The benefit of strength training on arterial blood pressure in patients with type 2 diabetes mellitus measured with ambulatory 24-hour blood pressure systems

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Summary. Background: An ambulatory 24-hour BP-monitoring (ABPM) is of paramount importance, while patients are engaged in their usual activities, for a better representation of blood pressure (BP). ABPM provides not only automated measurements of brachial-artery pressure over a 24-hour period but also a highly reproducible circadian profile. The purpose of this investigation was to evaluate the effect of strength training (ST) on BP in patients with type 2 diabetes mellitus (T2D) and to obtain new and important information on BP profiles over 24-hour by using an ABPM Material and methods: We recruited ten patients (mean age: 59.7 ± 7.3) from our Diabetes Department who participated in a 4-month systematic ST program on three non-consecutive days of the week. The ST program consisted of exercises for all major muscle groups. The numbers of sets for each muscle group were systematically increased from 3 at the beginning of the program to 4, 5 and finally 6 sets per week at the end of the program. The ABPM equipment (oscillometric Model Mobil-O-Graph® CE 0434) was applied before and after 4-month training period. Routine HbA1C levels were measured using standard techniques. All subjects took a cycling test to measure maximum oxygen uptake (VO₂peak) and maximum workload (Wmax) before and after the training period. Maximal strength was determined by one repetition maximum (1RM) in kp for the bench press, bench pull and leg press exercises, using the Concept 2 Dyno®. Results: Analysis of the pooled daytime and night-time data showed a significant reduction of mean arterial BP (from 93.8 ± 19.2 to 90.6 ± 14.3 mmHg; p < 0.01) after a 4-month ST program. The ABPM revealed that the ST program reduced BP to a greater extent during the day than during the night. This difference was significant for the diastolic BP (p < 0.05). The HR was significantly reduced by ST (p < 0.05). The above results suggest that ST is an effective method for reducing BP in patients with type 2 diabetes mellitus (T2D).

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Future CVD development. These results demonstrate that ST may not only increase muscle strength but also decrease BP and perhaps the risk of future CVD development.

Key words: Strength training, diabetes mellitus 2, hypertension, ambulatory 24-hour blood pressure monitoring, HbA1C

Introduction

The effectiveness of physical exercise has long been recognized for the treatment of T2D [1, 2]. Endurance training (ET) has been advocated as the most suitable form of exercise mode [3, 4], with many positive metabolic effects [5], such as improvements in lipid profile [6–8], reduced body fat [9, 10] and decreased blood glucose (BG) levels [11].

The beneficial effect of ET on blood pressure (BP) is well documented. Several large epidemiological studies and systematic reviews [12–16] have depicted an inverse relationship between physical activity and BP. Higher levels of physical activity and greater fitness are associated with a reduced incidence of hypertension and cardiovascular disease and mortality [17]. A recent study [18] documented the benefits of exercise in hypertensive patients and showed that ET decreases BP through a reduction in systemic vascular resistance and favourably affects concomitant cardiovascular risk factors. The BP-lowering effect of physical training seems to be independent of weight loss [19] and is believed to be mediated via reduced sympathetically induced vasoconstriction in the trained state, and decreased catecholamine levels.

Chronic essential hypertension is a major risk factor for cardiovascular disease [20]. The Framingham Heart Study proved that participants with high BP had higher rates of CVD as compared to those with optimal levels [21]. A meta-analysis encompassing 61 prospective studies underscored that the risk of cardiovascular death decreased linearly with decreasing BP up to a systolic BP of less than 115 mmHg and a diastolic BP of less than 75 mmHg [22].

The decrease in BP observed with ET in T2D patients [23, 24] and healthy elderly [25, 26] is now a well-recognized phenomenon and it is recommended to lower BP in patients with T2D [27].

In comparison, only limited information on the effect of strength training (ST) on T2D is available. Reports on the effects of ST on BP in T2D patients have so far been controversial. Of the limited papers available for ST, two [28, 29] report no beneficial changes in BP as a result of ST. Positive effects of ST on BP, however, have been observed in three additional studies, where the programs consisted of ST with 4 or 6 months duration [23, 30, 31]. In all studies, a significant reduction in systolic and diastolic BP was observed. However, in these studies only office- or self-monitored BP measurements, often repeated after few minutes, were performed. These results cover only a small fraction of BP during a 24-hour period and if measured in a doctor’s office a 20 to 30% increases in BP “white coat effect” [32] is possible.

An ambulatory 24-hour BP-monitoring (ABPM) is of paramount importance, while patients are engaged in their usual activities, for a better representation of blood pressure (BP). ABPM provides automated measurements of brachial-artery pressure over a 24-hour period and provides a highly reproducible circadian profile.

The purpose of this investigation was to evaluate the effect of ST on BP in T2D patients and to obtain new and important information on BP profiles over 24 hours by using an ABPM.

Patients, material and methods

Study population

We recruited ten patients (mean age: 59.7 ± 7.3) from our Diabetes Department who participated in a 4-month systematic ST program. All patients fulfilled the diagnosis of T2D, according to the WHO criteria, with a fasting glucose concentration of ≥7.0 mmol/l (≥126 mg/dl). A physician collected a medical history and performed a physical examination on all subjects. Subjects were excluded if they had rapidly progressive or terminal illness, myocardial infarction, uncontrolled arrhythmias, third-degree heart block, elevated blood pressure (>200/100 under therapy) or valvular heart disease, nephropathy (microalbuminuria > 50 μg/min albumin excretion), severe peripheral or autonomic neuropathy, or diabetic proliferative retinopathy. All participants were on oral anti-diabetic drug treatment and no participant was on insulin therapy. All participants were at least on triple antihypertensive medication. The participants were advised to maintain their current medications unaltered during the entire study period. No medication was newly started during the exercise period. The study was approved by a local ethics committee. The purpose, nature, and potential risks of the study were explained in detail to the participants prior to obtaining their written consent.
Training program
Ten subjects participated in a four-month systematic ST program on three non-consecutive days of the week. A brief warm-up period that involved 10 min of moderate cycling with very low intensity was performed before each training session. A professional instructor and an experienced physician instructed the patients on correct exercise techniques and supervised them throughout the entire training period as well. During the first two weeks, the weight was kept to a minimal level so that the patients could learn the exercise techniques and allow the muscles to adapt to the training as well as prevent muscle soreness. From the third week, the objective of the training was hypertrophy and started with three sets per muscle group per week. One set consisted of 10–15 repetitions without interruption until severe fatigue occurred and completion of further repetitions was impossible. The training load was systematically adapted to keep the maximum possible repetitions per set between 10 and 15. When more than 15 repetitions were successfully performed at a given weight, the weight was increased by an amount that permitted approximately ten repetitions to be performed. The numbers of sets for each muscle group were systematically increased from 3 at the beginning of the program to 4, 5 and finally 6 sets per week at the end of the program. The ST program consisted of exercises for all major muscle groups. Exercises to strengthen the upper body included bench press (pectoralis), chest cross (horizontal flexion of the shoulder joint), shoulder press (trapezius), pull downs (latissimus dorsi), bicep curls, triceps extensions and exercises for abdominal muscles (sit-ups). Lower body exercises included leg press (quadriceps femoris), calf raises and leg extensions (biceps femoris).

Testing
A: Ambulatory 24-hour blood pressure monitoring:
In all patients the oscillometric Model Mobil-O-Graph® CE 0434 (I.E.M. GmbH, Stolberg, Germany) was used. The ABPM equipment was applied before and after 4-month training period. The cuff was fixed to the non-dominant arm and the device was set to obtain automatic readings every 15 min during the day (7.00 a.m.–10.00 p.m.) and every 30 min at night (10.00 p.m.–7.00 a.m.). The Mobil O Graph ambulatory monitor fulfilled the criteria of the BHS protocol (British Hypertension Society, BHS).

B: Laboratory measurements
Routine HbA1c levels were measured using standard techniques.

C: Spiroergometry
Cardio-respiratory fitness was measured by an exercise stress test. All subjects performed a cycling test to exhaustion on an electrically braked cycle ergometer (Ergometrics 900, Ergoline, Germany) to measure maximum oxygen uptake (VO2peak) and maximum workload (Wmax) before and after the training period. HR was continuously monitored via an electrocardiogram, with BP measured in the final minute of each work level. The exercise was started with a work load of 25W and was then increased stepwise by 25W every 2 min until exhaustion.

D: Dynamometry
Maximum strength was determined by one repetition maximum (1RM) in kp using the Concept 2 Dyno®. 1RM is the maximum strength that a muscle group is able to generate with one single contraction. A maximum of 3 attempts are allowed and the best score counts are recorded. The representative exercises for the determination of 1RM, as measured by the Concept 2 Dyno, include bench press, bench pull and leg press, all performed in a seated position.

E: Statistical analysis:
Data analysis was performed using the Statistical Package for Social Sciences (SPSS 10.0). All parameters were described by mean values ± standard deviation (SD). Paired student’s t-test was used to examine significant differences of the same variables within the group before and after the training period. P<0.05 were considered statistically significant.

Results
A summary of the patients’ demographic and clinical characteristics at baseline and after 4-month ST is shown in Table 1. The analysis of the pooled data of daytime and nighttime showed a significant reduction of mean arterial blood pressure (MAD) (from 93.8 ± 13.5 to 90.6 ± 14.3 mmHg; p<0.01) after 4-month ST (−3.4% mmHg; Table 2). Significant reductions of BP were only observed during daytime, while nighttime measurements did not highlight any changes. Regarding the changes of HR after 4 months of ST, a significant increase of HR during ABPM was measured (from 69.8 ± 12.2 to 70.9 ± 13.2, +1.6%; p<0.01). ST led to raised HR during the day and reduced HR during the night (Table 2). Muscle strength data and cardio-respiratory data are provided in Table 1. VO2peak and Wmax improved significantly (19.9 ± 3.0 to 21.1 ± 3.1 ml/kg/min, p<0.05 and 128 ± 26 to 138 ± 32 W, p<0.05). Maximum strength (1RM) improved significantly for
the bench press (45 ± 13 to 57 ± 16 kg; p < 0.01), the bench pull (48 ± 12 to 59 ± 15 kg; p < 0.01) and the leg press (98 ± 28 to 129 ± 47 kg; p < 0.01). After 4 months of ST, HbA1C underscored a significant reduction by 14.5% (8.3 ± 1.7 to 7.1 ± 0.9%; p < 0.01). Lean body mass increased, percent of body fat decreased significantly after 4 months of ST (54.2 ± 6.6 to 56.2 ± 7.6 kg, p < 0.05 and 35.2 ± 6.8 to 33.9 ± 6.4%, p < 0.05).

**Discussion**

Up to 80% of patients with T2D will develop macrovascular disease [33]. Hypertension is a significant risk factor for CVD, and clinical trials of BP control in T2D have shown a consistent and dramatic benefit in preventing clinical outcomes, including cardiovascular mortality and morbidity [34]. The evidence for the BP-lowering effect is much less compelling for ST than for ET. ST has not yet been recommended as a sole intervention to reduce the risk of hypertension and to decrease BP in hypertensive subjects with T2D, but has been recommended by the ACSM as an adjunct to ET in the prevention, treatment and control of hypertension [14]. In the past, ST was considered a contraindication for hypertensive patients because of possible excessive pressure load it puts on the heart. However, many recent reviews demonstrate that ST does not exacerbate high BP and is not associated with precipitating cardiac events [14, 15, 18, 35].

The first and foremost aim of this study was to obtain new and important information on BP profiles over 24 hours in patients with T2D by using an ABPM. ABPM yields multiple BP readings during all of the patients’ activities, including sleep, and gives a far better representation of the BP burden than what will be obtained during a few minutes in the doctor’s office. The results of a large-scale prospective study [36] indicate that after adjustment for classic risk factors including office BP, the ABPM provide additional prognostic information concerning cardiovascular events but does not predict the risk of death from any cause. The second aim of this investigation was to evaluate the effect of ST on systolic and diastolic BP in patients with T2D measured with ABPM. Recent studies examining the results of ST have shown that dynamic ST is associated with a decrease in resting systolic and diastolic BP [23, 30, 31, 37] in hypertensive adults. However, these results are not in agreement with the results of older studies that tested the effect of ST on hemodynamic parameters and found no effect of ST on resting arterial systolic and diastolic BP [28, 29] in hypertensive patients with T2D.

**Tab. 1: Summary of patients’ demographic and clinical characteristics at baseline and after 4 months**

<table>
<thead>
<tr>
<th>Duration of diabetes (a)</th>
<th>9 ± 4</th>
<th>10.3 n.s. 72.1</th>
<th>12.9 n.s. 75.7</th>
<th>12.7 n.s. 75.7</th>
<th>12.8 n.s. 75.7</th>
<th>12.9 n.s. 75.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>HbA1C (%mean ± SD)</td>
<td>8.3 ± 1.7</td>
<td>7.1 ± 0.9</td>
<td>&lt;0.01</td>
<td>7.7 ± 0.7</td>
<td>&lt;0.01</td>
<td>7.8 ± 0.6</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>31.5 ± 4.1</td>
<td>30.9 ± 4.1</td>
<td>n.s.</td>
<td>31.5 ± 4.1</td>
<td>n.s.</td>
<td>31.5 ± 4.1</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>54.2 ± 6.6</td>
<td>56.2 ± 7.6</td>
<td>&lt;0.05</td>
<td>54.2 ± 6.6</td>
<td>&lt;0.05</td>
<td>54.2 ± 6.6</td>
</tr>
<tr>
<td>Percent body fat (%)</td>
<td>35.2 ± 6.8</td>
<td>33.9 ± 6.4</td>
<td>&lt;0.05</td>
<td>35.2 ± 6.8</td>
<td>&lt;0.05</td>
<td>35.2 ± 6.8</td>
</tr>
<tr>
<td>Peak VO₂ (ml x kg⁻¹ x min⁻¹)</td>
<td>19.9 ± 3.0</td>
<td>21.1 ± 3.1</td>
<td>&lt;0.05</td>
<td>19.9 ± 3.0</td>
<td>&lt;0.05</td>
<td>19.9 ± 3.0</td>
</tr>
<tr>
<td>Maximum workload (Wmax)</td>
<td>128 ± 26</td>
<td>138 ± 32</td>
<td>&lt;0.05</td>
<td>128 ± 26</td>
<td>&lt;0.05</td>
<td>128 ± 26</td>
</tr>
<tr>
<td>Bench press (kg)</td>
<td>45 ± 13</td>
<td>57 ± 16</td>
<td>&lt;0.01</td>
<td>45 ± 13</td>
<td>&lt;0.01</td>
<td>45 ± 13</td>
</tr>
<tr>
<td>Bench pull (kg)</td>
<td>48 ± 12</td>
<td>59 ± 15</td>
<td>&lt;0.01</td>
<td>48 ± 12</td>
<td>&lt;0.01</td>
<td>48 ± 12</td>
</tr>
<tr>
<td>Leg press (kg)</td>
<td>98 ± 28</td>
<td>129 ± 47</td>
<td>&lt;0.01</td>
<td>98 ± 28</td>
<td>&lt;0.01</td>
<td>98 ± 28</td>
</tr>
</tbody>
</table>

HbA1C: Glycosylated haemoglobin, BMI: Body mass index, Peak-VO₂: maximal oxygen uptake, Wmax: Maximum workload using a cycle ergometer, n.s.: not significant, p-value: difference within the group before and after 4 months of strength training.

Systolic: mean systolic pressure, diastolic: mean diastolic pressure, blood pressure: mmHg ± SD, nighttime: 10 p.m.–7 a.m., daytime: 7 a.m.–10 p.m., MAD: mean arterial blood pressure, p: p-value, n.s.: not significant, HR: heart rate (beats per minute).

**Tab. 2: Exercise Data at Baseline and after 4 months**

<table>
<thead>
<tr>
<th>24-Hour</th>
<th>Baseline</th>
<th>4 months p</th>
<th>%change</th>
<th>Baseline</th>
<th>4 months p</th>
<th>Daytime</th>
<th>Baseline</th>
<th>4 months p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic</td>
<td>122.3 ± 18.9</td>
<td>118.3 ± 17.2</td>
<td>&lt;0.01</td>
<td>3.3</td>
<td>110.0 ± 16.5</td>
<td>110.8 ± 17.2</td>
<td>n.s.</td>
<td>126.5 ± 17.7</td>
</tr>
<tr>
<td>Diastolic</td>
<td>73.4 ± 11.7</td>
<td>70.7 ± 13.1</td>
<td>0.02</td>
<td>3.7</td>
<td>66.8 ± 12.4</td>
<td>66.2 ± 12.7</td>
<td>n.s.</td>
<td>75.7 ± 10.6</td>
</tr>
<tr>
<td>MAD</td>
<td>93.8 ± 13.5</td>
<td>90.6 ± 14.3</td>
<td>&lt;0.01</td>
<td>3.4</td>
<td>85.4 ± 16.9</td>
<td>84.3 ± 16.4</td>
<td>n.s.</td>
<td>96.7 ± 12.9</td>
</tr>
<tr>
<td>HR</td>
<td>69.8 ± 12.2</td>
<td>70.9 ± 13.2</td>
<td>&lt;0.01</td>
<td>1.6</td>
<td>63.4 ± 12.3</td>
<td>62.7 ± 10.3</td>
<td>n.s.</td>
<td>72.1 ± 11.2</td>
</tr>
</tbody>
</table>

Systolic: mean systolic pressure, diastolic: mean diastolic pressure, blood pressure: mmHg ± SD, nighttime: 10 p.m.–7 a.m., daytime: 7 a.m.–10 p.m., MAD: mean arterial blood pressure, p: p-value, n.s.: not significant, HR: heart rate (beats per minute).
Randomized controlled trials examining the effects of ST on resting BP in adults have resulted in different findings. A recent meta-analysis of nine randomized controlled trials on mostly dynamic ST revealed a weighted net reduction in BP of 3.2 systolic and 3.5 mmHg diastolic [18]. These results are in agreement with two meta-analyses that also examined the effects of ST on resting systolic and diastolic BP in normotensive and hypertensive adults [35, 38]. Although the findings of these two studies, with a decrease of approximately 3 mmHg for both resting systolic and diastolic BP, were modest, a reduction of as little as 3 mmHg in systolic BP has been estimated to reduce coronary heart disease by 5–9%, stroke by 8–14%, and all-cause mortality by 4% [39].

In our study, a significant reduction of MAD (−3.4% mmHg) was observed after ST. We found significant reductions in daytime BP, while nighttime measurements did not reveal any changes. We found no extreme increases of BP during and after ST, and we support the findings of earlier investigations [40] that high-intensity ST does not negatively affect BP. We believe that the BP-lowering effect of ST in daytime is mediated via reduced sympathetically induced vasoconstriction and decreased catecholamine levels in the trained state.

Conclusion

We found no extreme increases of BP during or after training in patients with T2D, and we support the findings of earlier investigators, that high-intensity ST does not negatively affect BP. On the contrary, we found a significant reduction of mean arterial BP measured with an ambulatory 24-hour blood-pressure monitoring system. In conclusion, the results of this study confirm that ST does not increase BP, as it was once thought, and might even have potential benefits on resting systolic and diastolic BP. Although the number of studies on the effects of ST on BP is small, these results suggest that ST may not only increase muscle strength but also decrease BP and the risk of future development of CVD.

References


