] To summarize, the advantages of the new method used by the authors in the present study are as follows:

1. Aortic pressure wave can be obtained from the surface of the chest over the aortic area of auscultation using a simple and standard piezoelectric sensor during breath-holding.
2. This method of recording is more direct and reliable than a mathematical derivation from the peripheral arterial pressure recording.
3. The temporal association of the obtained waveform with the R waves of ECG and its behavior pre- and post-exercise is more toward confirming its origin from aorta.
4. The waveform characteristics can also be studied by averaging the waveforms over a short period of breath-holding which will be of help in understanding the central aortic hemodynamics [Figure 2a and b].
5. The map-s calculated from the waveform showed a reduction after mild exercise, more pronounced in hypertensives. This might help as a guide to better understand the pathophysiology in hypertension and plan effective management strategies.

Furthermore, there are three limitations in our study which need further refinement. One – breath-holding is not uniformly done by all subjects and requires training and practice. This limitation could be addressed by efficient signal processing. Two – the obtained waveforms were attenuated in magnitude even though they maintained temporal association with ECG. This was but inevitable due to surface recording. Again, efficient signal processing using amplifiers would solve the issue. Third – paucity of data. The study must be performed on a larger scale in men, women, children, and those with known aortic valve diseases to acquire good number of data to analyze within the groups and to establish certain norms.

Once the limitations are addressed, we believe that this method would prove to be a best alternative and supplement to the routine blood pressure measurement in all health-care centers in the country.

CONCLUSION

The method employed in the present study is a novel one but requires further refinement to address the limitations. The surface transmitted aortic pressure waves showed a good temporal association to R waves of ECG. The mean arterial pressures recorded from the brachial artery and the calculated mean pressure from the surface recorded transmitted aortic pressure waves was comparable. However, the study needs to be carried extensively in a larger group of individuals and compared between men, women, and children to establish normative data and to finally design a biomedical device useful to supplement the routine clinical blood pressure recording. This would prove to be a useful tool in roughly estimating the aortic pressures and help the clinician to understand the pathophysiology of hypertension in greater detail.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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