# Exercise Stress Testing In Blood Pressure Evaluation

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*Abstract*: The purpose of this study was: (1) to confirm exercise stress testing as a standard in the diagnosis of hypertension, (2) to clarify which measurements during exercise testing are most reliable, and (3) to refine the definition of normal blood pressure response during ergometric exercise testing.

Blood pressure response during maximal ergometric exercise testing was observed in 183 persons with no history of hypertension, 176 persons with borderline blood pressure readings, and 60 established hypertensives.

Men and women had significantly different blood pressure response to exercise ($P < 0.05$). Comparison of blood pressures at 100-watts workload, at peak exercise, and 5-minutes postexercise provided significant information for distinguishing between normal, borderline, and established hypertensive persons ($P < 0.025-0.001$). Comparing the slopes of pulse rate versus blood pressure linear regression curves was not helpful. Regression equations generated for predicting correct blood pressure classification improved classification accuracy (compared with random classification) by 44.9 percent in men and by 66.8 percent in women.

The results showed that ergometric stress testing in blood pressure evaluation is a safe and reliable procedure for aiding in a more accurate diagnosis of hypertension. (J Am Bd Fam Pract 1989; 2:161-8.)

The cardiovascular consequences of hypertension depend not only on resting blood pressure values but on blood pressure peaks induced by daily activity, exercise, and emotional responses.[1-3] It has been consistently shown that random resting blood pressure measurements are extremely variable in normal persons and even more variable in established and borderline hypertensives.[4] For these and other reasons, several authors have increasingly stressed the usefulness of exercise stress testing for the diagnosis of hypertension.[5-11]

Franz, in *Ergometry in Hypertensive Patients*, stated that determination of blood pressure response during standardized ergometry is clearly superior to resting blood pressure in diagnostic accuracy and specificity.[9] In contrast to random resting blood pressure measurements, this method controls the level of physical and (to some extent) psychological stress and provides comparable and reproducible information.

It has been suggested that exercise testing can be used to differentiate patients with borderline benign blood pressure elevations from those who will develop sustained hypertension[1,12-14] and also to predict which normal persons will develop clinically significant hypertension in the future.[5,15-19] Retrospective studies have suggested that 10 to 25 percent of persons with borderline hypertension may progress to sustained hypertension,[20] and two recent studies have reported that 80 to 97 percent of borderline hypertensives who react abnormally to exercise testing will develop established hypertension within 4 to 5 years.[4,21]

Different measurements have been recommended by a number of authors as best suited for diagnosis. Franz has argued that the most important measurements are: (1) blood pressure at a workload equal to 100 watts, and (2) blood pressure at 5-minutes postexercise.[9] Chaix[12] and Toto-Moukouo[22] have suggested that the slopes of blood pressure-heart rate linear regression curves during exercise are significantly different in hypertensive versus normal populations. Others suggest the analysis of blood pressure at peak workload.[6,13] The normal blood pressure response during exercise has been defined using a variety of protocols and endpoints[18,23-35] (Table 1).

The goals of this study were: (1) to confirm exercise stress testing as a standard in the evaluation of hypertension, (2) to clarify which measurements during exercise testing are most reliable, and (3) to refine the definition of normal blood pressure response during ergometric exercise testing.

## Methods

### Patient Characteristics

Patients included in this study were selected from a private family practice medical office between June 1986 and August 1988. Their stress tests

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were performed for a number of indications including chest pain, hypertension, and palpitations. Other stress tests were done on asymptomatic persons before they began a regular exercise program. None of the persons included in the study took medications that would affect blood pressure, and none had clinically important cardiovascular disease.

Patients were assigned to one of three blood pressure subgroups: (1) normal, (2) borderline, or (3) established hypertension. Those who were classified as normal had no history of hypertension. Persons were considered borderline if their blood pressure was 90 mmHg or greater on at least three out of six random diastolic blood pressure readings. Established hypertensives had at least

**Table 1.** *Summary of Studies Defining Normal Blood Pressure Response during Exercise.*

| Author | Year | Peak Blood Pressure (± 1 SD) | Subgroup | Number in Subgroup (if appl.) | Comments |
|---|---|---|---|---|---|
| Fraser, et al.[23] | 1954 | 129 (12)/64 (7) | Women 22–30 years | 11 | Treadmill — 3 mph @ 5% grade 10 minutes |
| | | 132 (19)/74 (11) | Men 18–39 years | 19 | |
| | | 141 (17)/69 (6) | Men 40–57 years | 11 | Intraarterial BP |
| Astrand[17] | 1965 | 212 (23)/96 (13) | Men mean age = 54 years | 80 | Ergometer to pulse rate >130 mmHg. |
| | | 196 (22)/96 (13) | Women mean age = 54 years | 103 | |
| Sannerstedt[24] | 1966 | 200 (15)/* | Men & Women | 87 | Ergometry to exhaustion<br>Intraarterial BP |
| Al-Eshaiker, et al.[34] | 1967 | 216 (17)/85 (16) | Men 20–30 years | 50 | Ergometry to exhaustion |
| Saltin, et al.[25] | 1969 | 185 (23)/* | Men | 42 | Ergometer to onset of blood lactate accumulation |
| Bruce, et al.[26] | 1974 | 185 (22)/71 (17) | Men mean age = 44.5 years | 1275 | Treadmill — Bruce protocol exhaustion |
| Pollack[27] | 1976 | 169 (10)/71 (10) | Balke protocol | | 51 males mean age = 40.5 |
| | | 177 (23)/75 (12) | Bruce protocol | | Various treadmill protocol |
| | | 175 (22)/77 (11) | Ellestad protocol | | |
| | | 176 (24)/77 (10) | Astrand protocol | | |
| Irving, et al.[28] | 1977 | 187 (22)/73 (19) | Men | 2532 | Treadmill — Bruce protocol exhaustion |
| | | 165 (2)/78 (12) | Women | 244 | |
| Wolthuis, et al.[35] | 1977 | 208 (*)/90 (*) | Men mean age = 37 years | 704 | Treadmill — Balke protocol exhaustion. Peak BP listed value for 90th percentile |
| Eriksen, et al.[29] | 1980 | 213 (*)/* | Men 40–60 years | 1004 | Ergometer to 90% predicted maximum |
| Franz, et al.[30] | 1982 | 188 (14)/92 (9) | Men 20–50 years | 173 | Ergometer to 100-watt workload |
| | | 185 (15)/93 (7) | Women 20–50 years | 150 | |
| Jackson, et al.[19] | 1983 | 183 (26)/* | Men mean age = 46 years | 3479 | Retrospective study |
| | | 159 (26)/* | Women mean age = 48 years | 1377 | Ergometer and treadmill to exhaustion. 20% of cohort are hypertensive |
| Hansen, et al.[31] | 1984 | 182 (23)/92 (11) | Men 34–74 years | 43 | Ergometer to exhaustion |
| | | 207 (27)/99 (12) | | | Intraarterial BP |
| Karlsson, et al.[32] | 1985 | 187 (16)/* | Men mean age = 33 years | 32 | Ergometer to onset of blood lactate accumulation |
| Rasmusen, et al.[33] | 1985 | 177 (*)/81 (*) | Indirect BP | | Erogmeter to exhaustion |
| | | 203 (*)/97 (*) | Intraarterial BP | | 10 men mean age = 32.6<br>17 women mean age = 32.2 |

*Data not available.

**Table 2.** *Patient Characteristics by Subgroup.*

|  | Normal | Borderline | Established Hypertension |
|---|---|---|---|
| Men | 106 | 115 | 51 |
| Women | 79 | 61 | 9 |
| Total | 185 | 176 | 60 |
| Age ±1 SD | 47.45±10.14 | 46.93±8.91 | 47.45±10.45 |
| Men | 48.14±10.12 | 46.06±8.60 | 47.80±11.02 |
| Women | 46.53±10.15 | 48.56±9.33 | 45.44±6.42 |
| Resting blood pressure mean (± 1 SD) |  |  |  |
| Men | 117 (14)/79 (9) | 130 (14)/89 (8) | 139 (12)/96 (7) |
| Women | 109 (16)/74 (10) | 130 (14)/88 (8) | 137 (12)/93 (8) |
| Race (men/women) |  |  |  |
| White | (94/66) | (102/53) | (38/4) |
| Hispanic | (10/13) | (12/8) | (11/2) |
| Oriental | (2/0) | (1/0) | (2/1) |
| Black | (0/0) | (0/0) | (0/2) |

four out of six random diastolic blood pressure readings above 94 mmHg.

Average age was 47.23 years (±9.67). There were 272 men and 149 women; 357 whites, 56 Hispanics, 6 Orientals, and 2 blacks. One hundred eighty-five had normal blood pressure, 176 were borderline, and 60 were established hypertensives. Characteristics by subgroup (including mean resting blood pressures values) are shown in Table 2.

### *Protocols*

Before testing, each person completed an exercise history questionnaire and signed an informed consent. When contraindications[36] were identified, testing was not performed.

Resting and hyperventilation ECGs were recorded after three baseline blood pressures were obtained with a mercury manometer in which the arm was positioned at the horizontal level of the fourth intercostal space with the manometer at the same level. The width of the cuff used was based on the circumference of the midpoint of the arm as described in the guidelines published by the American Heart Association.[37] The fifth phase (disappearance of sound) of the Korotkoff sounds was used to determine diastolic pressure.

Testing was performed on a Bosch microprocessor-controlled ergometer (Model Erg 550), which allows workload to be independent of pedal speed. It is more accurate for blood pressure measurement than a treadmill system because of a lower noise level and greater stability of the upper body.

Maximum oxygen consumption was estimated[38] and converted to expected maximal workload. A workrate increment was selected that would result in a test lasting between 6 and 12 minutes. In order to obtain meaningful comparisons among different age groups, it is necessary to reach a heart rate equal to at least 85 percent of the estimated maximal heart rate.[19] Data from 23 persons who were unable to perform to this level were not included in these results. We experienced no significant problems in relation to persons being unable to perform on the ergometer, nor did any complications arise during testing.

Using a modified Balke protocol, the workload was increased at 1-minute intervals in 25 to 50-watt increments. During the test, the 12-lead ECG was constantly monitored by a 3-channel oscilloscope (Marquette Case 12 system), and an ECG was printed at 1-minute intervals. Blood pressure and pulse rate were monitored each minute. Supine ECGs and blood pressures were recorded at 1-minute and 5-minutes postexercise.

### *Linear Regression and Statistical Analysis of Blood Pressure Response*

Variables included in the statistical analysis were resting, 100-watt, peak, and recovery blood pressure values.

Linear regression curves were calculated using the method of least squares. Linear regressions

**Table 3.** *Mean Blood Pressure Results (± 1 SD) by Blood Pressure Subgroup.*

| Subgroup | n | Blood Pressure 100 Watts | Blood Pressure Peak | Blood Pressure Recovery |
|---|---|---|---|---|
| Normal | | | | |
| Men | 106 | 160 (25)/92 (11) | 202 (25)/101 (12) | 134 (22)/76 (9) |
| Women | 79 | 156 (23)/91 (11) | 168 (23)/93 (10) | 122 (22)/73 (11) |
| Borderline | | | | |
| Men | 115 | 170 (21)/100 (9) | 217 (27)/109 (10) | 150 (29)/84 (10) |
| Women | 61 | 181 (21)/105 (8) | 196 (21)/109 (9) | 139 (20)/84 (8) |
| Established | | | | |
| Men | 51 | 186 (20)/112 (10) | 230 (20)/121 (10) | 160 (25)/93 (11) |
| Women | 9 | 196 (33)/112 (10) | 218 (22)/126 (26) | 147 (22)/92 (5) |

and correlation coefficients were calculated for pulse rate versus systolic blood pressure and for pulse rate versus diastolic blood pressure. Linear regression data that were retained exhibited significantly positive correlation coefficients ($r > 0.63$).

Means and standard deviations were calculated separately for men and women in each subgroup. An analysis-of-variance model was used to compare subgroups. When appropriate, post-hoc testing was performed using the Scheffé multiple comparison procedure. Finally, discriminant analysis was done using a regression classification technique. Regression equations for each subgroup were generated retaining independent variables with $F$ probability $< 0.10$.

## Results

### *Descriptive Statistics*

Mean results for blood pressure values are listed in Table 3, and 90th percentile values for these parameters are presented in Table 4. Table 5 shows mean results for the slopes of the pulse rate versus blood pressure linear regression curves.

**Table 4.** *Blood Pressure Results — 90th Percentile Values by Blood Pressure Subgroup.*

| Subgroup | n | Blood Pressure Resting | Blood Pressure 100 Watts | Blood Pressure Peak | Blood Pressure Recovery |
|---|---|---|---|---|---|
| Normal | | | | | |
| Men | 106 | 135/89 | 190/106 | 230/118 | 160/90 |
| Women | 79 | 130/84 | 185/103 | 197/108 | 142/90 |
| Borderline | | | | | |
| Men | 115 | 149/97 | 200/110 | 250/120 | 198/98 |
| Women | 61 | 152/95 | 208/118 | 218/120 | 160/92 |
| Established | | | | | |
| Men | 51 | 156/106 | 210/122 | 260/136 | 196/108 |
| Women | 9 | 154/100 | 240/124 | 247/158 | 176/100 |

### *Normal Subgroup*

Mean values (± one standard deviation) and 90th percentile values for the normal subgroup were:

1. Resting BP
   Men = 117 (14)/79 (9); 135/89
   Women = 109 (16)/74 (10); 130/84
2. BP at 100 watts
   Men = 160 (25)/92 (11); 190/106
   Women= 156 (23)/91 (11); 185/103
3. BP at peak exercise
   Men = 202 (25)/101 (12); 230/118
   Women = 168 (23)/93 (10); 197/108
4. BP 5-minutes postexercise
   Men = 134 (22)/76 (9); 160/90
   Women = 122 (22)/73 (11); 142/90

### *Subgroup Comparisons*

When analysis of variance was performed designating blood pressure subgroup as factor A and sex category as factor B, a significant AB interaction ($P < 0.05$) was identified for all variables except for diastolic recovery blood pressure and the slopes of the linear regression curves. In contrast, when patients within each subgroup were stratified according to age by decade (factor C), no significant AC or BC interaction ($P > 0.05$) for age category could be shown for any of the variables. For this reason, analysis of variance, Scheffé post-hoc testing, and discriminant analysis were subsequently used on data for men and women independently without respect to age category. $P$ values for subgroup comparisons are listed in Table 6.

**Table 5.** *Mean Slopes (±1 SD) for Pulse Rate versus Blood Pressure Linear Regression Curves by Blood Pressure Subgroup.*

| | n | Systolic | Diastolic |
|---|---|---|---|
| Normal | | | |
| Men | 106 | 1.049 (0.352) | 0.260 (0.149) |
| Women | 79 | 0.806 (0.376) | 0.259 (0.130) |
| Borderline | | | |
| Men | 115 | 1.070 (0.328) | 0.230 (0.146) |
| Women | 61 | 0.880 (0.301) | 0.292 (0.115) |
| Established | | | |
| Men | 51 | 1.178 (0.343) | 0.312 (0.196) |
| Women | 9 | 1.143 (0.309) | 0.378 (0.164) |

*Normal versus Established Hypertension*

Significant differences were identified between normal versus hypertensive patients for blood pressures at rest, 100 watts, peak, and 5-minutes recovery ($P < 0.001$–$P < 0.005$) (Table 6) for both men and women. For women, but not for men, there were also significant differences when the slopes of the pulse rate–blood pressure linear regression curves were compared ($P < 0.025$).

*Normal versus Borderline*

For normal versus borderline subgroups, there were significant differences for all variables ($P < 0.001$–$P < 0.005$) except systolic and diastolic slope ($P > 0.05$).

*Borderline versus Established Hypertension*

When comparing borderline versus established hypertension subgroups, significant differences were identified for all variables ($P < 0.01$–$P < 0.001$) except systolic recovery blood pressure and systolic slope for men. For women, however, there were no significant differences between these subgroups for any of the exercise parameters ($P > 0.05$) except systolic ($P < 0.025$) and diastolic ($P < 0.001$) peak blood pressures.

### *Discriminant Analysis*

Multiple regression prediction equations were calculated separately for men and women. The F-probabilities and Wilk's Lambdas for the variables retained in the discriminant analysis prediction equations are listed in Table 7 with regression coefficients for the equations in Table 8. These equations improve the classification accuracy (compared with random classification) by 44.9 percent for men and 66.8 percent for women.

## Discussion

The results of this study show that men and women exhibit significantly different blood pressure responses to exercise, but the age of the patient does not affect blood pressure response to exercise.

**Table 6.** *P Values for Subgroup Comparisons of Exercise Measurements: Hypertension Subgroups Compared.**

| | Normal versus Borderline | | Normal versus Established | | Borderline versus Established | |
|---|---|---|---|---|---|---|
| Exercise Measurement | Men | Women | Men | Women | Men | Women |
| Systolic BP resting | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS |
| Diastolic BP resting | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS |
| Systolic BP 100 watts | <0.005 | <0.001 | <0.001 | <0.001 | <0.001 | NS |
| Diastolic BP 100 watts | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS |
| Systolic BP peak | <0.001 | <0.001 | <0.001 | <0.001 | <0.01 | <0.025 |
| Diastolic BP peak | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Systolic BP recovery | <0.001 | <0.001 | <0.001 | <0.005 | NS | NS |
| Diastolic BP recovery | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS |
| Systolic slope | NS | NS | NS | <0.025 | NS | NS |
| Diastolic slope | NS | NS | NS | <0.025 | <0.01 | NS |

*Subgroups are first compared using a general linear model — analysis of variance. When F values are statistically significant, post-hoc testing is performed using the Scheffé test. NS = not significant.

**Table 7.** *F Probabilities for Variables Retained in Discriminant Analysis Regression Analysis.*

| Blood Pressure Variable | Men | Women |
|---|---|---|
| Diastolic resting | 0.0000 | 0.0059 |
| Diastolic 100 watts | 0.0002 | 0.0736 |
| Systolic maximum | — | 0.0794 |
| Diastolic maximum | — | 0.0002 |
| Diastolic recovery | 0.0178 | — |
| Wilk's lambda | 0.6113 | 0.4915 |

Measuring blood pressure response at rest, 100-watts workload, peak workload, and 5-minutes recovery provides information that may be used to help discriminate between normal and hypertensive persons and between normal and borderline persons for both men and women. These variables are also useful in differentiating between borderline and established hypertensives for men but not for women. There were no consistent significant differences between subgroups for the slopes of the pulse rate–blood pressure linear regression curves.

When compared with the results of other investigators (Table 1), normal values for peak exercise blood pressure and for linear regression slopes in this study tended to be higher.[10,20]

The regression equations produced by discriminant analysis may be used to estimate the probability that a patient should be classified in a particular subgroup. This is particularly helpful in predicting whether a borderline person is more likely to be normal or hypertensive.

The code for the equations listed below is: P = probability that individual is in given subgroup, NOR = normal, BORD = borderline, EST = established, DO = diastolic resting blood pressure, D100 = diastolic blood pressure at 100 watts, SP = systolic peak blood pressure, DP = diastolic peak blood pressure, DR = diastolic recovery blood pressure.

*For men:*

$$P(\mathrm{NOR}) = 2.960255 - 0.018955 \times \mathrm{DO} - 0.003741 \times \mathrm{D100} - 0.006824 \times \mathrm{DR}$$

$$P(\mathrm{BORD}) = -0.2477048 + 0.012068 \times \mathrm{DO} - 0.006011 \times \mathrm{D100} + 0.002694 \times \mathrm{DR}$$

$$P(\mathrm{EST}) = -1.71255 + 0.006887 \times \mathrm{DO} + 0.009752 \times \mathrm{D100} + 0.004131 \times \mathrm{DR}$$

*For women:*

$$P(\mathrm{NOR}) = 3.160482 - 0.013287 \times \mathrm{DO} - 0.002735 \times \mathrm{D100} - 0.003048 \times \mathrm{SP} - 0.007232 \times \mathrm{DP}$$

$$P(\mathrm{BORD}) = -1.664489 + 0.014140 \times \mathrm{DO} + 0.009926 \times \mathrm{D100} + 0.001795 \times \mathrm{SP} - 0.003588 \times \mathrm{DP}$$

$$P(\mathrm{EST}) = -0.4959931 - 0.000853 \times \mathrm{DO} - 0.007191 \times \mathrm{D100} + 0.001253 \times \mathrm{SP} + 0.010820 \times \mathrm{DP}$$

## Limitations and Future Issues

Two limitations of the study are: (1) that obesity was not examined as a possible interacting factor, and (2) that a larger population of blacks was not evaluated.

Other essential questions that warrant further study and that will require long-term collection of data and additional scrutiny are:

1. Can this method help to identify the subgroup of hypertensives at increased risk for cardiovascular sequelae?

**Table 8.** *Regression Coefficients for Subgroup Prediction Equations.*

| | Normal | | Borderline | | Established Hypertension | |
|---|---|---|---|---|---|---|
| Group | Men | Women | Men | Women | Men | Women |
| Constant | 2.960255 | 3.160482 | −0.2477048 | −1.664489 | −1.71255 | 0.4959931 |
| Blood pressure | | | | | | |
| Diastolic resting | −0.018955 | −0.013287 | 0.012068 | 0.014140 | 0.006887 | −0.000853 |
| Diastolic 100 watts | −0.003741 | −0.002735 | −0.006011 | 0.009926 | 0.009752 | 0.007191 |
| Systolic maximum | | −0.003048 | | 0.001795 | | 0.001253 |
| Diastolic maximum | | −0.007232 | | −0.003588 | | 0.010820 |
| Diastolic recovery | −0.006824 | | 0.002694 | | 0.004131 | |

2. Is this technique an accurate predictor of the development of hypertension in normal persons?
3. Could this approach be used effectively for monitoring the therapeutic response in treated hypertensives?

## Summary

Exercise stress testing in blood pressure analysis is a sensitive technique for distinguishing among normal, borderline, and genuinely hypertensive patients. Blood pressure measurements at 100-watts workload, peak workload, and 5-minutes postexercise are useful for diagnosing hypertension. Evaluating the slopes of the pulse rate versus blood pressure linear regression curves does not provide any significant additional diagnostic information. This experience suggests that ergometric stress testing in blood pressure analysis is a safe and reliable procedure for aiding in the diagnosis of hypertension.

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## GLEANINGS FROM A COMMONPLACE BOOK — *NJP*

"A future worth contemplating will not be achieved solely by flights to the far side of the moon. It will not be found in space. It will be achieved, if it is achieved at all, only in our individual hearts. This is the choice that has been presented man, a free agent, as one who can look before and after in the cosmos."

Loren Eiseley

"To see with one's own eyes, to feel and judge without succumbing to the suggestive power of the fashion of the day, to be able to express what one has seen and felt in a trim sentence or even in a cunningly wrought word—is that not glorious? Is it not a proper subject for congratulation?"

A. Einstein

"In evaluating American medicine it can be shown that the allurement of subspecialism allowed comprehensive care to lapse into a decline. Captivated by technology and its costly results, American medicine has forgotten the object of its existence—the whole patient. Needed to restore American medicine to its once highly respected place in society are well-trained family physicians, experienced clinicians, innovative health care systems, and de facto caring. The specialty of family practice has shown that the elements to check the centrifugal trend toward splintered care can be controlled.

"One need not gaze longingly to Ivy League medical schools for solutions to the practical problems that face health care. The successful state medical schools have found their answers right in their own purlieus. Family practice offers an agenda of strategies; some of these are new and some are such that they recapture the venerable qualities of the physician, all of which are practicable expedients that the public can appreciate and the family practice programs can implement, and even Deans can understand."

N.J. Pisacano