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Patients with Hypertensive Responses to Exercise or Dobutamine Stress Testing Differ In Resting Hypertensive Phenotype

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Abstract

Background—Little is known of the importance of echocardiographic measures of resting systemic vascular resistance (SVR), cardiac output (CO) and diastolic function in the development of a hypertensive response during dobutamine stress echocardiography.

Methods—We performed a retrospective review of 325 subjects who underwent stress echocardiography and a resting echocardiogram on the same day. Logistical regressions were performed to determine associations between hypertensive response to each type of stress test and clinical and hemodynamic measurements obtained by transthoracic echocardiography.

Results—Patients with a hypertensive response to dobutamine or exercise stress modalities had stage 1 hypertension. Those with a hypertensive response to dobutamine had a significantly elevated SVR and a lower CO compared to those with a hypertensive response to exercise or a non-hypertensive response to dobutamine. An SVR ≥ 2000 dynes*sec/cm⁵ showed excellent discrimination between patients who did and did not have a hypertensive response to dobutamine ($c = 0.80$). A hypertensive response to both stress modalities showed an association with measures of diastolic dysfunction.

Conclusions—The hemodynamic and echocardiographic phenotypes of individuals with a hypertensive response to exercise differ from those with a hypertensive response to dobutamine. Further work is necessary to understand and guide antihypertensive therapy when a hypertensive response to stress testing is discovered, and to inform choice of stress modality when resting hypertension is present.

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Keywords

stress echocardiography; dobutamine; hypertension; systemic vascular resistance; cardiac output

Introduction

In patients undergoing cardiac stress testing without known coronary artery disease or significant valvular disease, a hypertensive response to exercise [defined as a systolic blood pressure (SBP) ≥ 190 in women or ≥ 210 mm Hg in men or diastolic blood pressure (DBP) ≥ 110 mm Hg] independently predicts future hypertension and increased risk of adverse cardiovascular events and mortality.^{1–5}

To date, little is known about a hypertensive response to dobutamine during stress echocardiography. Dobutamine has β_1 cardiac adrenergic receptor agonist activity resulting in increased heart rate and contractility, as well as β_2 -vascular adrenergic receptor activity resulting in vasodilation. Increased inotropy with dobutamine augments cardiac output (CO) by activating a reflexive withdrawal of vascular sympathetic tone leading to vasodilation. Prior work suggests dobutamine infusion achieves similar heart rate and stroke volume augmentation to exercise, but at lower ventricular volumes and with lower blood pressure augmentation, supporting a greater vasodilatory response.⁶

The differences in cardiovascular physiological responses to exercise compared to dobutamine suggest hypertensive responses to these stimuli may relate to different physiological attributes. Prior work reports the hypertensive response to dobutamine is associated with male sex, age, baseline systolic blood pressure and atropine use.⁷ However, there are no current data relating resting SVR, CO or echocardiographic measures of diastolic function to the hypertensive response to dobutamine. The following study is designed to address whether resting systolic and diastolic function are associated with hypertensive responses during exercise or dobutamine stress echocardiography (DSE). Additionally, we analyzed data from patients who underwent treadmill stress echocardiography (TSE) at our institution during the same study period to examine the contributions of systolic and diastolic function to a hypertensive response to exercise. We then compared the factors most commonly associated with a hypertensive response to each type of stress.

Methods

Subjects

In this retrospective cohort study, we reviewed 413 same-day resting and stress transthoracic echocardiograms (TTE) completed between 2009 and 2011 at our institution. All stress echocardiograms were ordered to evaluate for cardiac ischemia for one of the following reasons: shortness of breath, palpitations, chest pain or pre-operative risk stratification. All exercise tests were performed following a standard Bruce protocol. Dobutamine stress echocardiograms were performed using a standard protocol that begins with a 10 mcg/kg/min dobutamine dose for three minutes, increasing the dose by 10 mcg/kg/min every

3 minutes until 85% of maximal predicted heart rate was achieved or the 50 mcg/kg/min dose was reached. If subjects were not making adequate progress on reaching their heart rate goal by the time the dobutamine dose was increased to 30 mcg/kg/min, 0.25 mg of atropine was administered every minute to a maximal dose of 1.5 mg.

Eighty-four subjects with coronary artery disease (CAD), resting LV ejection fraction less than 50%, resting regional wall motion abnormalities or inducible ischemia were excluded. An additional four subjects had technically inadequate images for measuring CO and SVR, leaving 181 subjects who underwent TSE and 144 subjects who underwent DSE for analysis. All subjects who were on chronic β -blockade had this medication held for at least 24 hours prior to stress testing.

Extracted Data

Following subject identification, data were extracted from both the stress test and resting TTE study for further analysis. These include subject age; sex; height; weight; body surface area (BSA); resting blood pressure prior to stress testing; peak blood pressure and heart rate responses to exercise; whether atropine was used (DSE only); whether the subject achieved 85% of the maximal predicted heart rate and whether there was evidence of inducible ischemia. From the resting TTE, we obtained the septal e' peak velocity of the mitral annulus, mitral inflow E wave peak velocity, left atrial volume, indexed left ventricular mass, the left ventricular outflow tract diameter and the velocity-time integral (VTI) for the left ventricular outflow tract (LVOT) in systole.

Resting arterial elastance (E_a) was calculated using 90% of the resting SBP (to estimate the end-systolic pressure) divided by the stroke volume from the resting TTE. Stroke volume was calculated using LVOT diameter measured in the parasternal long axis view during systole multiplied by the VTI of the LVOT velocity during systole measured in the apical view. As an additional control for body habitus, we calculated the indexed resting E_a by dividing E_a by body surface area⁸. Resting CO was calculated by multiplying the resting stroke volume by the resting heart rate. Resting SVR was calculated dividing resting CO into the difference between the mean arterial pressure (calculated as two times the resting DBP plus resting SBP, all divided by three) and an assumed central venous pressure of 5 mmHg for all subjects. Left ventricular mass was calculated using the Devereaux formula and indexed to body surface area. LV mass indices 95 g/m^2 in women and 115 g/m^2 in men were considered to be increased.

A hypertensive response to either exercise or dobutamine was *a priori* defined as a peak SBP was 190 mm Hg in women or 210 mm Hg in men during stress testing.⁵ For dobutamine stress testing, note that recently published data categorize a hypertensive response as two or more standard deviations greater than the normative age-stratified means.⁷

Statistical Analyses

Subjects were stratified into two groups: those undergoing DSE and those undergoing TSE. Baseline subject characteristics were compared between groups using unpaired tests or Chi-square testing as appropriate for a categorical variable. To determine associations between subject attributes and a hypertensive response to stress testing, we first constructed

univariable logistical regression models stratified by stress testing modality. Variables tested included age, sex, resting SBP, resting DBP, resting hypertension, PP (PP), E_a , E_a/BSA , mitral annular septal e' velocity, mitral inflow peak E wave velocity, mitral E/e' ratio, mitral inflow E/A ratio, LV mass index, left atrial volume and use of atropine.

Additionally, we created categorical variables to assess the predictive value of known clinical measurements of hypertension and diastolic dysfunction. These included left atrial volume ≥ 34 mm³, mitral septal e' velocity ≥ 7 cm/sec, mitral $E/e' \geq 14$, increased LV mass indexed to body surface area, resting SBP ≥ 140 mmHg, resting DBP ≥ 90 mmHg, resting pulse pressure (PP) ≥ 50 mmHg, SVR ≥ 2000 dynes*sec/cm⁵ and CO ≥ 4 L/min. Data were analyzed using SPSS 21.0 A P-value of <0.05 was considered significant.

Results

Subject Characteristics

Baseline subject characteristics are presented in Table 1. At baseline, the DSE subjects were older, with higher resting heart rates, and with higher resting SBP and pulse pressure. Overall, while a similar number of subjects in both groups had stage 1 hypertension, patients undergoing DSE had a greater prevalence of stage 2 hypertension compared to those who underwent TSE. DSE subjects also had higher body mass indices, higher resting stroke volumes and CO with lower resting SVR. LA size, LV mass (both unadjusted and normalized to BSA) and thickness of the inferolateral and septal walls were all higher in the DSE group. Resting E/e' was higher and e' velocity was lower in DSE subjects relative to TSE subjects. 26 of 181 subjects who underwent treadmill testing (14.4%) and 11 subjects who underwent DSE (7.6%) had a hypertensive response to stress testing.

Comparisons of clinical and echocardiographic attributes of patients who had a hypertensive response to stress testing compared to those who did not are reported in Table 2 (DSE) and Table 3 (TSE). Individuals with a hypertensive response to DSE had a significantly higher resting SVR, inferolateral wall thickness, indexed left ventricular mass, as well as lower resting CO and cardiac index (CI) than those without a hypertensive response. Both groups had stage 1 hypertension without a significant difference in resting blood pressure. In contrast, those who had a hypertensive response to the exercise modality had a significantly higher resting SBP, DBP, PP and septal wall thickness. There were no differences noted between groups with respect to SVR or indexed LV mass. Resting CO and CI was higher in patients with a hypertensive response to exercise. When only individuals with a resting SBP > 140 mmHg were compared within the treadmill exercise group, there was still no significant difference in resting SVR (1781 ± 584 dynes*sec/cm⁵ versus 2107 ± 787 for those with and without a hypertensive response, respectively; $P = 0.32$).

Using the alternative definition of a hypertensive response to dobutamine, a total of 29 subjects had a hypertensive response during DSE in our study. SVR remained significantly higher in those with a hypertensive response (2061 ± 832 vs. 1584 ± 647 dynes-sec/cm⁵, $P = 0.011$). LV Mass index tended to be higher in those with a hypertensive response (94.5 ± 19.6 vs. 85.8 ± 22.3 gm/m², $P = 0.06$), while both the septal thickness (12.2 ± 1.5 vs. 10.6 ± 2.0 , $P < 0.001$) and inferolateral wall thickness (12.2 ± 2.0 vs. 11.1 ± 2.1 mm, $P = 0.01$)

were higher in those with a hypertensive response. CO and CI trended lower in those with a hypertensive response during DSE, but the difference was not statistically significant (4.6 ± 2.1 vs. 5.1 ± 1.6 L/min, $P = 0.23$; 2.3 ± 1.0 versus 2.6 ± 0.8 L/min/m², $P = 0.09$).

Comparing those with a hypertensive response during DSE and TSE, we found no significant differences in resting heart rate, blood pressure or BMI (Table 4). SVR was significantly higher in those with a hypertensive response during DSE ($P = 0.02$). CO ($P = 0.09$) and CI ($P = 0.08$) also trended lower in this group. Indexed left atrial volume ($P=0.02$), left ventricular mass ($P=0.053$), and left ventricular septal wall thickness ($P=0.01$) were also higher in the patients who underwent DSE.

Stress Test Findings

Subjects in the DSE group demonstrated lower peak heart rates (141 ± 21 versus 163 ± 23 beats/min, $P < 0.001$), lower peak SBP (155 ± 32 vs. 175 ± 22 mm Hg; $P < 0.001$), lower peak DBP (73 ± 14 versus 78 ± 13 mm Hg; $P = 0.001$), and lower rises in systolic pressure (13 ± 23 versus 43 ± 20 mm Hg; $P < 0.001$) compared to those in the TSE group. There was no significant difference between groups in the number of subjects who failed to achieve 85% of maximal predicted heart rate (85.6% for DSE and 89.5% for TSE; $P=0.29$).

Association of Blood Pressure Response to Exercise and Dobutamine with Subject Characteristics and Echocardiographic Measurements Associated with Systolic Function

Univariable associations between a hypertensive response to exercise and dobutamine are detailed in Tables 5 and 6, respectively. For DSE, the strongest predictors of a hypertensive response to stress were resting SVR > 2000 dynes*sec/cm⁵ and CO < 4 L/min. Also, those demonstrating a hypertensive response during DSE did not show an association with sex and PP. However, these patients did demonstrate an association with a resting SBP > 140 mm Hg. Concerning exercise stress testing, in our dataset, female sex, elevated resting SBP and DBP, PP, and resting hypertension at the time of stress testing were associated with an increased incidence of hypertensive response to exercise. Importantly, neither SVR > 2000 dynes*sec/cm⁵ nor CO < 4 L/min predicted a hypertensive response. Even when only patients with a resting SBP > 140 mm Hg were considered in TSE group, neither SVR [OR = 0.59; 95% CI (0.15 – 2.27); $P = 0.44$] nor CO [OR = 0.35; 95% CI (0.08 – 1.50); $P = 0.16$] was not significantly associated with a hypertensive response.

SVR > 2000 dynes-sec/cm⁵ [OR 4.52 (1.91 – 10.75); $P = 0.001$] remained a significant predictor of a hypertensive response for the 29 patients who satisfied the alternative definition of a hypertensive response to dobutamine.⁷

Association of Blood Pressure Responses to Exercise and Dobutamine with Measurements of Diastolic Function and Left Ventricular Mass

While an e' septal velocity of < 7 cm/sec trended toward an association with an increased risk of a hypertensive response during DSE (OR = 3.00, 95% CI 0.86–10.42; $P = 0.08$), no measure of diastolic function (including $E/e' > 14$, mitral E/A ratio or LA volume index > 34 mL/m²) was found to be significant. On the other hand, increased LV mass index was

significantly associated with an increased risk of developing a hypertensive response during DSE (OR = 4.04, 95% CI 1.12–14.59; $P = 0.03$).

For exercise stress testing, a mitral E/e' ratio ≥ 14 was significantly associated with a hypertensive response during TSE (OR = 6.09, 95% CI 1.70 – 21.80, $P = 0.006$, Table 6). However, Index left atrial volume ≥ 34 mm/m², septal e' ≤ 7 , mitral E/A ratio and LV mass index were not associated with a hypertensive response during TSE.

Receiver Operator Characteristics for Hypertensive Responses to Each Stress Test Method

With respect to dobutamine stress testing, an SVR over 2000 dynes-sec/cm⁵ has the most favorable characteristics for prediction of a hypertensive response (c -statistic = 0.80; 95% CI 0.67 – 0.94; $P < 0.001$, Figure). ROC curves for a resting CO < 4 L/min ($c = 0.73$; 95% CI 0.57 – 0.89; $P = 0.01$), indexed LV mass ($c = 0.67$; 95% CI 0.50 – 0.84; $P = 0.07$), and SBP ≥ 140 mm Hg ($c = 0.66$; 95% CI 0.52 – 0.82; $P = 0.06$) were less favorable.

For prediction of a hypertensive responses during treadmill stress, no variable was highly robust in predicting those who developed a hypertensive response from those who did not [(SBP ≥ 140 mmHg; $c = 0.67$; 95% CI 0.55 – 0.79; $P = 0.007$), (E/e' ≥ 1 ; $c = 0.58$; 95% CI 0.45 – 0.71; $P = 0.20$), (resting PP > 50 mm Hg; $c = 0.64$; 95% CI 0.53 – 0.75; $P = 0.02$)].

Discussion

In our study, we found that a hypertensive response to dobutamine and treadmill exercise was associated with distinct hypertensive phenotypes. Specifically, hypertensive responses to dobutamine were most strongly associated with a high resting SVR, a lower resting CO and a higher indexed left ventricular mass. Our data show there was little association with echocardiographic parameters of diastolic dysfunction, and only a borderline association with elevated resting mean arterial pressure. Conversely, a hypertensive response to exercise was not significantly influenced by resting SVR but was more strongly associated with elevations in resting blood pressure, higher cardiac outputs, and a widened resting pulse pressure as well as evidence of impaired diastolic function.

Furthermore, in our dataset, female sex was independently associated with an increased risk of a hypertensive response to exercise, but not a hypertensive response to dobutamine. To our knowledge, these data are the first to report associations between SVR, CO and echocardiographic parameters of diastolic function and a hypertensive response to dobutamine.

These differing resting hypertensive profiles suggest hypertensive responses to exercise testing or dobutamine testing could help clinicians better tailor their choices of antihypertensive agents for these patients. More specifically, based on resting hemodynamic profiles, individuals with hypertensive responses to exercise may be more likely to respond to antihypertensive agents that are negative inotropes, while those with hypertensive responses to dobutamine may be more likely to respond to afterload reduction agents. Finally, our data suggest measurement of resting SVR and cardiac output before DSE can predict who may

have a hypertensive response to dobutamine. This information holds clinical value insofar as suggesting to the ordering provider that an alternative imaging modality may be better suited for ischemic evaluation

The differences in phenotypes associated with hypertensive responses between the two stress modalities likely relate in part to differences in the physiological responses to each stressor. Our data suggest resting elevations in mean arterial blood pressure and less efficient diastolic function are most strongly associated with a hypertensive response to exercise. Further, we observed no significant differences in SVR or heart rate between those who did and did not have a hypertensive response to exercise while patients who had a hypertensive response to exercise had higher resting cardiac output. These data suggest reducing resting stroke volume could be effective in treating hypertension in these patients. This hypothesis merits testing in future investigations using beta-adrenergic blockade or non-dihydropyridine calcium-channel blockers to reduce MAP compared to afterload reduction agents.

In contrast to the patient profile of those who developed hypertensive responses to exercise, the phenotype of those with a hypertensive response to dobutamine was more closely associated with higher resting SVR and lower resting cardiac output with less strong associations with resting blood pressure. Dobutamine increases heart rate and stroke volume to a similar extent to exercise at lower end systolic and diastolic volumes suggesting reduced venous return relative to exercise.⁶ The rise in blood pressure during dobutamine stress also tends to be lower than with exercise, suggesting a more robust arterial vasodilator response and lower peripheral resistance with dobutamine at equivalent cardiac outputs compared to exercise.⁶ This physiological response to dobutamine likely relates to dobutamine's β_2 receptor agonist activity in large and medium-sized arteries. As dobutamine induces hypertension this population suggests impaired vasodilatory responses to dobutamine related to potentially both impaired vascular β_2 -receptor responsiveness and impairment of reflex sympathetic withdrawal. These data further suggest that resting hypertension in these patients may be more responsive to afterload reduction than negative inotropic agents.

Both hypertensive responses to exercise and hypertensive responses to dobutamine were associated with the presences of indicators of adverse ventricular remodeling. These findings are consistent with prior data showing an association of impaired diastolic function with hypertensive response to exercise and hypertension.⁹ To our knowledge, our data are the only data to report on the association between hypertensive response to dobutamine and measures of diastolic function. Further, data regarding the strength of association between diastolic function and hypertensive response to exercise are conflicting.^{9, 10} Whether diastolic function mechanistically contributes to hypertensive response to dobutamine or hypertensive response to exercise or whether they are associated in that they are both consequences of hypertension remains unclear and merits further investigation.

We found that resting SVR $2000 \text{ dynes} \cdot \text{sec}/\text{cm}^5$ provided good discrimination between those who had hypertensive responses to dobutamine versus those who did not develop a hypertensive response. This suggests the potential of using resting measurements of SVR from resting echocardiography to predict those who may not be able to complete their tests due to excessive hypertension. Affirmative confirmation of this finding would suggest

resting SVR could then be used to guide at-risk patients toward a stress testing modality (pharmacological stress nuclear or stress MRI) that would more likely afford a complete ischemic evaluation.

Our study has some limitations. The overall size of this study is relatively small, with less than 40 subjects having hypertensive responses to exercise and dobutamine. The small study size precludes robust multivariable analyses. A study in a larger cohort of subjects to validate our findings is warranted. While we did not find an association between the use of atropine and hypertensive response to dobutamine, prior work has reported such an association.⁷ The discrepancy between our work and the previous study may relate to differences in patient population as well as protocols for the use of atropine. Additionally, we found male sex was protective with respect to hypertensive response to exercise. The reasons for this finding are unclear but may relate to the specific make-up of our subject population. This study is also a retrospective analysis and therefore we are unable to directly compare responses to exercise and dobutamine in the same subjects. In light of the greater prevalence of stage 2 hypertension and LV mass in the DSE group, the differences in the predictors of hypertensive responses to the different types of stress may in part relate to differences in the degree of target organ damage between stress test groups. A prospective study of patients with hypertension in which each study subject undergoes both forms of stress testing would support the hypothesis generated by these study data. Additionally, due to the retrospective nature of this study, information regarding which anti-hypertensive medications were prescribed to individuals in the study population at the time of stress testing was unavailable.

Balanced against these limitations are novel findings demonstrating differences in the hypertensive phenotype of those with hypertensive responses to exercise versus hypertensive responses to dobutamine that could have clinical implications. The data support the hypothesis that resting echocardiographic data showing SVR > 2000 dynes*sec/cm⁵ and would support using exercise or a pharmacological agent other than dobutamine to avoid a hypertensive response to stress testing that could potentially lead to a non-diagnostic test or a false-positive test due to hypertension induced wall motion abnormalities. These data also suggest differences in the resting hemodynamics between those with a hypertensive response compared to those with a hypertensive response to dobutamine that could be clinically relevant and warrant further study.

Conclusions

The hemodynamic and echocardiographic phenotypes of individuals with hypertensive responses to exercise stress differ from those with hypertensive responses to dobutamine stress testing. A hypertensive response to either modality gives additional information as to underlying hemodynamics of a patient's hypertension and may inform the choices for therapy. Additionally, patients with a resting SVR > 2000 dynes*sec/cm⁵ may be better off undergoing ischemic evaluations using a pharmacological agent other than dobutamine. Further work is necessary to further validate these findings and test the ability of hypertensive responses to stress to guide anti-hypertensive therapies.

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Figure.

ROC curve for using SVR ≥ 2000 dynes*sec/cm⁵ as the cut-off point for predicting hypertensive response to dobutamine.

Table 1
Clinical Characteristics of Study Population (n=325)

Data expressed as mean (standard deviation) along with 95% confidence interval of the difference. P value < 0.05 considered significant. BSA, body surface area; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; LVOT, left ventricular outflow tract; LVVTI, LVOT velocity time integral; Ea, arterial elastance; LA, left atrium; LV, left ventricle; SVR, systemic vascular resistance

Variables	Treadmill Stress n=181 (SD)	Dobutamine Stress n=144 (SD)	p value
Sex (%Female)	57.9	61	0.81
Age (years)	53(14)	61(15)	<0.001
BSA (m ²)	1.9 (0.2)	1.9(0.3)	0.44
Body Mass Index (kg/m ²)	28.3±5.8	30.5±8.0	0.001
Hypertension by Historical Report (%)	34.9	50.3	0.005
Resting Heart Rate (bpm)	68 (12)	73 (14)	0.001
Resting SBP (mmHg)	128 (19)	143 (24)	<0.001
Resting DBP (mmHg)	74 (10)	75 (12)	0.45
Resting PP (bpm)	54 (14)	68 (21)	<0.001
LVOT Diameter (cm2)	2.0 (0.2)	2.0 (0.2)	0.61
Stage of Hypertension based on Resting Blood Pressure at time of testing			<0.001
Stage 1(% within test type)	18.2	20.1	
Stage 2(% within test type)	7.2	30.6	
LVVTI (cm)	19.5 (3.7)	22.0 (4.9)	<0.001
Ea (mmHg/mL)	2.06 (0.72)	2.02 (0.89)	0.66
Ea/BSA	1.10(0.45)	1.09 (0.61)	0.80
Resting Stroke Volume (mL)	61(18)	68(20)	0.001
Resting Cardiac output (L/min)	4.1(1.3)	5.0(1.7)	<0.001
Resting SVR (dynes*sec/cm ⁵)	1826(578)	1679(707)	0.04
Mitral Inflow E Velocity (cm/s)	73.1 (19.9)	81.5 (23.6)	0.001
Mitral Inflow A Velocity (cm/s)	65.7 (19.9)	82.2 (26.1)	<0.001
Mitral E/A Ratio	1.19 (0.42)	1.09 (0.49)	0.06
Septal e' Velocity	10.3 (3.5)	9.3 (3.7)	0.01
Septal a' Velocity	8.1 (2.9)	7.3 (2.7)	0.01
E/e'	8.0 (3.9)	10.0 (4.4)	<0.001
LA volume (mL/m2)	28.6 (9.2)	33.5 (13.7)	<0.001
LV Mass (g)	154 (51)	170 (50)	0.005
LV Mass Index (g/m2)	80 (22)	88 (22)	0.001
LV Septal Thickness (mm)	10.6±2.2	11.5±2.5	<0.001
LV Inferolateral Thickness (mm)	10.3±5.0	11.0±2.1	0.045
LV End-Diastolic Dimension (mm)	43.3±7.1	44.5±6.3	0.07
Hypertensive Response to Stress Testing (%)	14.4	7.6	N/A

Variables	Treadmill Stress n=181 (SD)	Dobutamine Stress n=144 (SD)	p value
Atropine Used (%)	N/A	78	N/A

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Table 2

Comparison of Clinical and Echocardiographic Attributes of Patients Undergoing DSE. (N=144 subjects)

	No HTN Response (N=133)	HTN Response (N=11)	P Value
Age	61±15	61±13	1.00
BMI (kg/m ²)	30.5±7.8	31.6±8.3	0.66
Resting HR	74±14	68±14	0.20
Resting SBP	142±24	153±17	0.14
Resting DBP	74±12	80±13	0.12
Resting PP	68±19	72±20	0.42
Resting MAP	97±14	105±10	0.08
SVR (dynes*sec/cm⁵)	1639±713	2180±489	0.02
CO (L/min)	5.1±1.8	3.9±1.2	0.03
CI (L/min/m²)	2.6±0.9	2.0±0.6	0.02
E _a	2.00±0.91	2.35±0.69	0.21
Mitral E/A Ratio	1.10±0.51	1.04±0.28	0.70
Septal e' velocity	9.3±3.7	8.5±3.7	0.48
E/e'	9.9±4.3	10.8±5.3	0.50
LA Volume Index	33±14	36±9	0.48
LV Mass Index	86±22	101±18	0.03
LV Septal Thickness (mm)	11.3±2.1	12.5±2.0	0.06
LV Inferolateral Thickness (mm)	10.8±2.0	12.2±1.3	0.03
LV End-Diastolic Dimension (mm)	43.0±7.3	43.6±6.0	0.77

Table 3

Comparison of Clinical and Echocardiographic Attributes of Patients Undergoing Treadmill Echocardiogram.
(N=181 subjects)

	No HTN Response (N=155)	HTN Response (N=26)	P Value
Age	52±14	55±10	0.30
BMI (kg/m²)	27.7±5.6	31.3±6.4	0.004
Resting HR	68±12	70±12	0.47
Resting SBP	125±16	144±22	<0.001
Resting DBP	73±10	80±10	0.002
Resting PP	52±19	64±16	<0.001
Resting MAP	90±11	101±13	<0.001
SVR (dynes*sec/cm ⁵)	1838±594	1756±475	0.51
CO (L/min)	4.0±1.2	4.6±1.3	0.02
CI (L/min/m²)	2.1±0.6	2.4±0.7	0.01
E _a	2.08±0.74	1.98±0.53	0.52
Mitral E/A Ratio	1.20±0.43	1.012±0.40	0.38
Septal e' velocity	10.5±3.6	8.7±2.8	0.02
E/e'	7.6±3.6	10.3±4.8	0.01
LA Volume Index	29±9	29±8	0.88
LV Mass Index	79±21	84±27	0.32
LV Septal Thickness (mm)	10.3±2.1	11.3±2.2	0.02
LV Inferolateral Thickness (mm)	10.3±5.8	10.4±2.1	0.93
LV End-Diastolic Dimension (mm)	44.0±5.4	42.5±5.8	0.20
Exercise Time (seconds)	590±196	506±170	0.04
Peak Double Product	27878±5257	33434±4398	<0.001

Table 4

Comparison of Clinical and Echocardiographic Attributes of Patients with Hypertensive Responses Different Types of Stress Testing

	Exercise (N=26)	Dobutamine (N=11)	P Value
Age	55±10	61±13	0.18
BMI (kg/m ²)	31.3±6.4	31.6±8.4	0.90
Resting HR	70±12	68±14	0.71
Resting SBP	144±22	153±17	0.22
Resting DBP	80±10	80±13	0.84
Resting PP	64±16	72±20	0.17
Resting MAP	101±13	105±10	0.41
SVR (dynes*sec/cm⁵)	1756±475	2180±489	0.02
CO (L/min)	4.6±1.3	3.9±1.2	0.09
CI (L/min/m ²)	2.4±0.7	2.0±0.6	0.08
E _a	1.98±0.53	2.35±0.69	0.08
Mitral E/A Ratio	1.012±0.40	1.04±0.28	0.54
Septal e' velocity	8.7±2.8	8.5±3.7	0.23
E/e'	10.3±4.8	10.8±5.3	0.76
LA Volume Index	29±8	36±9	0.02
LV Mass Index	84±27	101±18	0.053
LV Septal Thickness (mm)	10.4±2.1	12.5±2.0	0.12
LV Inferolateral Thickness (mm)	10.4±2.1	12.2±2.0	0.01
LV End-Diastolic Dimension (mm)	42.5±5.8	43.6±6.0	0.61

Table 5

Associations between clinical and echocardiographic attributes with a hypertensive response to dobutamine.
(N=144 subjects)

	Odds Ratio	95% CI	P Value
Age	1.00	0.96,1.04	1.00
Female Sex	0.77	0.22,2.655	0.77
Resting HR	0.97	0.92,1.02	0.19
Resting SBP	1.02	0.99,1.05	0.14
Resting DBP	1.04	0.9,1.09	0.12
Resting HTN	6.02	0.91 484.48	0.09
Resting PP	1.03	0.98,1.04	0.42
Resting MAP	1.04	0.99,1.09	0.09
Resting SVR 2000	16.88	3.45,82.58	<0.001
Resting Cardiac Output < 4 L/min	7.19	1.81,28.59	0.005
E _a	1.41	0.82,2.4	0.22
E _a /BSA	1.36	0.60,3.07	0.47
Mitral E/A Ratio	0.76	0.19,3.02	0.69
Septal e' Velocity 7	3.00	0.86,10.42	0.08
E/e' 14	1.81	0.44,7.36	0.41
LA Volume index 34 mL/m ²	2.25	0.62,8.08	0.22
Increased LV Mass Index	4.04	1.12,14.59	0.03
Resting SBP 140	4.85	1.01,23.31	0.049
Resting DBP 90	1.89	0.37,9.63	0.44
Resting PP 50	0.80	0.16,3.96	0.78
Resting MAP 100	2.91	0.81,10.42	0.10
Age 50	1.20	0.25,5.87	0.82
Achieved 85% MHR	0.22	0.06,0.85	0.03
Use of Atropine	0.73	0.18,2.91	0.65

Table 6

Associations between clinical and echocardiographic attributes with a hypertensive response to exercise.
(N=181 subjects)

	Odds Ratio	95% CI	P Value
Age	1.01	0.99, 1.05	0.30
BMI (kg/m²)	1.09	1.02,1.16	0.007
Male	0.23	0.08,0.69	0.009
Resting HR	1.01	0.98, 1.05	0.46
Resting SBP	1.31	1.17,1.49	<0.001
Resting DBP	1.07	1.02, 1.11	0.003
Resting HTN	4.05	1.54,10.63	0.005
Resting PP	1.06	1.03,1.09	0.001
Resting MAP	1.08	1.04,1.12	<0.001
Resting SVR 2000	0.73	0.29,1.85	0.51
Resting Cardiac Output < 4 L/min	0.46	0.19,1.09	0.08
Ea	0.81	0.42,1.56	0.52
E _a /BSA	0.67	0.23,1.99	0.47
Mitral E/A Ratio	0.78	0.26,2.34	0.66
Septal e' Velocity 7	1.85	0.74,4.66	0.19
E/e' 14	6.09	1.70,21.8	0.006
LA Volume index 34	1.82	0.71,4.65	0.21
Increased LV Mass Index	1.52	0.96,3.95	0.39
LV Septal Thickness (mm)	1.24	1.03,1.23	0.02
LV Inferolateral Thickness (mm)	1.00	0.93,1.08	0.93
LV End-Diastolic Dimension (mm)	0.95	0.88,1.03	0.20
Resting SBP 140	4.48	1.89,10.63	0.001
Resting DBP 90	3.24	0.76,13.81	0.11
Resting PP 50	3.46	1.32,9.10	0.01
Resting MAP 100	4.68	1.93,11.34	0.001
Age 50	1.91	0.76,4.81	0.17
Achieved 85% MHR	0.88	0.24,3.27	0.85