Hypertension is a risk factor for heart disease, and chronic exercise is recognized as a method for reducing resting blood pressure. Recent studies report that while exercise may benefit the majority of the population, the response is not always uniform; some individuals have an adverse blood pressure response to chronic aerobic exercise programmes. The purpose of this study was to examine the individual changes in resting blood pressure in response to exercise training regimens aimed at increasing muscle mass and strength. We have also included exercise (resistance and aerobic) in combination with blood flow restriction (BFR). Of 74 individuals, 11% had an increased risk, 16% had a decreased risk and 73% had no change in risk classification following exercise. The statistical analysis found that the group that decreased risk with exercise tended to have higher baseline levels of blood pressure. However, there were little baseline differences between the group that increased risk or the group that had no change in risk, suggesting that starting values may not necessarily determine who will see a beneficial response. In conclusion, the blood pressure adaptation to resistance training and exercise with BFR is not homogeneous with some participants increasing, decreasing or staying in the same risk category following an exercise intervention. These are important findings as they would not have been noted or discussed when looking only at the group means. Future research may identify molecular predictors so that individuals at risk for adverse events can be identified prior to exercise.
statistically looking at group means. Therefore, the purpose of this investigation is to examine the individual changes in resting blood pressure in response to exercise training regimens aimed at increasing muscle mass and strength. In addition, we have included exercise (resistance and aerobic) in combination with blood flow restriction (BFR) into this exploratory analyses to determine the prevalence of adverse events to this novel mode of exercise which has been show to stimulate muscle size and strength gains with low exercise intensities (Loenneke et al., 2012).

Methods
Blood pressure data on 74 adults from four separate studies were available for retrospective analyses. All blood pressure measurements were taken at the same time of day for each participant following a period of quiet rest. Participants were asked to abstain from caffeine and food for 3 h prior to each testing session. These studies will be briefly described, followed by the operational definitions for changes in the classification of blood pressure risk.

Lower body resistance training on arterial compliance and calf blood flow
Recreationally active but not resistance trained men (age: 21 years) completed a 6-week (3 sessions per week) training intervention using low-intensity isotonic machine-based resistance exercise with BFR (20% 1RM, n = 10), moderate intensity (45% 1RM, n = 9) or high-load resistance exercise (70% 1RM, n = 12). For analyses, the moderate intensity and high-load resistance exercise were combined into a single group, traditional resistance training (Falci et al., 2012). Participants were excluded for any of the following: known cardiovascular, pulmonary or metabolic disease, orthopaedic problems and smoking.

Upper body resistance training on carotid arterial compliance
Untrained men (age: 24 years) completed a 6-week (3 sessions per week) training intervention using low-intensity free weight bench press exercise with BFR (30% 1RM, n = 10) or high-load free weight bench press exercise (75% 1RM, n = 9) (Ozaki et al., 2013). All participants were normotensive (≤140/90 mmHg), were non-smokers, were not taking any medication and were free of overt chronic diseases as assessed by medical history.

Effects of leg blood flow restriction on carotid arterial compliance
Sedentary men and women (age: 66 years) completed a 10-week (4 sessions per week) walking intervention at 45% of heart rate reserve with (n = 13) and without (n = 10) BFR. Only BFR walking data will be discussed (Ozaki et al., 2011). All participants were normotensive (≤140/90 mmHg) and free of overt chronic diseases as assessed by medical history, physical examination and complete blood chemistry and hematological evaluation.

Effects of low-intensity walking with blood flow restriction on muscle strength and aerobic capacity
Physically active men and women (age: 68 years., n = 11) completed a 6-week (5 sessions per week) walking intervention at 67 m min⁻¹ with BFR (Abe et al., 2010). All participants filled out a medical questionnaire and had a health interview with a physician prior to the study to ensure that there were no existing health risks. Participants who suffered from a chronic disease such as cardiovascular disease, diabetes, cancer, orthopaedic disorders, deep vein thrombosis or peripheral vascular disease were excluded from the study.

Operational definitions
An adverse response was defined as an increase in SBP, DBP and/or MAP of at least 10 mmHg which would place the participant in a higher risk classification category (Table S1) (Chobanian et al., 2003). A decreased risk was defined as a decrease in SBP, DBP and/or MAP of at least 10 mmHg which would place the participant in a lower risk classification category. If the value did not move the participant into a different risk classification category, then it was defined as no change. The change value of 10 mmHg was based on the definition used previously as an adverse response by Bouchard et al. (2012) for SBP. This is to help take into account the measurement of error, including the variance among laboratories or laboratory technicians, and the normal day-to-day biological variation of the trait. We arbitrarily applied the same change value for DBP and MAP.

Statistical analysis
Values are represented by means and medians with variability represented in standard deviations (SD). Resting MAP was calculated as \[\frac{1}{2} \times (DBP + SBP)\]. One-way ANOVAs were used to determine differences in age, BMI, SBP, DBP, MAP, pulse pressure (PP) and percent changes in strength. If significance was found, a Tukey’s post hoc test determined where the differences existed. Significance was set at P ≤ 0.05. In addition, percentages were used to represent the prevalence of those increasing, decreasing or maintaining their risk classification.

Results
Table 1 presents data on age, BMI, SBP, DBP, MAP, PP and percent change in strength with training separated by those who had an increased risk, decreased risk or by those who had no change in their risk. There were significant differences
between groups for BMI (P = 0.004), SBP (P<0.001), DBP (P<0.001), MAP (P<0.001), PP (P<0.001) and percent changes in strength (P = 0.034) with training (Table 1).

Means, medians, and the minimum (Min) and maximum (Max) for BMI: Body Mass Index; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure; PP: Pulse Pressure.

aDecreased risk different than No change in Risk.

bIncreased risk different than decreased risk.

cIncreased Risk different than No change in Risk.

Table 1  Characteristics of those in differing risk categories.

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Age (Mean, SD)</th>
<th>BMIa</th>
<th>SBPa,b,a</th>
<th>DBPa</th>
<th>MAPb,a</th>
<th>PPb,a</th>
<th>Δ Strength (%)b,c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased risk (n = 8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>43 (23)</td>
<td>23-3</td>
<td>126 (10)</td>
<td>72 (6)</td>
<td>89 (8)</td>
<td>54 (5)</td>
<td>6 (10)</td>
</tr>
<tr>
<td>Median</td>
<td>47</td>
<td>20-4</td>
<td>127</td>
<td>73</td>
<td>91</td>
<td>54</td>
<td>5</td>
</tr>
<tr>
<td>Min–Max</td>
<td>19 to 69</td>
<td>20-2 to 29-4</td>
<td>108 to 137</td>
<td>59 to 79</td>
<td>75 to 98</td>
<td>48 to 63</td>
<td>-14 to 17</td>
</tr>
<tr>
<td>Decreased risk (n = 12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>46 (26)</td>
<td>26-1</td>
<td>149 (25)</td>
<td>81 (17)</td>
<td>104 (19)</td>
<td>68 (11)</td>
<td>21 (18)</td>
</tr>
<tr>
<td>Median</td>
<td>45</td>
<td>25-0</td>
<td>135</td>
<td>74</td>
<td>97</td>
<td>65</td>
<td>17</td>
</tr>
<tr>
<td>Min–Max</td>
<td>19 to 78</td>
<td>20-3 to 41-6</td>
<td>123 to 193</td>
<td>57 to 110</td>
<td>77 to 138</td>
<td>48 to 83</td>
<td>-7 to 57</td>
</tr>
<tr>
<td>No Change in risk (n = 54)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>33 (20)</td>
<td>22-4</td>
<td>114 (14)</td>
<td>63 (9)</td>
<td>81 (11)</td>
<td>51 (8)</td>
<td>18 (12)</td>
</tr>
<tr>
<td>Median</td>
<td>23</td>
<td>21-7</td>
<td>115</td>
<td>63</td>
<td>80</td>
<td>53</td>
<td>16</td>
</tr>
<tr>
<td>Min–Max</td>
<td>18 to 76</td>
<td>17-7 to 30-6</td>
<td>80 to 143</td>
<td>48 to 80</td>
<td>59 to 104</td>
<td>33 to 65</td>
<td>0 to 51</td>
</tr>
</tbody>
</table>

Figure 1 graphically represents the prevalence of those increasing, decreasing or not changing in risk classification partitioned by training modality. In addition, the number of

Figure 1  Percentages of those participants in each exercise modality separated out by risk classification (a): Systolic Blood Pressure (b): Diastolic Blood Pressure (c): Mean Arterial Pressure.

Means, medians, and the minimum (Min) and maximum (Max) for BMI: Body Mass Index; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure; PP: Pulse Pressure.

aDecreased risk different than No change in Risk.

bIncreased risk different than decreased risk.

cIncreased Risk different than No change in Risk.
participants in each category per study can be found in Table S2.

**Discussion**

This retrospective analysis on studies aimed at increasing muscle mass suggests that some participants do have an adverse response in blood pressure following traditional resistance training and low-intensity exercise in combination with BFR. Furthermore, resting blood pressure is reduced in some participants, but most do not change risk categories.

The statistical analysis found that the group that decreased risk with exercise tended to have higher baseline levels of blood pressure. However, there were little baseline differences between the group that increased risk or had no change in risk, suggesting that starting values may not necessarily determine who will see a beneficial response to training. Baseline PP, an indirect marker of aortic stiffness, was highest in the decreased risk group. Increased PP is a predictor of global PP, an indirect marker of aortic stiffness, was highest in the decreased risk group. Increased PP is a predictor of global cardiovascular mortality, independent of other known cardiovascular factors such as age, MAP, total cholesterol and smoking (Benetos et al., 1997). This finding suggests that those with the highest PP’s at baseline may have the greatest capacity to decrease risk with exercise. In addition, the percent increases in strength were found to be lowest in the group that had an increased risk with exercise, suggesting that low responders to exercise are more likely to experience an increase in resting blood pressure. Although that is an attractive hypothesis, caution should be applied when interpreting this strength finding, because previous research has shown that while aerobic exercise in combination with BFR increases muscle size and strength, it is less than that observed with resistance training (Loenneke et al., 2012). Therefore, the low strength value in the increased risk group is likely more of a function of the exercise mode itself. The findings from this investigation and others suggest that these effects may have genetic ties (Rice et al., 2002a,b; Young et al., 2005; Rankinen & Bouchard, 2008; Bouchard et al., 2012). It is unlikely that one molecular marker will explain the heterogeneous blood pressure adaptation to exercise training; instead, it is likely that blood pressure will be influenced by multiple genes, with each having only a modest effect (Rice et al., 2002b).

In conclusion, the blood pressure adaptation to resistance training and exercise with BFR is not uniform with some participants increasing, decreasing or staying in the same risk category following an exercise intervention. Although, the number of participants having an adverse response is low for SBP (4%), DBP (3%) and MAP (5%), the data does indicate that these adverse events do occur and it is unlikely due to measurement error as the change needed to be considered real is ≥10 mmHg, a robust change. In addition, there were little baseline differences between the group that increased risk or the group that had no change in risk, suggesting that starting values may not necessarily determine who will see a beneficial response. These are important findings as they would not have been noted or discussed when looking only at the group means. Future research may identify molecular predictors so that individuals at risk for adverse events can be identified and offered proper guidance for reducing any potential health risk to exercise.

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**Conflict of interest**

The authors declare no conflict of interest.

**References**


Ozaki H, Yasuda T, Ogawara R, Sakamaki-Sunaga M, Naito H, Abe T. Effects of high-intensity and blood flow-restricted low-intensity resistance training on carotid

**Supporting Information**

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Baseline values for risk classification.

**Table S2.** Number of participants increasing, decreasing, or not changing risk separated out by each individual study included in the analysis.