THE PHYSIOLOGICAL RESPONSES OF CHRONIC HEART FAILURE PATIENTS TO MAXIMAL STRENGTH TEST AND A BALKE INCREMENTAL TEST

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ABSTRACT
It has been demonstrated that resistance exercises may improve chronic heart failure (CHF) patients’ functional ability and quality of life, however, physicians do not recommend this form of exercise because of a concern for reported increases in afterload and blood pressure (BP) during the exercise. This study compared the heart rate (HR), BP and rate pressure product (RPP) of CHF patients for a Balke incremental test and a maximal strength test (MS). Fifteen men diagnosed with CHF participated in the study. All subjects performed both a Balke incremental test and MS test for eight different resistance exercises. The subjects’ HR and BP were monitored during the incremental test and immediately after each resistance exercise. HR, systolic BP and RPP were significantly lower during the MS test than during both the peak Balke incremental test and during exercise at 80% of peak VO₂ (p < 0.05). No significant RPP differences were found between upper and lower body resistance exercises (p > 0.05). The physiological responses in this study were less severe during a MS test than those reported during an incremental Balke treadmill test. Also the finding suggests that MS tests may be an acceptable method to assess the maximal strength of patients with moderate heart failure.

KEY WORDS: Chronic heart failure, incremental test, rate pressure product.

INTRODUCTION
A decrease in work capacity (Delp et al., 1997), exercise intolerance (De Sousa et al., 2000; Simonini et al. 1996; Sullivan et al. 1997) and a reduction in muscle mass and strength (Mancini et al., 1992; Pollock et al., 1998) are characteristics of people with chronic heart failure (CHF).

Aerobic training such as walking or cycling is the traditional activity prescribed in exercise cardiac rehabilitation (ACSM, 2000; Coats, 1993; Fletcher et al., 2001; Pollock et al., 2000). However, resistance training is the preferred method to increase muscle strength which is essential in order to maintain and improve the patients functional ability (Pu et al., 2001; Sparling et al., 1990), help improve their independence and confidence (ACSM, 2000) and assist in prevention of osteoporosis, obesity and other chronic conditions (Pollock et al., 2000). Nevertheless, health professionals do not commonly prescribe this form of exercise to their patients mainly because of a concern for increases in wall tension due to elevation in blood pressure and afterload.

Intensity is a fundamental factor in training prescription for both aerobic and resistance exercise. Exercising at 40-85% peak aerobic capacity (VO₂) is the recommended intensity for aerobic training in
Physiological responses of CHF patients

An acceptable method to determine peak VO\(_2\) in cardiac patients is the Balke incremental treadmill test where walking speed remains constant and slope is increased every 2 minutes by 2.5% (or every 1 minute by 1%) (Hanson, 1984). The Balke test is recommended for cardiac patients since the elevation in workload is moderate and therefore considered safe even for patients with severe left ventricular dysfunction (Conn et al., 1982; Hanson, 1984; Nieman, 2003).

The maximal strength (MS) test has previously been used to assess maximal strength of healthy middle aged (Hurley et al., 1988), elderly (Shaw et al., 1995) and coronary artery disease subjects (Featherstone et al., 1993; Ghilarducci et al., 1989). Although several studies with CHF patients have used the MS test as a maximal strength indicator (Maiorana et al., 2000; Meyer et al., 1999; Pu et al., 2001) there is lack of data on the hemodynamic responses of these patients to MS tests compared to aerobic exercise.

Therefore to help investigate the responses of CHF patients to resistance exercises, the purpose of this study was to compare the physiological responses of CHF patients to both a Balke incremental treadmill test and a MS test.

METHODS

Subjects

Fifteen men age 57±10.2yrs who were diagnosed with left ventricular systolic dysfunction (EF, 34.7±7.3) volunteered to participate in the study (subject’s clinical characteristics are shown in Table 1). The study protocol was approved by both the Human Research Ethics Committee Southern Cross University (ECN-02-110) and John Flynn Private Hospital (02/08). Prior to participation, all subjects were informed about the nature of the study and signed an informed consent.

Subjects who had the following contraindications were excluded from the research: smokers, those with locomotor disability, ventricular arrhythmias, unstable angina or who had a resting diastolic pressure above 95mmHg, a resting systolic pressure above 160mmHg or uncontrolled congestive heart failure, acute myocarditis, severe valvular stenosis and persons who were unable to consent for themselves.

Study protocol

All subjects completed a medical examination to identify secondary conditions or contraindications for exclusion. Subjects performed a Balke incremental treadmill test (TRACMASTER, JAS Fitness System 210AC/R, USA) where walking speed remained constant (3km·h\(^{-1}\)) whilst the grade was increased by 2.5 percent every two minutes (Hanson, 1984). Patients were instructed not to eat or drink caffeine for at least two hours before the tests.

Table 1. Subject’s (n = 15) clinical characteristics. Data are means (±SD).  

| Age (yrs) | 57.0 (10.2) |
| Weight (kg) | 91.3 (12.1) |
| Height (m) | 1.78 (.08) |
| Resting HR (bpm) | 69.8 (12.5) |
| Resting SBP (mmHg) | 110.5 (19.7) |
| Resting DBP (mmHg) | 70.9 (8.5) |
| Peak VO\(_2\) (ml·kg\(^{-1}\)·min\(^{-1}\)) | 14.6 (2.3) |
| EF (%) | 34.7 (7.3) |
| Medication * |
| Beta-blockers: |
| Carvedilol | 11 |
| Bicor | 2 |
| Atenolol | 1 |
| Inderal | 1 |
| Diuretics | 5 |
| ACE inhibitors | 12 |
| Ant cholesterol | 10 |
| Digoxin | 3 |
| Anti arrhythmic | 4 |
| Pain reliefs | 7 |
| Diabetes medications | 3 |

* number of subjects on each medication, some subjects on multiple medications.

Abbreviations: HR = heart rate, SBP = systolic blood pressure, DBP = diastolic blood pressure, EF = ejection fraction, ACE = angiotensin-converting enzymes.

During the test the subjects HR was monitored by 12 lead electrocardiograph (ECG). Brachial blood pressure was measured by auscultation every 2 minutes. Aerobic capacity (VO\(_2\)) was determined by gas analysis (Medgraphics, cardio2 and CPX/D System Operators Manual – Utilizing Breezeex Software, 142090-001, Revia, MN, providing data every 15 seconds). Calibration against three standard alpha gases was conducted prior to each test. Myocardial oxygen consumption which is represented by the RPP was calculated via the equation SBP×HR/100 (where SBP, systolic blood pressure, HR, heart rate) (Fletcher et al., 2001; Siegelova et al., 2000). HR, systolic and diastolic blood pressure and RPP at peak and at 80% of peak VO\(_2\) during the incremental test were reported. Criteria to terminate the test followed the recommendation of the American Association of Cardiovascular and Pulmonary Rehabilitation and the American College of Sport Medicine (AACVPR, 1999; ACSM, 2000).
Approximately one week after the incremental test patients performed a MS test which was defined as the heaviest weight a subject could lift (between one and four repetitions) with a proper lifting technique and normal breathing pattern, and without compensatory movements (Levinger et al., in press). Two days prior to the MS test subjects completed a familiarization session with the resistance equipment and were instructed in correct lifting techniques. A correct breathing technique was explained and practiced in order to avoid a Valsalva maneuver. Tests were performed on resistance exercise equipment (Schwinn 780 SI Strength System) for chest press, leg press, lateral pull-down, triceps extension, knee extension, upright row, seated row and biceps curl following 5-10 minutes of warm-up on a treadmill and a stretching regime. MS was determined using a similar protocol to Hagerman et al. (2000), which included 1 set of 10 repetitions followed by gradually increasing weights (by 10-20%, the amount of weight added and the number of repetitions were depended on the perception of effort of the patient) until failure. The resting periods between sets were 60-90 seconds and between exercises 90-150 seconds. Blood pressure (auscultation) and HR (polar watch) were monitored immediately after each exercise.

Data Analysis
Paired T-tests was used to assess hemodynamic (HR, SBP, DBP and RPP) differences between the peak Balke incremental test and the MS test and to assess differences between hemodynamics during exercise at 80% of peak VO2 and MS test.

A repeated measure ANOVA was used to assess RPP differences between each of the resistance exercises using Bonferroni method adjustment. The results are reported as means ±standard deviation (SD). A 0.05 level of significance was used to determine statistical differences (SPSS 11.0 for Windows).

RESULTS
The common criteria for terminating the incremental test were falls of SBP≥10mmHg with increased workload (N=3), ST depression>2 mm (N=4) and no increase of VO2 despite an increase of workload (N=4). Four subjects had their test terminated at RPE of 15 (upper most criterion which was approved by the Ethics committee). The mean RPE and the mean respiratory exchange ratio (RER) at termination of the test were 13.4±1.3 and 0.91±0.1 respectively. Additionally, no injuries, muscle soreness or other local adverse effect were recorded during and for 24 hours after the MS tests.

Table 2. Comparison between HR, SBP, DBP and RPP at peak Balke incremental walking test and immediately after eight resistance exercises (average) MS test. Data are means (±SD).

<table>
<thead>
<tr>
<th></th>
<th>Peak incremental test</th>
<th>MS test</th>
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</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>106.3 (18.9)</td>
<td>86.9 (12.7) *</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>134.1 (22.2)</td>
<td>118.3 (15.1)*</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>72.0 (7.6)</td>
<td>74.0 (8.7)</td>
</tr>
<tr>
<td>RPP</td>
<td>138.7 (26.1)</td>
<td>101.5 (16.2)*</td>
</tr>
</tbody>
</table>

* Indicates significant p < 0.01 between tests.

Abbreviations: HR = heart rate, SBP = systolic blood pressure, DBP = diastolic blood pressure, RPP = rate pressure product (HR×SBP/100).

HR, SBP and RPP were significantly lower during the MS test than during both the peak Balke incremental test and walking at 80% of peak VO2 (Table 2 and 3). DBP did not differ between the two tests (p>0.05).

Table 3. Comparison between HR, SBP, DBP and RPP at 80% of peak VO2 during Balke incremental walking test and immediately after eight resistance exercises (average) MS test. Data are means (±SD).

<table>
<thead>
<tr>
<th></th>
<th>80% of peak VO2</th>
<th>MS test</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>96.9 (12.8)</td>
<td>86.9 (12.7)*</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>131.8 (23.1)</td>
<td>118.3 (15.1)*</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>73.2 (10.5)</td>
<td>74.0 (8.7)</td>
</tr>
<tr>
<td>RPP</td>
<td>126.4 (28.1)</td>
<td>101.5 (16.2)*</td>
</tr>
</tbody>
</table>

* Indicates significant p<0.01 between tests.

Abbreviations: HR = heart rate, SBP = systolic blood pressure, DBP = diastolic blood pressure, RPP = rate pressure product (HR×SBP/100).

No significant RPP differences were found between upper and lower body resistance exercises (p > 0.05). The only significantly RPP difference was during the biceps curl and triceps extension exercises (105±17.7 vs. 95.1±19.6, p < 0.05) and the seated row and triceps extension exercises (106.4±20.3 vs. 95.1±19.6, p < 0.05).

DISCUSSION
The important findings of the study were that the physiological responses as determined by HR, BP and RPP changes, were less severe during a MS test than those reported during an incremental Balke treadmill test. Therefore, MS tests may be an

Levinger et al.
acceptable method to assess the maximal strength of patients with moderate heart failure.

The rationale for assessing maximal strength are, firstly, to assist in determining an accurate exercise intensity; secondly, to monitor objective changes in skeletal muscle strength (Shaw et al., 1995). The resistance training intensity level that has been recommended for cardiac patients is between 50-70% of MS (10-15 repetitions) (ACSM, 2000). However, there is a lack of information on the hemodynamic responses to maximal strength tests in CHF patients which makes it difficult to determine the resistance training intensity for this population.

Previous studies have demonstrated that RPP during intensities of 80%-100% of maximal strength exercise is lower than during submaximal aerobic treadmill exercise in patients with coronary artery disease (Crozier et al., 1989; Featherstone et al., 1993; Ghilarducci et al., 1989; Kelemen et al., 1986). The RPP responses to the incremental and strength tests reported in this study for CHF patients are in accordance with those reported for other cardiac patients. The RPP at peak VO₂ during the incremental tests (Table 2) and during exercising at 80% of peak VO₂ (Table 3) were significantly higher than during the strength tests. However, in our study both lower HR and SBP contributed to the decrease in RPP where in other studies the lower RPP was mainly due to lower HR (Featherstone et al., 1993; Kelemen et al., 1986). The HR and SBP attained in the present study compared to Featherstone et al. (1993) and Kelemen et al. (1986) was much lower in intensity as depicted by the difference in the end point of the incremental test. Patients in the current study may not have reached their true peak VO₂ as the incremental tests were terminated at submaximal exercise levels, evident by the relatively low RER and RPE. However, since a significant lower HR, SBP and RPP were observed between the treadmill and strength tests, it may emphasis that during peak aerobic exercise the differences between aerobic and resistance exercises is even greater than reported. In addition, Meyer et al. (1999) and King et al. (2000) reported a substantial increase in both HR and SBP during exercise at 60% and 80% of MS compared to resting values, however, they did not examine these responses in comparison to responses during aerobic exercise. McKelvie et al. (1995) used direct measurement of blood pressure to examine the different responses of 10 CHF patients to both aerobic (cycling at 70% of peak VO₂) and resistance (leg press at 70% of one repetition maximum) exercises. They reported no significant difference in SBP between the two tests however both HR and RPP were significantly lower during the leg press exercise compared to cycling.

Our finding supports Ghilarducci et al. (1989) Stewart et al. (1989) and Karlsdottir et al. (2002) who reported similar hemodynamic responses during weight lifting using upper and lower extremities but is in contrast to Vander et al. (1986) and MacDougall et al. (1985) who reported higher RPP during lower extremities exercises. The MS tests provoked similar RPP responses between most exercises. The only RPP difference was observed during biceps curl exercise and triceps extension and during seated row and triceps extension. Although both triceps extension and biceps curl exercises were performed with the subjects standing, the RPP during biceps curl was significantly higher. The higher RPP during biceps curl may be as a result of postural muscles of the trunk activated to stabilize the body during the test. Additionally, the higher RPP may indicate that some of the patients exhibited an increase in the intrathoracic pressure. The higher RPP during seated row may be as a result of the activation of larger muscle groups of the back (especially latissimus dorsi) compared to a smaller muscle of the triceps (triceps brachii).

In contrast to Featherstone et al. (1993) who reported a decrease in DBP during treadmill tests and Haslam et al. (1988) who reported an increase in DBP during strength exercises, we did not find any change in DBP during the incremental test nor during the MS test (p > 0.05). These data support the findings of Sparling et al (1990) who reported no change in DBP during resistance training. Others studies reported an increase in the DBP compared to resting values during strength testing (Karlsdottir et al., 2002; King et al., 2000; Squires et al., 1991). An increase in DBP of between 1 to 13 mmHg during resistance exercise (Stralow et al., 1993), with the combination of lower HR has been suggested to improve coronary artery filling at a higher perfusion pressure (McCarty, 1998; 1999).

In light of our results the MS test may be a suitable method to assess the patient’s maximal strength prior to entering a rehabilitation program. Also it appears that resistance training may be a suitable training method for CHF patients.

In view of the current study results, there are three limitations that should be acknowledged. Firstly, our results may not be generalized to the entire CHF population, as the number of subjects is relatively small. Secondly, we measured the blood pressure noninvasively immediately after each strength test. An indirect measurement of systolic blood pressure (by auscultation) may be up to 13% lower during rest compared to direct measurements (by brachial artery catheter) and up to 35% lower immediately after weight lifting (Wieck et al., 1990) which may suggest that the actually SBP
during the weight lifting and immediately after is higher than reported. However, it is important to note that most studies which examined the BP responses during acute and chronic exercises used the auscultation technique (Delagardelle et al., 1999; Featherstone et al., 1993; Karlsdottir et al., 2002; Maiorana et al., 2000; Stewart et al., 1998; Stralow et al., 1993). Nevertheless, further studies employing direct blood pressure measurements are needed in order to clarify this issue. Thirdly, due to equipment limitations, MS was defined as the heaviest weight subject could lift between 1 to 4 repetitions (approximately 85-95% of one repetition maximum). Further studies are needed in order to assess the safety of resistance exercise of varying intensities including one repetition maximum.

CONCLUSIONS

The physiological responses, as measured by HR, BP and RPP, to a maximal strength test in this study were lower compared to both peak incremental test and compared to walking at 80% of peak VO2. Also the finding suggests that MS tests may be an acceptable method to assess the maximal strength of patients with moderate heart failure.

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Physiological responses of CHF patients


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KEY POINTS

- The physiological responses of CHF patients to maximal strength test were less severe than those reported during a walking incremental test.
- There were similar hemodynamic responses during upper and lower resistance exercises.
- Maximal strength test appears to be an acceptable method to assess the maximal strength of patients with moderate CHF.