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ORIGINAL ARTICLE

How well do office and exercise blood pressures predict sustained hypertension? A Dundee Step Test Study

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Exercise systolic blood pressure (BP) appears to be a better predictor of cardiac mortality than casual office BP. We tested whether this could be explained by exercise systolic BP being a better predictor of sustained hypertension than casual office BP. Exercise systolic BP was measured using the lightweight 3-min single stage, submaximal Dundee Step Test in 191 consecutive subjects (102 male, age 52 (s.d. 13) years) who were referred to a specialist hypertension clinic for assessment. Exercise systolic BP was compared with office BP and daytime ambulatory BP (ABP). Sustained hypertension was defined as a mean daytime systolic and/or diastolic ABP of ⩾140/90 mm Hg. Receiver operating characteristic (ROC) curves of exercise systolic BP and office BP in predicting sustained hypertension were compared. The positive predictive value of office diastolic BP ⩾90 mm Hg and office systolic BP ⩾140 mm Hg for sustained hypertension were 64% and 67% respectively. However, exercise systolic BP ⩾180 mm Hg had a positive predictive value of 76%. Twenty-two percent (42/191) of subjects had an exercise systolic BP rise to ⩾210 mm Hg, and 93% of this group had sustained hypertension on ABP. Whilst exercise systolic BP was a better predictor of sustained hypertension using currently recommended office BP treatment thresholds, the ROC curves of these indices were not different. In a multiple regression analysis, exercise systolic BP was an independent predictor of sustained hypertension, accounting for 36% of the variance of daytime systolic ABP after adjusting for age, gender and antihypertensive drug treatment. In conclusion, exercise systolic BP was a marginally better predictor of sustained hypertension than office BP. This may partly explain why exercise systolic BP is a potent predictor of cardiac mortality.
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Introduction

Resting blood pressure (BP) measured in the office setting does not always reflect the BP profile throughout the day, especially when an individual leads an active life. This problem with office BP is further compounded by the presence of the 'white coat effect', that is, the reactive rise in BP that occurs in the office environment.[1] This effect is present in subjects with white coat hypertension and also occurs in sustained hypertension where it complicates therapeutic decision making.[2,3] Whether hypertension should continue to be managed by measuring office BP is increasingly being questioned.[4–6] Ambulatory BP monitoring (ABP) allows the assessment of BP over a more prolonged period, and the mean of ABP readings correlates more closely with target organ damage[2,7] and outcome.[6] However, ABP is expensive, uncomfortable, and usually only available in specialist centres.[8] Another potential BP assessment method is the exercise BP. Although exercise BP has been shown to be more potent than casual office BP in predicting target organ damage[9] and of cardiac mortality,[10,11] it has not yet entered clinical practice. We have assessed the diagnostic value of exercise BP, obtained using the 3-min Dundee Step Test,[12] and office BP, in predicting whether sustained hypertension was present in a population of patients referred to a specialist hypertension clinic.

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Subjects and methods

Participants

We studied consecutive subjects referred to our specialist hypertension clinic during a 14-month period between May 1998 and July 1999. These subjects all had raised office BP readings (⩾160/90 mm Hg) confirmed over a period of at least 3 months prior to their referral by primary-care physicians. We excluded subjects who were unable to exercise or who had seated office systolic BP ⩾200 mm Hg. Prior to being studied, subjects who were taking antihypertensive therapy had their treatment withdrawn for at least 1 week if there were no contraindications, such as previous history of accelerated

hypertension, ischaemic heart disease or cerebrovascular disease.

Blood pressure measurements

BP was measured in triplicate by trained hypertension research nurses using a standard mercury sphygmomanometer at 1-min intervals after patients had been sitting quietly for 2 min. The mean of these three readings was used to define office BP. Each patient then underwent a 3-min single-stage submaximal Dundee Step Test, the methodology of which has been described elsewhere.[12] An ABP (Spacelabs 90207, Redmond, WA, USA) was then obtained from each patient on an active day.[13] Daytime (08.00–22.00, BP sampling every 15 min) mean systolic ABP of ⩾140 mm Hg and/or mean diastolic ABP of ⩾90 mm Hg defined sustained hypertension.

Statistical methods

Data on BPs were recorded as mean and standard deviation. The sensitivity, specificity and positive predictor value (PPV) for levels of ABP predicted by different thresholds of office BP and exercise systolic BP were calculated and tabulated. The relationship between systolic ABP, office systolic BP and exercise systolic BP were assessed in a multiple linear regression with systolic ABP as outcome.[2,6,7] The assessment of fit was given by the value of the R-squared, that is, the proportion of variability of the outcome explained by the predictor(s). Possible confounding variables adjusted for in the regression analysis were age, gender, and an indicator of whether drug treatment continued or had been stopped. In order to assess the assumption of normality for the outcome in the regression analysis, the studentised residuals were plotted against the predicted systolic ABP. A linear relationship was assumed for predictors with the systolic ABP. The functional form of this relationship was assessed by fitting a cubic smoothing spline.[14] All statistical analyses were carried out using SAS version 6.12.

Results

General characteristics

We studied 191 consecutive hypertension clinic referrals (102 male, mean age 52 (s.d. 13) years). Of that number, 62.3% (119/191) of subjects were assessed taking no drug treatment. Sustained hypertension on ABP was present in 61.3% (117/191) of subjects. The remaining patients either had white coat hypertension, were normotensive on no treatment or had controlled treated hypertension. The mean (s.d.) office, exercise systolic and ambulatory BP values of the study population were 168 (23)/103 (11) mm Hg, 187 (27) mm Hg and 143 (16)/89 (11) mm Hg respectively.

Prediction of sustained hypertension

The current standard in research and practice, ie, an office diastolic BP ⩾90 mm Hg had a sensitivity of 96% but a very low specificity of 12% in predicting sustained hypertension (Table 1). Office systolic BP also had low specificity. Exercise systolic BP had better predictive power of 76% if the threshold of 180 mm Hg[12] was exceeded and even better if 210 mm Hg was exceeded. The PPV of exercise systolic BP was higher than that of office diastolic or systolic BPs at the recommended treatment thresholds. The use of exercise systolic BP of 180 mm Hg thus represented nearly a 20% gain in diagnostic power over that of office diastolic BP (⩾90 mm Hg) in our study population. Excluding subjects with isolated systolic hypertension (systolic ABP ⩾140 mm Hg and diastolic ABP <90 mm Hg, $n = 29$) and isolated diastolic hypertension (systolic ABP <140 mm Hg and diastolic ABP ⩾90 mm Hg, $n = 6$) did not significantly alter the sensitivity or specificity of either office BP or exercise BP. By increasing the exercise systolic BP threshold to ⩾210 mm Hg, the PPV improved to 93%, represented by 22% (42/191) of the study population.

The further a receiver operating characteristic (ROC) curve bends toward the left upper corner of the graph, the more discriminating was the test (Figure 1). There appeared to be a trend in the order of exercise systolic BP, office systolic BP and office diastolic BP in better predicting sustained hypertension. However, the ROC curves of these indices were not different, with areas under the ROC curves of 0.776, 0.764 and 0.748 for exercise systolic BP, office systolic BP and office diastolic BP respectively.

Regression analysis

Variables were entered in a multiple linear regression. Plots of the residuals against predicted systolic ABP showed that these were approximately normally distributed. When office systolic BP was regressed on systolic ABP as outcome there was a highly significant ($P < 0.0001$) positive relationship.

Table 1 Blood pressure thresholds and the prediction of the presence of sustained hypertension

	BP thresholds (mm Hg)	*Sensitivity (%)*	*Specificity (%)*	*Positive predictive value (%)*
Office BP measurements				
Diastolic BP	90	96	12	64
Systolic BP	140	97	22	67
	150	93	42	72
	160	77	60	75
Exercise systolic BP	180	80	59	76
	210	33	96	93

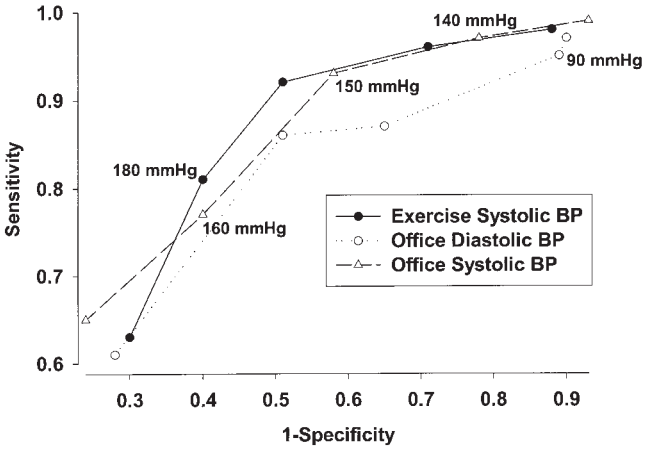

Figure 1 Receiver operating characteristic curves (ROC) for exercise systolic blood pressure and office blood pressure in predicting sustained hypertension.

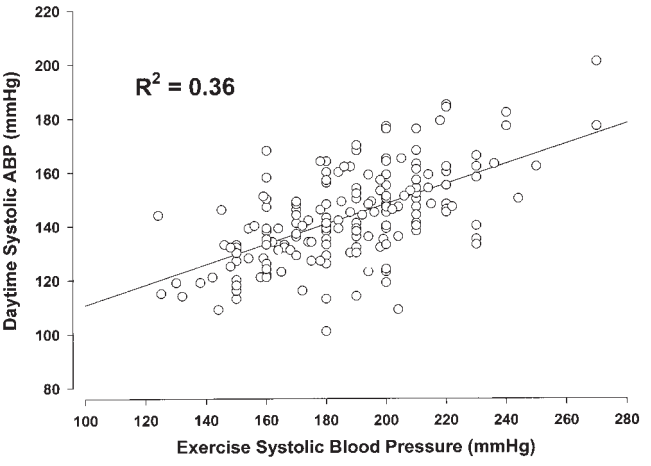

Figure 2 Exercise systolic blood pressure as a linear predictor of mean daytime systolic ambulatory blood pressure.

Office systolic BP accounted for 33% of the variation in systolic ABP. However, when exercise systolic BP alone was regressed on systolic ABP, this was also highly significant ($P < 0.0001$) with an increased amount of variation explained (36%). An increase of 10 mm Hg in exercise systolic BP was associated with an increase of 3.7 mm Hg in mean daytime systolic ABP. Adjusting for age, gender, and drug treatment did not appreciably change the significance of these results. When these factors were considered individually, only age was weakly but significantly associated with systolic ABP ($R^2 = 2.4\%$, $P = 0.018$). Neither gender ($P = 0.073$) nor drug treatment ($P = 0.173$) were significantly associated with systolic ABP. When office systolic BP and exercise systolic BP were assessed simultaneously as predictors of systolic ABP, both variables remained statistically significant in the multiple linear regression adjusting for age, gender and treatment (Table 2). The partial correlation coefficient between exercise systolic BP and systolic ABP after adjusting for office BP was 0.28. When the office BP residuals after regression on systolic ABP was plotted against exercise systolic BP residuals after regression on systolic ABP, a significant correlation was also found ($r = 0.885$, $P < 0.001$). Thus, exercise systolic BP was a significant predictor of ABP, independently of office systolic BP despite the high collinearity between these two indices. Figure 2 shows the regression line obtained. Fitting a smoothed cubic spline demonstrated that the assumption of an approximate linear relationship was justified.

Discussion

Exercise BP obtained using the 3-min Dundee Step Test provided marginally greater diagnostic certainty in determining whether an individual has sustained hypertension. This is in contrast with office BP which had very low specificity for sustained hypertension, suggesting that it lacked the ability to discriminate against the 'white coat effect'. The independent predictive value of exercise BP is relevant because systolic ABP has consistently been shown to have greater prognostic value than office BP or diastolic ABP.[2,7] The prognostic value of exercise BP may thus be partly explained by its ability to predict the daily BP 'load' which causes target organ damage. Exercise testing also helps to identify treated hypertensive patients with 'controlled' resting office BP, but uncontrolled exercise BP,[15] who may continue to have further target organ damage and adverse outcome.[16–18]

An exercise test may unmask abnormal underlying haemodynamics pathognomonic of the hypertension disease process. Hypertensive individuals have impaired peripheral vasodilation during exercise and this leads to uncontrolled BP rise.[9]

Table 2 Results of adjusted and unadjusted linear regression on systolic ABP as outcome

Predictor	*Unadjusted regression coefficient (s.e.)*	*P-value*	R^2	*Adjusted regression coefficient (s.e.)*	*P-value*	R^2
Office systolic BP	0.409 (0.042)	0.0001	0.33	0.214 (0.068)	0.002	0.39
Exercise systolic BP	0.374 (0.036)	0.0001	0.36	0.218 (0.059)	0.0003	0.39
Age	0.221 (0.093)	0.018	0.02	–0.014 (0.087)	0.869	0.39
Gender	4.312 (2.385)	0.072	0.01	2.963 (1.902)	0.121	0.39
Treatment	3.500 (2.481)	0.160	0.01	2.101 (2.177)	0.336	0.39

s.e., standard error.

Importantly, exercise BP relates better to cardiac mortality[10,11] than office BP, and it also identified normotensive individuals who are more likely to develop hypertension in the future.[9,19] Furthermore, exercise BP may assess the sum total of the effects of traditional coronary risk factors such as hypercholestrolaemia and glucose intolerance on the peripheral vasculature.[20] Whether treating hypertension guided by exercise BP improves outcome is currently being assessed in a randomised controlled trial which will report in 5 years' time.[21]

Our study population was limited to patients referred for hypertension assessment in a tertiary centre. Hence the findings of this study cannot be extrapolated to the general population. Others[9,19] however have assessed exercise BP in the general population and have found that it is of prognostic value over and above that of office BP. It is likely that our findings would be reproducible in the wider population. Nonetheless, routine exercise BP assessment can not be recommended at present to detect sustained hypertension in clinical practice as its value over that of office BP was only marginal, and it was dependent on the treatment thresholds. Furthermore, the office BP in this study was not assessed on multiple occasions which might increase its predictive value of sustained hypertension although in some patients the 'white coat effect' might not habituate even with repeated visits, therefore the need for ABP.

The assessment of office BP and exercise BP in this study was not randomised, but was sequential within a single visit in each patient. As such, it was unlikely that a 'learning effect' for exercise BP measurement would have occurred. Even if it did, this would be minor and systematic in nature. About one-third of patients were assessed on treatment. Again, this should not represent a methodological issue since the primary objective of the study was to relate office and exercise BPs to ABP within individuals, irrespective of the treatment status. In other words, the fact that each patient had all the BP assessments (office BP, exercise BP and ABP) done at the same visit, each patient effectively acted as his or her own control. However, beta-blockade in particular would blunt BP rise during exercise, hence beta-blockers could potentially reduce the predictive value of exercise BP in defining sustained hypertension. Reassuringly, the multiple regression analysis suggested that drug treatment as a whole did not influence our findings although our study was not designed to assess the effect of individual drugs on office or exercise BPs.

Conclusions

Exercise BP measured using the Dundee Step Test was a marginally better predictor of sustained hypertension at the currently recommended treatment thresholds for office BP.

Contributors

POL and TMM conceived, carried out the project and prepared the manuscript. PTD analysed the data and took part in preparing the final draft.

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