The impact on glycemic control through progressive resistance training with bioDensity™ in Chinese elderly patients with type 2 diabetes The PReTTy2 (Progressive Resistance Training in Type 2 Diabetes) Trial

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ABSTRACT

Aims: To evaluate the effects of a novel, low-volume, high-intensity Progressive Resistance Training (PRT) technique on blood glucose control in elderly Chinese patients with Type 2 Diabetes.

Materials and methods: The PReTTy2 trial enrolled 300 male and female patients with Type 2 Diabetes in a randomized resistance training program with the bioDensity™ technique. 100 were control patients with no training intervention and 200 had resistance training. Anthropometry, biochemical parameters, HbA1c and fasting plasma glucose (FPG) were measured at baseline, 3-month and 6-month intervals.

Results: 265 patients completed the study with no adverse events. There were no statistically significant differences in HbA1c for all patients, control and PRT groups, at baseline ($p = 0.60$), 3 months ($p = 0.42$) and 6-months ($p = 0.45$). Subgroup analysis with baseline HbA1c > 7.5% (58 mmol/mol), showed statistically significant differences in HbA1c and FPG between groups at 6 months ($p < 0.05$). All PRT group patients had statistically significant differences from baseline at 6 months for HDL ($1.25 + 0.32$ vs. $1.17 + 0.26$ mmol/L, $p < 0.001$), LDL (3.23 ± 0.89 vs. 2.93 ± 0.80 mmol/L, $p < 0.001$) and total cholesterol (4.97 ± 1.22 vs. 4.58 ± 1.03 mmol/L, $p < 0.001$).

Conclusions: PRT improves glycemic indices in elderly patients with Type 2 Diabetes with poor glucose control as an adjunct to diet and medication. Progressive Resistance Training with bioDensity™ is feasible, safe and effective in elderly patients with Type 2 Diabetes.

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1. Introduction

As one of the most prevalent chronic metabolic diseases of the twenty-first century [1], diabetes is a complex disease requiring on-going medical oversight and care that, by applying multifactorial strategies, can reduce physiologic risks and improve glycemic control. The latest Standards of Medical Care for Diabetes – 2018 [2] recommend that patients should have lifestyle and management changes as an essential aspect of diabetes care in order to maintain the highest quality of life and improving longevity in older adults. As a part of lifestyle intervention, *physical activity* is defined as "bodily movement produced by the contraction of skeletal muscle that substantially increases energy expenditure" [3]. This term can be interchanged with the term exercise, which, for patients with Type 2 Diabetes consists of aerobic and resistance training [2].

Specifically focusing on resistance training, people with Type 2 Diabetes should progress in frequency, duration and intensity their exercise activities. Many older adults may be unable or unwilling to intensify or even be able to do their resistance exercises, performed with weights or weight machines, even though it may improve their HbA_{1c} levels [4].

BioDensity™ (bD^{TM}) is a relatively new mode of Resistance Training that is accessible in health/fitness and rehabilitation settings (Supplemental Fig. 1). It is a safe, self-induced, progressive resistance loading that induces a neuromusculoskeletal stimulus providing levels of resistance up to multiples of body weight, which could not be done with conventional resistance training [5].

Few randomized clinical trials (RCT) have been done among Chinese elderly adults on the effects of PRT on Type 2 diabetes management. The purpose of our project was to study the effect of a PRT program with bD^{TM} on glycemic control and cardiovascular risk factors.

The primary outcome of our study was improving glycemic control as measured by HbA_{1c} and FPG. Secondary outcomes included (1) anthropometry characteristics, (2) cardiovascular risk factors measured by total cholesterol (TC), triglycerides (TG), HDL-cholesterol (HDL-C), LDL-cholesterol (LDL-C), systolic blood pressure (SBP) and diastolic blood pressure (DBP).

2. Materials and methods

2.1. Study design

The study was a multi-center, randomized, parallel controlled trial at 4 ambulatory clinics of Huashan Hospital, Shanghai, PRC. Inclusion criteria included willingness to participate in the study, diagnosis of type 2 Diabetes, aged 50 to 75 years, regular medical follow up, treatment with diet and/or oral antihyperglycemic medications for at least 60 days, not insulin dependent and the ability to do high-intensity resistance training sessions. Patients that were enrolled did not have any changes to antihyperglycemic or lipid-lowering medications during the study. If changes were required, due to individual clinical needs, to these medications during the study, the patient(s) were dismissed from the study so as not to confound results. Exclusion criteria included: history or physical findings suggestive of ischemic heart disease, active oncologic diagnosis, psychiatric disorders, uncontrolled hypertension (>160/90 mmHg), advanced diabetes neuropathy, diabetes retinopathy, hematologic disorders with a platelet count less than 100,000, current or prior participation in a structured PRT program, or patients with a medical condition listed in the American College of Sports Medicine absolute exercise contraindications [6].

Following completion of enrollment, participants were randomized using a computer-generated random number sequence methodology. All research staff involved in the assessment were blinded to the group allocation. Participants were randomly assigned to one of two groups: The PRT group was assigned to receive community-based bD^{TM} exercise intervention; A control group that had no additional training interventions.

The study was approved by the Human Investigation Ethics Committee at Huashan Hospital. Written informed consent was obtained from all participants prior to commencing the study.

2.2. Resistance training assessment

Participants were trained to perform four isometric exercises (Supplemental Fig. 1) on a bioDensity™(bD^{TM}) resistance training equipment (Performance Health Systems, Inc., Northbrook, IL), which is a commercially available modality approach to neuromuscular and osteogenic loading [7]. The exercises performed on the bD^{TM} equipment causes limited-range muscle contractions at or near the optimal force production joint angles. Each exercise is designed to be performed at or near "optimal biomechanical positioning" (i.e., joint angles) to facilitate maximal force production/application through multiple motor unit recruitment [7]. Theoretically, performing muscular contractions in "optimal biomechanical positioning" allows for self-induced skeletal loading up to multiples of body weight.

The participants performed one training session per week. For each of the four exercises (chess press, leg press, core pull and vertical lift) they performed a maximal contraction for five seconds. Participants accomplished every session within 5–10 min weekly during the study and were supervised by qualified trainers. The isometric contraction exercises have approximately a five-centimeter range of motion with minimal change in the joint angle. Over the study period the participants were able to increase the multiples of body weights on the bD^{TM} device. The male subjects had an average weight of 69.6 Kg. and the female subjects had an average weight of 63.7 Kg. We measured all multiples of body weight (MOB's), but the most significant increase is usually expected in the leg press (Supplemental Fig. 1). By the end of the 6 months of the study the male subjects generated an average of 290.5 Kg on the leg press, which is 4.2 MOB's and the female subjects generated 220.9 Kg on the leg press, which is 3.5 MOB's.

The training was defined as high-intensity because these multiples could never be achieved with conventional free weights or weight machines in elderly subjects.

2.3. Clinical evaluation

All participants completed a lifestyle questionnaire to obtain information on educational background, employment details, history of additional illnesses or chronic diseases, family history of diabetes, smoking and alcohol history, current medications, dietary supplement use and exercise habits.

A comprehensive medical examination, including medical history and physical examination were completed prior to beginning the study. Resting blood pressure was documented at baseline and prior to each session the study subjects performed. Height was measured to the nearest 0.1 cm and body weight to the nearest 0.1 kg. Waist circumference was measured at the level of the umbilicus with the participant in a standing position. Information on any alterations to current medications or any new medications prescribed by the participants' doctors was also collected by research staffs through medical record reviews and monthly phone calls. All participants were instructed to **maintain their usual medical care**, nutritional habits and other current lifestyle patterns.

In addition, baseline laboratories, after overnight fasting included Na, K, Cl, Creatinine, BUN, Calcium, Phosphorus, ALT, AST, GGT, Total Bilirubin, Total Cholesterol, LDL-C, HDL-C and Triglycerides, plasma glucose, plasma insulin, HbA_{1c} and Urinalysis were collected on all study patients at baseline. Fasting plasma glucose and HbA_{1c} were drawn at the 3-month and 6-month interval on every study subject. Blood was drawn within 3 days after the most recent exercise session at the end of the intervention period. All patients had a nutritional assessment completed by research personnel.

The primary outcome of our study was improving glycemic control measured by HbA1c and FPG. Secondary outcomes included (1) anthropometry characteristics, (2) cardiovascular risk factors measured by total cholesterol (TC), triglycerides (TG), HDL-cholesterol (HDL-C), LDL-cholesterol (LDL-C), systolic blood pressure (SBP) and diastolic blood pressure (DBP). All laboratory measures were acquired at baseline and during the 3- and 6-month intervals of the study.

2.4. Statistical analysis

The sample size was based on an anticipated standard deviation effect of 1.1%; an alpha level of 0.05; and a desired power of 90%. Assuming possible dropouts, 300 participants were recruited.

Statistical analysis was conducted using SPSS 24.0 (IBM Company). All data was checked for normality prior to analysis, presented as means ± SD for normally distributed variables and median for variables without a normal distribution, respectively. Both anthropometry and biochemical measurements on the primary outcomes and secondary outcomes were compared between groups using independent t-tests for normally distributed continuous data and non-parametric tests for variables without a normal distribution. The data was analyzed by paired-t test while using

before-after analysis. P values ≤0.05 were considered statistically significant for all analyses. Subgroup analysis: The baseline HbA1c >7.5% was chosen according to 2017 AACE/ACE Consensus Statement [8].

2.5. Adverse events

Any adverse events were recorded by the research staff during the monthly phone calls to participants and medical record reviews. For this study, an adverse event was defined as any health-related unfavorable or unintended medical occurrence that developed or worsened during the study period and was not related to the subject's diabetes or other co-morbidities.

3. Results

From January 2015 to May 2016, 599 patients were evaluated for eligibility; 299 were excluded due to reasons including refusal to participate, hepatic or renal disease, cardiac insufficiency and unstable medication regimen. Three hundred (300) patients met inclusion criteria and were recruited and randomized (200 to the PRT group and 100 to the control group, Fig. 1).

Thirty-five (35) patients were dismissed during the study due to inconsistent or interruption of their attendance for the bDTM intervention, relocation to another city or significant medication regimen change. A total of 265 patients (88.3%) completed the study (165 bD™ intervention and 100 control, Fig. 1).

3.1. Patients' anthropometry data and laboratory tests at baseline

Patients' characteristics at baseline after randomization are shown in Table 1. There were no statistical significant differences between the control group and the PRT group in age, 66.7 ± 6.7 years vs. 65.7 ± 8.6 years (p = 0.312), weight (kg) 66.1 ± 10.9 vs. 66.6 ± 10.9 (p = 0.714), height (cm) 161.4 ± 8.6 vs. 162.9 ± 7.3 (p = 0.131), BMI (kg/m^2) 25.3 ± 3.3 vs. 25.0 ± 3.3 (p = 0.553), waist measurement (cm) was 86.9 ± 10.1 vs. 88.1 ± 8.7 (p = 0.310), hip measurement (cm) 97.6 ± 7.5 vs. 97.8 ± 6.9 (p = 0.832), weight: height ratio 0.89 ± 0.07 vs. 0.90 ± 0.06 (p = 0.185) and systolic blood pressure (SBP mmHg) 124.5 ± 15.0 vs. 128.1 ± 14.2 (p = 0.07) respectively. No significant differences were observed in anthropometry and biomarkers between the two groups at baseline (Table 1).

4. Effects on glucose control

4.1. Population analysis

There was no statistically significant difference between all control and PRT patients at baseline for HbA_{1c}. Results for all patients in the control group [6.92 ± 1.26 (52 mmol/mol ± 13.8 mmol/mol)] vs. all patients in the PRT group [6.83 ± 1.31 (51 mmol/mol ± 14.3 mmol/mol), p = 0.603)] Table 1. Similarly, there was no statistically significant difference between control and PRT patients at baseline for fasting plasma glucose (FPG) in mmol/L, the baseline group results
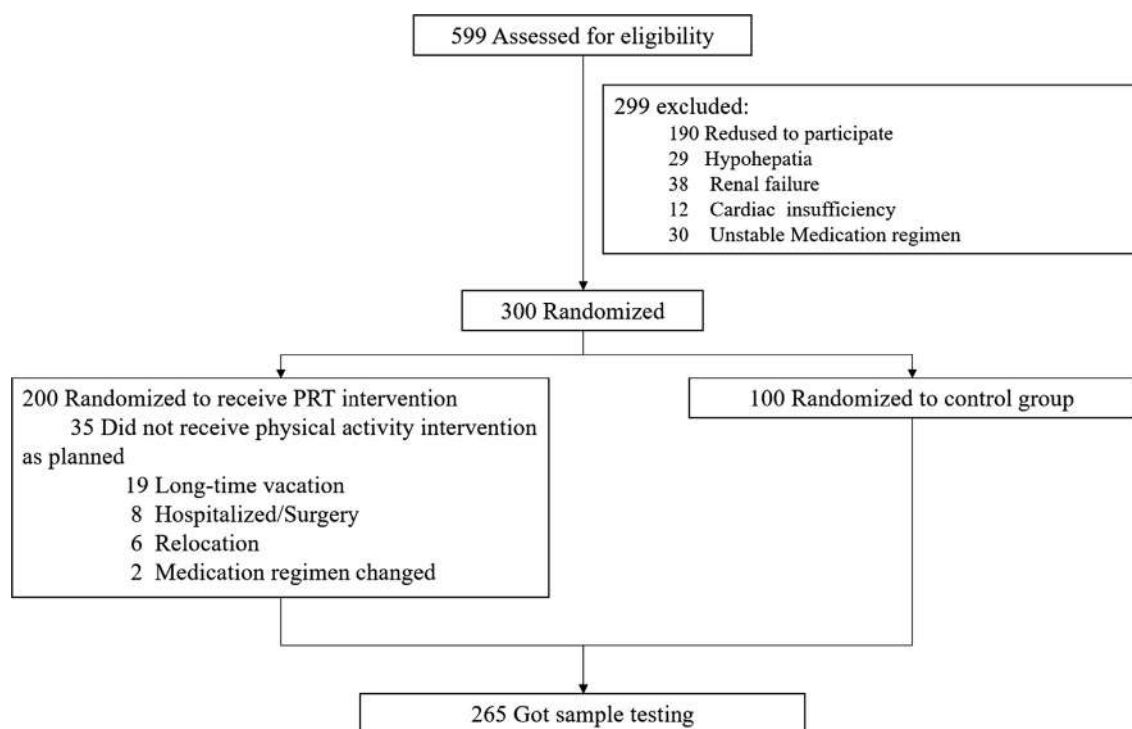
Fig. 1 – Flow of patients' screening, recruitment and testing.

Table 1 – Patients' anthropometry and laboratory results at baseline.

	Control	PRT	P value
N	100	165	
Sex (% male)	43%	47.58%	0.372
Age (year)	66.72 ± 6.68	65.66 ± 8.58	0.312
Weight (kg)	66.09 ± 10.98	66.57 ± 10.95	0.740
Height (cm)	161.40 ± 8.59	162.95 ± 7.34	0.131
BMI (kg/m^2)	25.31 ± 3.31	25.04 ± 3.32	0.553
Waist (cm)	86.88 ± 10.13	88.12 ± 8.70	0.310
Hip (cm)	97.57 ± 7.51	97.77 ± 6.96	0.832
Weight: Height Ratio	0.89 ± 0.07	0.90 ± 0.06	0.185
SBP	124.52 ± 15.03	128.10 ± 14.24	0.070
DBP	78.82 ± 8.75	78.29 ± 8.56	0.645
Duration of Diabetes (median 25%, 75%)	8 (4, 12)	9 (3, 15)	0.776
HbA1c % (mmol/L)	6.92 ± 1.26 (52 ± 13.8)	6.83 ± 1.31 (51 ± 14.3)	0.603
FPG (mmol/L)	7.84 ± 2.49	7.62 ± 2.87	0.526
HDL (mmol/L)	1.25 ± 0.30	1.25 ± 0.32	0.981
LDL (mmol/L)	3.28 ± 0.87	3.22 ± 0.93	0.611
TG (mmol/L) (median 25%, 75%)	1.42 (0.92, 2.04)	1.38 (0.95, 1.99)	0.763
TC (mmol/L) (median 25%, 75%)	4.99 ± 1.16	4.95 ± 1.23	0.787
ALT (IU/L) (median 25%, 75%)	19.00 (14.50, 25.50)	20.00 (15.00, 27.00)	0.299
AST (IU/L) (median 25%, 75%)	20.00 (17.00, 24.25)	21.00 (18.00, 27.00)	0.062
Uric Acid (mmol/L)	318.68 ± 79.03	307.67 ± 70.31	0.251
Scr (umol/L)	70.70 ± 9.86	67.65 ± 15.74	0.123
BUN (mmol/L)	5.69 ± 1.34	5.73 ± 1.40	0.804
γ-GGT (mmol/L) (median 25%,75%)	23.00 (18.00, 31.50)	22.00 (17.00, 31.75)	0.402

were 7.84 ± 2.49 and PRT group results were 7.62 ± 2.87, p = 0.526, respectively Table 1.

At the end of the study period there was no statistically significant difference in the HbA1c between all patients in the control and PRT groups. All patients in the control group at the 3-month interval for HbA1c [6.73 ± 0.94 (50 mmol/mol ± 10.3 mmol/mol)] vs. all patients in the PRT group 6.63 ± 0.98 (49 mmol/mol ± 10.7 mmol/mol) p = 0.427] and at the 6-month interval all patients in the control group [6.85 ± 1.17 (51 mmol/mol ± 12.8 mmol/mol)] vs. all patients in the

PRT group [6.75 ± 0.93 (50 mmol/mol ± 10.2 mmol/mol)] p = 0.454 (Supplemental Fig. 2).

In addition, there was no statistically significant difference in FPG between all patients in the control group and all patients in the PRT group at the 3-month interval in mmol/L. The control group results were 7.39 ± 2.82 and the PRT group results were 7.29 ± 1.89, p = 0.75. At the 6-month interval there was a moderate statistically significant difference between all patients in the control group 7.88 ± 2.21 and all patients in the PRT group 7.29 ± 2.00, p = 0.03 (Supplemental Fig. 2).

4.2. Subgroup population analysis

Further analysis of the baseline and 6-month HbA1c levels resulted in a statistically significant difference in the PRT group [baseline HbA1c level $\geq$ 5.5% (36.6 mmol/mol) p = 0.019, $\geq$6.0% (42 mmol/mol) p = 0.002, > 6.5% (48 mmol/mol) p < 0.001, $\geq$7.0% (53 mmol/mol) p < 0.001, >7.5% (58 mmol/mol) p < 0.001 and >8.0% (64 mmol/mol) p < 0.001, respectively (Fig. 2)].

When subgroup analysis was performed on all participants with $HbA_{1c} \geq 7.5\%$, who performed 18 to 24 weeks of PRT training (once a week frequency), both the HbA1c and FPG at 6 months interval showed a statistically significant different (p < 0.05; Fig. 3).

4.3. Effects on other metabolic parameters

An unexpected finding in all patients of the PRT group was a statistically significant difference from baseline compared to the 6-month interval in HDL (1.25 ± 0.32 vs. 1.17 ± 0.26 mmol/L, p < 0.001), LDL (3.23 ± 0.89 vs. 2.93 ± 0.80 mmol/L, p < 0.001) and total cholesterol (4.97 ± 1.22 vs. 4.580 ± 1.03 mmol/L, p < 0.001).

Additionally, the PRT group was divided into lower (17.22–23.73 kg/m^2), medium (23.73–25.96 kg/m^2) and higher (25.96–36.29 kg/m^2) body mass index (BMI). At baseline, there was no statistically significant difference in HbA_{1c} within all participants in the PRT group (Fig. 4A).

When subgroup analysis was performed on the patients with HbA1c > 7.5% in the PRT group, there was a statistically significant difference between baseline and the 6-month interval HbA1c for the lower [8.823 ± 1.178 (65 mmol/mol
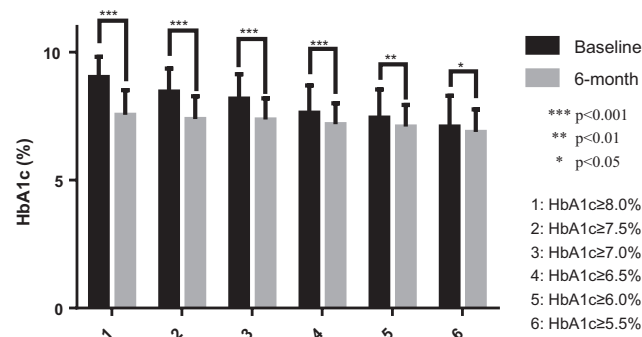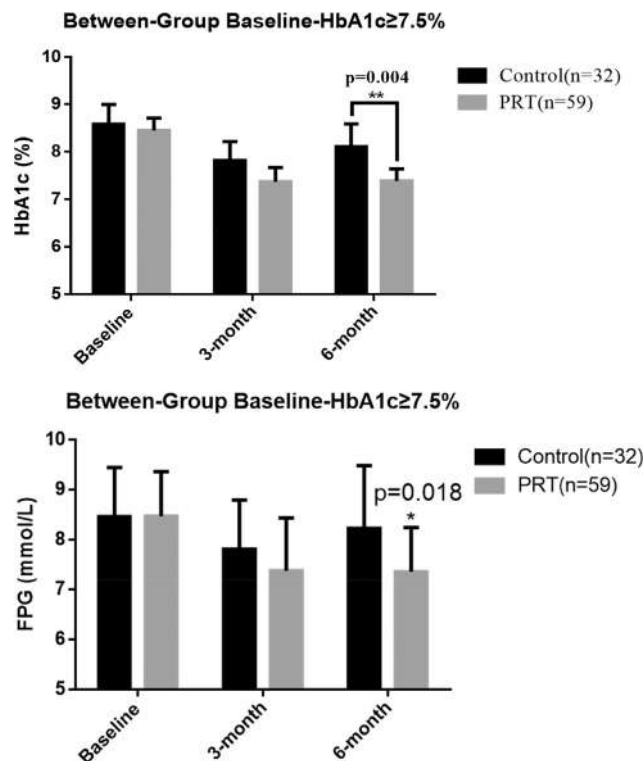

Fig. 3 – HbA$_{1c}$ and FPG at baseline, 3, 6 months among patients with HbA1c (%) $\geq$ 7.5 (Control group vs. PRT group).

± 12.9 mmol/mol) vs 7.654 ± 0.923 (56 mmol/mol ± 10.2 mmol/mol) p = 0.010], medium [8.194 ± 0.718 (60 mmol/mol ± 7.8 mmol/mol) vs 7.319 ± 0.955 (56 mmol/mol ± 10.4 mmol/mol) p = 0.010] and higher [8.469 ± 0.761 (62 mmol/mol ± 8.3 mmol/mol) vs 7.238 ± 0.844 (53 mmol/mol ± 9.2 mmol/mol) p = 0.001] BMI patients (Fig. 4B).

4.4. Safety assessment

There were no adverse events reported during the course of the entire project.

5. Discussion

A number of important studies have shown that when patients with a diagnosis of Diabetes carry out a routine fitness program and/or physical activity with greater levels of demand and complexity there is a direct association with significantly lower cardiovascular and overall mortality [9–11], and this can't be explained by only lowering glucose levels. The American Diabetes Association guidelines recommend 150 min of exercise per week as an appropriate exercise program for patients with Diabetes.

Exercise or physical activity can help patients with Diabetes achieve a variety of goals, including improved cardiorespiratory fitness, glycemic control, decreased insulin resistance, improved lipid profile, positively affect blood pressure and maintain weight or potential weight loss [12–14].

When patients perform average to above-average aerobic physical activity and have improved levels of cardiorespira-

Fig. 2 – HbA$_{1c}$ After 6-month Resistance Training at 6 different % levels.

Lower BMI(kg/m2)	Medium BMI(kg/m2)	Higher BMI(kg/m2)
17.22-23.73	23.73-25.96	25.96-36.29

4A. General Group Analysis
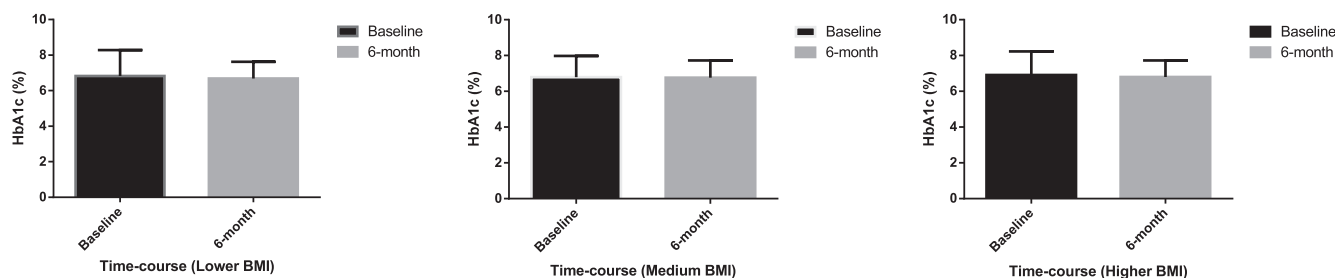
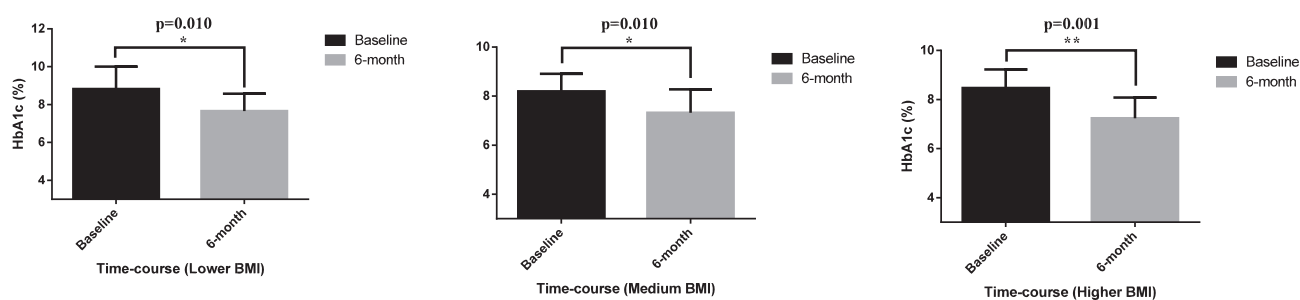### 4B. Subgroup Analysis with HbA$_{1c} \geq 7.5\%$

Fig. 4 – BMI levels and HbA$_{1c}$ decrease in the PRT group at 6 months of bD^{TM} intervention.

tory wellness there is an association with a substantial reduction in morbidity and mortality in men and women with Type 1 and Type 2 Diabetes. Studies have demonstrated that, in patients with Type 2 Diabetes, regular physical activity [11,15,16] and/or moderate to high cardiorespiratory health have an association with a decrease in cardiovascular and overall mortality from 39% to 70% over a 15 to 20-year follow-up [17].

A review of randomized trials showed that resistance training improves glycemic control, as measured by HbA$_{1c}$, decreases insulin resistance and increases muscular strength in adults with Type 2 Diabetes [18].

In addition, it has been shown that resistance training increases lean muscle mass [19] and bone mineral density [20,21], leading to an improved functional status, potentially preventing sarcopenia and osteoporosis. Resistance exercise in these studies was carried out using standard weight machines and/or free weights.

In our study, the application of a novel resistance training approach, with the bioDensity^{TM} equipment provided the patients with isometric resistance exercises in which a high-intensity low-volume approach was implemented. Isometric resistance training has been demonstrated to have functional [22,23] and physiologic benefits [24].

We applied higher forces than are typically used in conventional resistance exercise by using an axial bone loading technique with the bD^{TM} device that is typically used for osteoporosis treatment [25]. By applying these higher forces there may be stimulation to increase density adaptation in muscle tissue and thereby increasing insulin receptor sites, which would improve glucose management as seen in the ADA Standards of Medical Care for Diabetes [2]. Though it is recommended to exercise at least twice a week, the short duration and frequency of the resistance exercise sessions allow for the participants to be more compliant than with conventional resistance training exercises.

After a minimum of 18 weeks (one session per week) and up to a total of 24 weeks of PRT we observed no statistical difference between all patients in the control and PRT groups. We believe that the initial lack of statistical difference, when all patients were included, is due to the baseline lower glucose and HbA$_{1c}$ levels in patients with HbA$_{1c} \leq 6.5\%$ impacting on the overall results. But when we performed a subgroup analysis on the PRT group with a HbA$_{1c} \geq 7.5\%$, we found statistically significantly lower FPG and HbA$_{1c}$ at 3 months and 6 months as compared to baseline. The participants maintained their normal dietary, medication and lifestyle regimens throughout the entire study and the only new variable was the inclusion of the bD^{TM} exercise regimen.

Also, our study showed that in patients with low, normal and high BMI, with poor glucose control (HbA1c ≥ 7.5), had statistically improved HbA$_{1c}$ due to the PRT training. This was observed in all three of the BMI groups (Fig. 4).

During the study, all the patients that were enrolled, and finished the study, had no changes in their antihyperglycemic and lipid-lowering medications.

We believe that the mechanism in reducing FPG and HbA$_{1c}$ in patients with higher blood levels at baseline with bD^{TM} resistance training is similar to conventional resistance training. The activation of the calmodulin-dependent protein kinase (CaMK) II, further results in activation of transcription factors and target genes including glucose transporter protein 4 (GLUT4), thus improving blood glucose control clinically [26]. Furthermore, muscle fiber changes also contribute to the improvement of glycemic control.

Castorena, et al showed that after 4–6 weeks of resistance training there was a marked increase in skeletal muscle glucose uptake in Type 2 Diabetes patients, mainly due to a shift from type IIx fibers to type IIa fibers. Previous fiber analysis revealed that type IIa fibers had the most GLUT4 content and greatest glucose uptake among the fiber subgroups [27]. Also, type IIa fibers have a greater insulin response and more notable glycogen depletion and re-synthesis during resistance training than type IIx fibers [28].

In addition, our study found that a secondary beneficial effect on our study population was that all patients in the PRT group had a statistically significant improvement in their lipid profile (HDL, LDL, TC) from baseline after 6 months of bD^{TM} resistance training. These findings are consistent with the study by Ajayi-Vincent et al that showed significant decrease in total cholesterol; triglycerides and low-density protein (LDL) concentrations in a resistance training group of subjects compared to control [29]. Furthermore, this was most evident with progressive higher intensity and duration at the end of the study.

6.   Limitations

Our study was limited to 24 sessions and therefore could not provide information whether continuation of the PRT over a longer period of time would bring the HbA$_{1c}$ and FPG to currently acceptable levels (HbA$_{1c}$ ≤ 6.5 and FPG 80–130 mg/dl). In addition, although the protocol for the study called for participants not to change their lifestyle, there was no control of the participants activities outside of the controlled environment, with exception of their antihyperglycemic and lipid-lowering medications, where the study was performed, which may have impacted positively or negatively depending on the lifestyle variable. However, well-matched controls in similar living conditions were enrolled to minimize the bias. Another limitation in our study was the lack of additional metabolic variables such as indices of insulin resistance, which would have provided further evidence of glycemic control in our patients.

The oral glucose tolerance test and continuous glucose monitoring, including the assessment of post-prandial glycemia, might be more reliable to represent the improvement of blood glucose level. In addition to body composition analysis, visceral adipose tissue and muscle tissue may be better markers than body weight or BMI for resistance training. Unfortunately, measuring these markers can be difficult to implement in a community-based study.

7.   Conclusions

We conclude, that after 6 months of progressive resistance training, applying the bioDensity^{TM} resistance training device, we were able to lower fasting plasma glucose and HbA$_{1c}$, without any adverse physical effects or injuries in elderly Type 2 Diabetes patients with elevated HbA$_{1c}$ (≥7.5%).

In addition, a secondary beneficial effect was a statistically significant improvement in the lipid metabolism (HDL, LDL, TC) in all PRT participants after 6 months of resistance training with bD^{TM}. Therefore, we recommend the bioDensity^{TM} device as a safe and efficacious resistance training device with similar efficacy as conventional weight training. Furthermore, we recommend it as an adjunct to medication and nutritional control in lowering blood glucose and HbA1c, as well as, improving the lipid metabolism in elderly Type 2 Diabetes patients.

Appendix A.   Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2019.02.011.

REFERENCES

[1] Chen L, Magliano DJ, Zimmet PZ. The worldwide epidemiology of type 2 diabetes mellitus–present and future perspectives. Nat Rev Endocrinol 2011;8(4):228–36.

[2] Professional Practice Committee. American diabetes association standards of medical care in diabetes 2018. Diabetes Care 2018;41(Suppl. 1):S1–2.

[3] Physical activity. http://www.who.int/topics/physical_activity/en/.

[4] Willey KA, Singh MAF. Battling insulin resistance in elderly obese people with type 2 diabetes: bring on the heavy weights. Diabetes Care 2003;26:1580–8.

[5] Smith DT, Moynes RA, Rockey SS, et al. BioDensity™: a novel resistance training approach and learning effects in 1,685 males and 2,689 females. J Nov Physiother Nov Physiother 2014;4:215. https://doi.org/10.4172/2165-7025.1000215.

[6] American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. Philadelphia: Lippincott Williams & Wilkins; 2000.

[7] Jaquish J, Singh R, Hynote E, Conviser J. Osteogenic Loading: A new modality to facilitate bone density development. JIR: Nevada City; 2012.

[8] Garber Alan J, Abrahamson Martin J, Barzilay Joshua I, et al. Consensus statement by the American Association of Clinical Endocrinologists and American College of Endocrinology on the Comprehensive Type 2 Diabetes Management Algorithm-2017 Executive Summary. EndocrPract 2017;23(2):207–38.

[9] Church TS, Cheng YJ, Earnest CP, et al. Exercise capacity and body composition as predictors of mortality among men with diabetes. Diabetes Care 2004;27:83–8.

[10] Wei M, Gibbons LW, Kampert JB, et al. Low cardiorespiratory fitness and physical inactivity as predictors of mortality in men with type 2 diabetes. Ann Intern Med 2000;132:605–11.

[11] Hu FB, Stampfer MJ, Solomon C, et al. Physical activity and risk for cardiovascular events in diabetic women. Ann Intern Med 2001;134:96–105.

[12] Chudyk A, Petrella RJ. Effects of exercise on cardiovascular risk factors in type 2 diabetes: a meta-analysis. Diabetes Care 2011;34:1228–37.

[13] Snowling NJ, Hopkins WG. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients: a meta-analysis. Diabetes Care 2006;29:2518–27.

[14] Wing RR, Goldstein MG, Acton KJ, et al. Behavioral science research in diabetes: lifestyle changes related to obesity, eating behavior, and physical activity. Diabetes Care 2001;24:117–23.

[15] Gregg EW, Gerzoff RB, Caspersen CJ, et al. Relationship of walking to mortality among US adults with diabetes. Arch Intern Med 2003;163:1440–7.

[16] Hu G, Jousilahti P, Barengo NC, et al. Physical activity, cardiovascular risk factors, and mortality among Finnish adults with diabetes. Diabetes Care 2005;28:799–805.

[17] Church TS, LaMonte MJ, Barlow CE, Blair SN. Cardiorespiratory fitness and body mass index as predictors of cardiovascular disease mortality among men with diabetes. Arch Intern Med 2005;165:2114–210.

[18] Gordon BA, Benson AC, Bird SR, et al. Resistance training improves metabolic health in type 2 diabetes: a systematic review. Diabetes Res Clin Pract 2009;83(2):157–75.

[19] Ryan AS, Hurlbut DE, Lott ME, et al. Insulin action after resistive training in insulin resistant older men and women. J Am Geriatr Soc 2001;49:247–53.

[20] Nelson ME, Fiatarone MA, Morganti CM, et al. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. JAMA 1994;272:1909–14.

[21] Engelke K, Kemmler W, Lauber D, et al. Exercise maintains bone density at spine and hip EFOPS: a 3-year longitudinal study in early postmenopausal women. Osteoporos Int 2006;17:133–42.

[22] Symons TB, Vandervoort AA, Rice CL, Overend TJ, Marsh GD. Effects of maximal isometric and isokinetic resistance training on strength and functional mobility in older adults. J Gerontol A Biol Sci Med Sci 2005;60:777–81.

[23] Tillin NA, Pain MT, Folland J. Explosive force production during isometric squats correlates with athletic performance in rugby union players. J Sports Sci 2012;31:66–76.

[24] Tillin NA, Pain MT, Folland JP. Short-term training for explosive strength causes neural and mechanical adaptations. Exp Physiol 2012;97:630–41.

[25] Jaquish J. Multiple-of-bodyweight axial bone loading using novel exercise intervention with and without bisphosphonate use for osteogenic adaptation. Osteoporos Int 2013;24:s594–5.

[26] Hortobágyi T, Dempsey L, Fraser D, et al. Changes in muscle strength, muscle fiber size and myofibrillar gene expression after immobilization and retraining in humans. J. Physiol 2000;524(Pt 1):293–304.

[27] Castorena C, Arias E, Sharma N, et al. Fiber type effects on contraction-stimulated glucose uptake and GLUT4 abundance in single fibers from rat skeletal muscle. Am J Physiol Endocrinol Metab 2015;308(3):E223–30.

[28] Vøllestad N, Blom P, Grønnerød O. Resynthesis of glycogen in different muscle fiber types after prolonged exhaustive exercise in man. Acta Physiol Scand 1989;137(1):15–21.

[29] Ajayi-Vincent O, Adesina M. Effects of resistance training on the blood lipid variables of young adults. Eur Sci J 2013;9(12).