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Comparison of Direct vs. Indirect Blood Pressure Measurements on Treadmill and Bicycle in Hypertensive Responders

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Abstract

Objectives: This study tested whether the systolic and diastolic blood pressures measured simultaneously by direct and indirect methods provide similar readings for blood pressure response during symptom-limited exercise on a treadmill and bicycle, and if it can be used to monitor blood pressure in hypertensive patients treated with β-blockers.

Method: Comparisons were made with simultaneously determined intra-arterial catheter and auscultation measurements on a treadmill and bicycle. Eight hypertensive patients (41.9 ± 2.0 years) active participants in supervised aerobic programs (12.1 ± 1.2 METs work capacity) for at least 12 months were recruited to the study.

Results: At rest, indirect systolic pressure was highly correlated with the direct method (r=0.85), with mean of 139 ± 7 and 134 ± 6 mmHg, respectively, at peak treadmill exercise (r=0.90), with mean of 198 ± 11 and 189 ± 9 and bicycle (r=0.92) with mean of 204 ± 10 196±9 mmHg respectively. Indirect diastolic blood pressure correlates well with intra-arterial at rest (r=0.82), with mean of 96 ± 11 and 88 ± 9 mmHg, respectively. However, at peak treadmill exercise, the correlation coefficient between the direct and the indirect methods was low (r=0.40), with mean of 105 ± 9 and 112 ± 12 mmHg, respectively. At peak bicycle exercise correlation was (r=0.58) with mean of 107 ± 9 and 112 ± 12 mmHg.

Conclusions: These results suggest that at peak treadmill exercise and bicycle, the indirect method tends to bias low compared with direct therefore it is not valid for the assessment of diastolic pressure in hypertensive patients. Intensity should be considered when using cardiovascular variables as outcome measures.

Keywords: Aerobic exercise; Auscultation; Intra-arterial blood pressure; Systolic blood pressure; Diastolic blood pressure; β-blockers

Introduction

Blood pressure (BP), like all biological variables, varies widely in different people and, in the same individual, at different times of the day. Typically, a normal value for systolic BP would be 120 mmHg at age 20, increasing perhaps to 140 mmHg at 60. Diastolic pressure also increases with age but rather less. Estimates of BP in apparently healthy people show values that can be 20 or even 40 mmHg higher or lower than the average values [1]. This, and the fact that BP varies considerably during the day, it would be very difficult to decide on the basis of a single auscultator measurement whether a patient suffers from hypertension [2]. Perhaps the four most common errors with the measurement of BP by means of auscultation are: a) Using the wrong size cuff, b) Applying the cuff incorrectly, c) Not positioning the stethoscope directly above the artery incorrect placement will result in too low of a systolic and too high of a diastolic pressure measurement, and d) Incorrect interpretation of the sounds heard. There are many more ways to obtain inaccurate results such as trying to obtain a measurement in a noisy environment, not supporting the arm at the correct level, wrong definition of systole or diastole, not pumping high enough, releasing the pressure too rapidly, too much (or even too little) finger pressure on the stethoscope, manometer not at eye level, hand not palm up. The point is that it is easy to obtain an inaccurate measurement without realizing it, and a correct measurement is only obtained with a great deal of attention being paid to every detail. This attention is seldom present in a clinical environment [3]. Definitions of hypertension are constantly changing but, generally, if systolic BP is consistently greater than 160 mmHg or diastolic BP more than 95 mmHg, a person is considered to be hypertensive [4]. Hypertensive responders have a long term medical condition in which the BP in the arteries is persistently elevated [5], they are characterized by a dramatic rise in systolic blood pressure during aerobic exercise [6]. Systolic hypertension may or may not be present at rest. Measuring BP in hypertensive in a clinical environment, accuracy may be of high importance. Even a few mmHg can make the difference between being prescribed medication or just having the blood pressure monitored. In general, if the measurement is erroneously low, for example, the patient may be denied the most valuable drug treatment to prevent future stroke and heart attack, whereas if, on the other hand, the measurement is incorrectly high, the individual may be commenced on lifelong blood pressure lowering drugs unnecessarily, with side effects. Unfortunately, some of the least accurate measurements (auscultatory) take place in the clinical environment where accuracy is most important [7]. Therefore, accurate measurement of arterial pressure is necessary for diagnosis of hypertension and for assessment of its therapy. It has also shown to be valuable for defining the effects of antihypertensive drugs therapy. Results of such studies are crucial for advancing antihypertensive management [8]. On the other hand, Invasive measurement is the only direct measurement of blood pressure which in theory this measurement could be highly accurate. Thus, the purpose of the present study was to compare the intra-arterial method with the auscultator conventional sphygmomanometer at rest, on a treadmill and bicycle peak aerobic exercises in hypertensive responders taking medications.

Methods

Subjects: Eight adult males (41.9 ± 2.0 years) with documented hypertensive response to graded treadmill exercise volunteered to participate in this study. Criteria for hypertensive response to exercise were: a) A minimum increase in systolic BP of 60 mmHg above rest and a peak systolic BP ≥ 220 mmHg, or, b) a minimum increase in diastolic BP of 20 mmHg above rest and a peak diastolic BP ≥ 100 mmHg. All eight subjects met the criterion for hypertensive systolic BP response. Three subjects also met the criterion for hypertensive diastolic BP response. Three subjects were hypertensive at rest (systolic BP ≥ 140 mmHg and/or diastolic BP ≥ 90 mmHg). Four subjects were taking medications; three took diuretics and one took a beta-adrenergic blocker. These subjects were screened and tested while taking their dosages. Time of day in which medication was taken and exercise tests were administered was kept constant throughout the study. All subjects were in good health, physically active for at least 12 months (12.1 ± 1.2 METs work capacity) and none were members of competitive team. Findings from standard physical examination were normal in all subjects except accentuation of the aortic component of the second heart sound. Resting 12-lead electrocardiogram revealed normal sinus rhythm in all. However, left ventricular hypertrophy was found in all subjects using the electrocardiographic surrogates [9]. A written consent form was obtained from each subject, approved by the Clinical Science Center Committee on Human Subjects.

Procedures and measurements: Subjects reported to the lab two times. On the first session, subjects were given a brief explanation on the experimental procedures and potential risks. They were given a verbal reminder not to drink coffee, smoke, or perform intensive physical activity 24 hr prior to testing. During the second session all subjects underwent two stresses test one on a treadmill and the other on a bicycle. Heart rate and electrocardiogram were monitored continuously, using a Burdick Eclipse 400 3-channel, 12-lead ECG recorder system, and oscilloscope. Five-second recordings were obtained at rest and at peak exercises. Measurements of direct and indirect blood pressures were taken simultaneously at rest and at peak treadmill and bicycle exercises. The auscultatory BP was monitored using a standard sphygmomanometer cuff and mercury manometer mounted at eye level [10]. Auscultation was determined using a modified stethoscope with 60-cm conduction tube connected to anesthesia diaphragm secure over the brachial artery of right arm with Velcro strap [1]. Systolic BP was defined as the first audible Korotkoff sound while diastolic BP was accepted either as 5th (disappearance) or phase 4th (muffling) if 5th phase was indeterminate. The direct BP was taken from the brachial artery of the left arm. The anticubita surface was prepared with Betadine and alcohol and 1% Lindocaine. Local anesthetic was infiltrated over the brachial artery. A physician then inserted a 20-gauge, 11/4" Jelco cathelon catheter percutaneously into the brachial artery two to three centimeters distal to the antecubital fossa. The indwelling 20-gauge brachial artery catheter was coupled with 20 cm polyethylene that was maintained at right artery level. The transducer system showed a linear static calibration response that was flat to 25 Hz with a damping coefficient of 0.25. Arterial blood pressure was continuously recorded on the Gould recorder at a paper speed of 10 mm sec^{-1}. The exact time of the indirect pressure was recorded and marked on the Gould recorder, taken at the same time using an electrical event marker. In addition, the intra-arterial system was calibrated prior to each kind of exercise performed by each patient. Systolic and diastolic pressures were calculated from the numerical average of consecutive arterial pulse pressure within a 5-second interval at the marked points described above [1,11].

Exercise protocols: Comparisons were made with simultaneously determined intra-arterial catheter and auscultation measurements on a treadmill and bicycle. Resting time between the tests was 90 minutes and the order of testing was balanced over subjects. Following warm-up, patients underwent one test on a graded maximal treadmill test utilizing the standard Bruce Protocol [12]. The other maximal exercise test was performed on an electrical cycle ergometer. The initial load on the electrical cycle ergometer was 50 watts which thereafter the load was increased by 25 watts. Maximal tests were terminated by the following criteria: a) Attainment of the age predicted maximum heart rate, b) When the subject could not keep up with the load, and abnormal ECG responses according to the guidelines of the American College of Sports Medicine [13].

Statistical Methods

The bivariate correlation coefficient was employed to evaluate the validity of the indirect measurement of BP as predictor of direct intra-arterial BP.

Discussion

The present study demonstrated that at rest and peak dynamic exercises systolic BP values reached by the indirect method correlated highly with the direct recordings. But, a low correlation between indirect method and direct method was observed for diastolic BP at peak treadmill and bicycle tests. Measurement of arterial BP can be divided into invasive and non-invasive methods. The method of obtaining the most accurate reading of resting and during aerobic exercise BP is invasively through an arterial line [1]. Measurement of arterial pressure by conventional Sphygmomanometer is subject to error, including faults in the instrumentation and the use of an occluding cuff of incorrect size. The measurements in the present study for systolic and diastolic BPs at rest using the auscultatory method with standard cuff, are acceptable, still subject to error. Sources for error are the uncertainty in interpreting the Korotkoff sounds during systole and diastole. This may be due to intensity and distinction [14], uncalibrated or damaged equipment or by using the wrong equipment. Mercury manometers, for example, can yield inaccurate readings if the air vent at the top of the column is clogged or the mercury has oxidized, Incorrect cuff size [1,14] and variations in blood pressure during the respiratory cycle, which has an inherent difference between auscultation blood pressure, which is determined at one distinct point in the respiratory cycle and direct BP over several respiratory cycles

[15]. In addition, when BP is measured in an environment with low temperature BP readings may be higher than expected [16]. These problems may be worse and more serious depending on the mode and intensity of exercise and motion artifact that influence the fluctuation of BP during exercise [14]. Thus, the reliability of the sphygmomanometer method in recording arterial pressure during exercise is frequently questioned, although some investigators [17] have found that systolic BP in the brachial artery correlates highly with left ventricular pressure. It has been observed that on moving from the central aorta to peripheral arterial sites, systolic BP increases, and diastolic BP decreases, thus mean arterial BP remains relatively unchanged [1]. The relationship between central and peripheral atrial pressure is not constant among hypertensive individuals and may be influenced in a major way by changes in peripheral vascular impedance and since systolic hypertension may or may not be present at rest, accurate recording of brachial systolic BP at rest and during exercise is essential for the interpretation of the results. These BP measurements may be used as an indicator of the force opposing the left ventricle ejection [18,19].

In the present study, mean systolic BP measured by means of auscultation, were higher in all conditions measured compared to those readings of the intra-arterial, but we did not feel that this differences were clinically significant. It seems that a 10-20 mmHg discrepancy in systolic pressure should not affect a decision making.

The high correlations between the direct and indirect methods in the present study, during the aerobic tests is due to the effect of exercise in rendering Korotkoff sounds louder and more distinctly, thus, enabling the reading of systolic BP by auscultation close to the point at which sounds begin, and blood starts to flow through the obstructed artery. This finding may suggest that when measuring contractility in hypertensive patients during aerobic exercise by the end systolic volume-pressure ratio, the validity of the systolic BP defined by the auscultatory method will correctly represent the intra-arterial systolic BP value.

At rest we found that the intra-arterial diastolic pressure was 8 mmHg lower than that measured by the indirect method with acceptable correlation (r=0.82). This result is in agreement with the reported values previously [20] in which auscultatory diastolic blood pressure was higher 4 mmHg than that measured by the intra-arterial method. Aerobic exercise dilates muscular arteries and reduces arterial pressure augmentation [21], an effect that will ultimately enhance ventricular-vascular coupling and reduce the pressure load on the left ventricle. The sympathoadrenal and renin-angiotensin systems play an important role in BP control and regulation of cardiovascular function during exercise [22]. However, in the present study, the differences between the means of the two methods were with low correlations and with higher values in the indirect one. The reasons for these discrepancies is the increase in artifact motion during exercise testing which dampens and may mask the auscultatory Korotkoff-sounds, thus making detection of the proper Korotkoff-sounds during exercise difficult at best. Furthermore, the presence of inaudible Korotkoff-sounds may further explain the published discrepancies between auscultatory and intra-arterial blood pressure measurements during exercise [23]. These problems (particularly the latter) may be further aggravated during exercise because of the problems of ambient noise and motion artifact. Problems with motion and noise artifact have prevented reliable quantification of arterial pressure during exercise. This results are in agreement with previous studies during dynamic and isometric exercises demonstrating low diastolic correlation between the two methods [1,11]. Emerging evidence that nonfatal and fatal cardiovascular diseases increase progressively with higher levels of BP [24] makes early identification of persons at increased risk for developing hypertension a priority. It has been suggested that the development of hypertension is preceded by a pre-hypertensive state that may be manifested by abnormal dynamic physical stress tests [25], widely used in hospitals. However, most studies have chosen to define exaggerated BP response only by the auscoltatory method to determine BP level at maximal effort [25]. These methodological uncertainties may make it unclear whether the information gathered from exercise BP measurement is valuable for evaluating an individual's hypertensive risk profile.

Results

All patients completed both tests achieving heart rate values of 178 ± 16 beats min^{-1} (range 152-204), without difficulty or abnormal symptoms, dysrhythmias or electrocardiographic abnormalities. Mean descriptive data are presented in Table 1.

	Variable	Range
N of cases	8	-
Age (years)	41.9 ± 2.0	25-54
Weight (kg)	85.0 ± 9	66-106
Height (cm)	177.0 ± 10.1	165-187
Fat (%)	19.2 ± 7.1	14-24
Heart rate (beats min^{-1})	73 ± 10.0	60-90
Work capacity (METs)	12.1 ± 1.2	11-14

Table 1: Descriptive data of the hypertensive patients (values are mean ± SD).

Table 2 presents the means and standard deviations of the simultaneous direct and indirect BP measurements in eight hypertensive responders at rest, peak treadmill and bicycle.

Condition	Variable	Method	Correlation	Means ± SD	test	P value
Rest	systolic	Direct	0.85	134 ± 6	1.57	N. S
		Indirect	-	139 ± 7	-	-
	Diastolic	Direct	0.82	88 ± 11	5.71	P<0.02
		Indirect	-	96 ± 9	-	-

Treadmill	Systolic	direct	0.90	189 ± 9	8.4	P<0.05
		Indirect	-	198 ± 11	-	-
	Diastolic	direct	0.40	105 ± 9	9.6	P<0.05
		Indirect	-	112 ± 12	-	-
Bicycle	Systolic	direct	0.92	196 ± 9	11.8	P<0.05
		Indirect	-	204 ± 10	-	-
	Diastolic	direct	0.58	107 ± 9	3.1	P<0.05
		Indirect	-	112 ± 12	-	-

Table 2: Descriptive statistics (mean ± SD) of systolic and diastolic pressures measured simultaneously by auscultation and intra-arterial methods.

It discloses that at rest mean systolic BP recorded indirectly did not differ significantly from those measured directly.

At peak treadmill and the bicycle mean systolic BPs recorded indirectly were significantly ($P<0.05$) higher than those measured directly. The diastolic auscultatory readings did not differ significantly between methods at rest. However, at peak of both exercises the intra-arterial values observed were significantly $P<0.05$ lower than those of the indirect measurement. In addition, Table 2 reveals that analysis of the data using coefficient of correlations between systolic corresponded cuff and intra-arterial BPs are very high. Correlation for diastolic blood pressure, on the other hand, correlated well at rest ($r=0.82$) and somehow for bicycle ($r=0.66$). However, at peak treadmill exercise the correlations were low ($r=0.40$).

Conclusions

The medications (diuretics and beta-adrenergic blocker) did not influence the BP measurements in hypertensive responders. the validity of an auscultation method at rest and peak aerobic exercises, for predicting future hypertension is reliable for systolic blood pressure, while except for readings at rest, during peak dynamic exercises it is not trustworthy for the definition of diastolic blood pressure.

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