

Battling Insulin Resistance in Elderly Obese People With Type 2 Diabetes

Bring on the heavy weights

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ABSTRACT — Exercise improves insulin resistance and has beneficial effects in preventing and treating type 2 diabetes. However, aerobic exercise is hindered in many type 2 diabetic patients because of advancing age, obesity, and other comorbid conditions. Weight lifting or progressive resistance training (PRT) offers a safe and effective exercise alternative for these people. PRT promotes favorable energy balance and reduced visceral fat deposition through enhanced basal metabolism and activity levels while counteracting age- and disease-related muscle wasting. PRT improves insulin sensitivity and glycemic control; increases muscle mass, strength, and endurance; and has positive effects on bone density, osteoarthritic symptoms, mobility impairment, self-efficacy, hypertension, and lipid profiles. PRT also alleviates symptoms of anxiety, depression, and insomnia in individuals with clinical depression and improves exercise tolerance in individuals with cardiac ischemic disease and congestive heart failure; all of these aspects are relevant to the care of diabetic elders. Moreover, PRT is safe and well accepted in many complex patient populations, including very frail elderly individuals and those with cardiovascular disease. The greater feasibility of using PRT over aerobic exercise in elderly obese type 2 diabetic individuals because of concomitant cardiovascular, arthritic, and other disease provides a solid rationale for investigating the global benefits of PRT in the management of diabetes.

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ADVANCING AGE AND TYPE 2 DIABETES

— The value of tight blood glucose control in type 2 diabetes has been convincingly demonstrated in the U.K. Prospective Diabetes Study, among other studies. Improvement in glycemic control per se, irrespective of the means of attaining this, is the critical factor in reducing the risk of chronic diabetic complications (1). Gaining and maintaining good glycemic control hinges on enhancing insulin availability or secretion and overcoming

insulin resistance. Unfortunately, advancing age, central obesity, and physical inactivity hinder medical management and may hasten development of chronic complications, particularly in elderly people who may have lived with diabetes for decades. Even when glycemic control is near optimal with medication, reducing insulin resistance by any other means must be explored in view of these adverse consequences (1).

Because skeletal muscle is the biggest reservoir for glucose disposal (2), muscle

wasting from aging and inactivity exacerbate problems of peripheral glucose uptake. Muscle weakness, decreased muscle mass, decreased activation of glycogen synthase, and changes in type IIb skeletal muscle fiber numbers are related to and may precede insulin resistance, glucose intolerance, and type 2 diabetes (3–5). Visceral fat deposition in older adults may be causally related to elevated cortisol secretion in response to stressors (6). Thus, decreased muscle mass, increased visceral adiposity, and the typical decline in physical activity with age compound insulin resistance. Moreover, individuals with diabetes have less muscular strength than age-matched counterparts, possibly due to peripheral neuropathy and reduced vascular supply (5), compounding the muscle atrophy and weakness of age and further compromising insulin sensitivity and glycemic control.

CONVENTIONAL LIFESTYLE WEAPONS TO TARGET INSULIN RESISTANCE IN TYPE 2 DIABETES

— Dietary modification to induce weight loss is central to management of obese people with type 2 diabetes (5,7). However, the long-term difficulty of reducing total daily energy intake is well documented (8). Energy restriction as the sole means of improving glycemic control is only modest in its effect (9) because of the progressive nature of type 2 diabetes and must usually be augmented by medication (1). Conventional energy restriction recommendations are often perceived as negative, difficult, or even impossible to maintain (8), particularly in elderly people where a change to eating habits established over a lifetime may be onerous, complicated, expensive, and frightening. Weight cycling after repetitive unsuccessful attempts at weight loss by dieting can lead to lean tissue loss and decreased metabolic rate, worsening the energy balance equation (10). Dietary modification in isolation is rarely effective in sustaining long-term

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Abbreviations: 1RM, one repetition maximum; ADA, American Diabetes Association; BP, blood pressure; CWT, circuit-type weight training; HR, heart rate; IGT, impaired glucose tolerance; IOP, intraocular pressure; PRT, progressive resistance training; RPP, rate-pressure product.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

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weight loss and consequent improvements in insulin sensitivity.

In view of its general and diabetes-specific health benefits, detailed guidelines for exercise in type 2 diabetes have been developed by internationally reputed organizations (5,7). Unfortunately, many clinicians and patients still see exercise as a means to enhance weight loss and that improvements in insulin and glucose dynamics occur solely as a function of this. This misconception persists despite solid evidence that exercise alone, in the absence of any change in body weight or composition, is able to significantly enhance insulin sensitivity and glucose homeostasis (11,12). Exercise directly targets the metabolic derangements of diabetes compared with many medications that primarily increase available insulin supply. Moreover, most medications can only be used once fasting glucose levels rise and may produce hypoglycemia if used in patients with very mild diabetes or in the elderly, whereas exercise is appropriate long before overt hyperglycemia develops. Exercise can reduce the need for medication as well as improve cardiovascular risk factors such as hypertension, dyslipidemia, and elevated fibrinolytic activity (5).

AEROBIC EXERCISE AND TYPE 2 DIABETES — Aerobic exercise enhances insulin sensitivity acutely (13) and with chronic training (14–16) in type 2 diabetes. This is due to adaptive changes in skeletal muscle including increased GLUT4 transporter proteins on muscle fibers (17), increased muscle glycogen storage (18), and the cumulative effects of acute exercise bouts (5,13). This finding suggests that exercise enhances insulin sensitivity and glycemic control by changing muscle metabolism, not merely by promoting body composition change (11,12).

Chronic aerobic training induces favorable changes in weight, body composition (10), and cortisol response to stress (19). In obese adults, it increases adherence to a hypocaloric diet (10), and when coupled with a weight-reduction diet, enhances insulin sensitivity more than dieting alone (20). Although the mechanism is not fully understood, exercise also promotes long-term weight loss and is the best predictor of long-term weight control (21). Moreover, exercise preferen-

tially mobilizes visceral adipose tissue (22), reducing insulin resistance.

Aerobic exercise and the prevention of type 2 diabetes

Increased physical activity plays a substantial role in prevention of type 2 diabetes. Two large studies found a strong dose-response relationship between exercise and relative risk of developing type 2 diabetes in healthy adults. Each incremental increase in volume or intensity of physical activity decreased relative risk of developing type 2 diabetes, with the protective effect persisting even after adjustment for BMI (23,24). Physical activity unequivocally reduces the risk of developing type 2 diabetes in individuals with impaired glucose tolerance (IGT) (12,25,26). In the Da Qing IGT and the Finnish Diabetes Prevention Studies, cumulative incidence of diabetes was 20% lower with exercise (equating to 20–30 min of daily physical activity) when compared with control subjects (12,25). The U.S. Diabetes Prevention Program found that the cumulative incidence of diabetes was 58% lower in individuals treated with intensive diet and exercise than with placebo. Moreover, overall diabetes incidence was 39% lower with intensive lifestyle intervention than with metformin therapy, and this effect was enhanced with age (26).

These findings validate the potency of small amounts of daily exercise in preventing diabetes. Exercise alone, at the relatively conservative amount of 4 h each week, is enough to substantially reduce the risk of developing diabetes (12).

Aerobic exercise as treatment for type 2 diabetes

Intervention studies have demonstrated that many positive effects on insulin sensitivity and glucose homeostasis occur after aerobic exercise. Acutely, a single bout of exercise can increase the glucose disposal rate (13), and chronic training, even without changes in body composition, leads to improvement in insulin sensitivity of up to 30% in individuals with IGT (14) and type 2 diabetes (14,15). Significant improvements in glycemic control have been seen after as little as 10 weeks of walking for 60 min three times weekly (15,16). Unfortunately, the applicability of many of these studies to the wider diabetic population is limited by small sample sizes, restriction of subjects to those

without comorbid disease, short training duration, and poor study designs that lack proper randomization procedures or control groups.

However, a meta-analysis of 14 randomized controlled trials of at least 8 weeks' duration, comparing an exercise intervention with a concurrent nonexercising control group in adults with type 2 diabetes, found that the 528 subjects had a mean fall in HbA_{1c} of 0.74% ($P = 0.00003$) after exercise and this fall was not related to body weight change (11). This finding supports the concept that exercise alone, in the absence of body composition change, is able to enhance glucose homeostasis (11,12).

Feasibility of aerobic exercise in older obese people with type 2 diabetes

Because of the interaction of age-related changes and pathophysiology of diabetes and other diseases, the potential benefits of physical activity for elderly obese people with diabetes are enormous. However, translation of aerobic exercise recommendations (5,7) into appropriate activity regimens for these individuals is challenging and often impossible to implement. Even walking may be difficult or risky because of clustering of conditions such as arthritis, cardiovascular disease, peripheral vascular disease, neuropathy, and mobility impairment. When other common problems including hypertension, sleep apnea, low self-efficacy, poor self-esteem, and depression are added into the equation, they compound the large personal and economic cost of diabetes, impede compliance with treatment goals, and reduce quality of life.

PROGRESSIVE RESISTANCE TRAINING: A NEW STRATEGY FOR FIGHTING INSULIN RESISTANCE

— Weight lifting or progressive resistance training (PRT) is now advocated as an important part of exercise for general fitness and well-being (27). It is recommended by the American College of Sports Medicine for the elderly (28) and the obese (10), in secondary prevention of coronary heart disease (29) and in type 2 diabetes (5). Its use in diabetes is supported by the American Diabetes Association (ADA), although not in older individuals or individuals with long-standing diabetes (7), but the reasons given for this are

Table 1—Recommendations for use of PRT in clinical populations

Clinical group	Organization	Recommendation
Elderly	ACSM (28)	“Because sarcopenia and muscle weakness may be an almost universal characteristic of advancing age, strategies for preserving or increasing muscle mass in the older adult should be implemented. . . . Strength training, in addition to its positive effects on insulin action, bone density, energy metabolism, and functional status, is also an important way to increase levels of physical activity in the elderly.”
	ADA (7)	“High-resistance exercise using weights may be acceptable for young individuals with diabetes, but not for older individuals or those with long-standing diabetes.”
Overweight and obese	ACSM (10)	“It is recommended that resistance exercise supplement the endurance exercise program in overweight and obese adults [who] are undertaking modest reductions in energy intake to lose weight. Resistance exercise should focus on improving muscular strength and endurance in this population.”
Type 2 diabetes	ACSM (5)	“It is recommended that resistance training at least 2 days per week should be included as part of a well-rounded exercise program for persons with type 2 diabetes whenever possible. A minimum of 8–10 exercises involving the major muscle groups should be performed with a minimum of one set of 10–15 repetitions to near fatigue. Increased intensity of exercise, additional sets, or combinations of volume and intensity may produce greater benefits and may be appropriate for certain individuals.”
	ADA (7)	“Moderate weight training programs that utilize light weights and high repetitions can be used for maintaining or enhancing upper-body strength in nearly all patients with diabetes.”

vague and not supported by scientific justification (Table 1). There is also no evidence base from which the ADA draws its recommendation to limit PRT to light weights and high volumes of repetitions for the upper body. Thus, conflicting opinions offered in these guidelines indicate the need for a better understanding of the risks and benefits of PRT in type 2 diabetes.

PRT is defined as exercise in which the resistance against which a muscle generates force is progressively increased over time (28). It increases muscular size and strength, changes body composition by increasing lean body mass and decreasing visceral and total body fat (30), and leads to changes in neuroendocrine and cardiovascular function (31). These

adaptations are a function of the intensity and volume (sets \times repetitions \times load) of the exercise (31). Resistance training at intensities between 60 and 100% of the maximal capacity (the one repetition maximum [1RM]) elicit structural, functional, and metabolic changes in skeletal muscle, with higher intensities leading to greater adaptation (32).

PRT has potential roles in athletic conditioning, in rehabilitation, in counteracting age- and disease-related muscle wasting, and in maintaining health and preventing disease (32). Reductions in visceral adiposity occur in older adults after PRT, even when changes in total body fat and weight are small (30). Habitual adaptation to PRT lowers the cortisol response to acute stress (19), increases total

energy expenditure and physical activity in healthy (33) and frail older adults (34), and relieves anxiety, depression, and insomnia in clinical depression (35). It has positive effects on bone density (33), osteoarthritic symptoms (32,36), mobility impairment (34,37), self-efficacy (38), hypertension (39), lipid profiles (40,41), and exercise tolerance in cardiac ischemic disease (42) and congestive heart failure (43); all of these aspects are relevant in the care of older obese patients with diabetes.

PRT and the prevention of type 2 diabetes

There are little data available on the role of PRT in preventing type 2 diabetes. Given its mechanism of action, PRT could potentially play a significant role, but this warrants further investigation. Its role in preventing type 2 diabetes in individuals with IGT was demonstrated with the inclusion of supervised, progressive, circuit-type weight training (CWT) as part of the intensive lifestyle intervention in the Finnish Diabetes Prevention Study. The degree to which PRT contributed to the reduced risk of diabetes after lifestyle intervention is difficult to quantify but cannot be discounted. This is because the participation rate in supervised CWT sessions in the first year of the study was up to 85%, and no less than 50%, depending on the study center (12). If relative risk for diabetes is reduced by CWT (moderate intensity PRT of \sim 50% 1RM), then PRT of higher intensities (60–100% 1RM), which elicits greater structural, functional, and metabolic changes in skeletal muscle than CWT, could have an equivalent, if not greater, effect. This hypothesis is yet to be tested.

PRT as treatment for type 2 diabetes

Of relevance to the treatment of type 2 diabetes are the effects of PRT on insulin action, lipid metabolism, and glucose metabolism. PRT has been shown to improve glucose disposal rates, increase glycogen storage capacity, increase GLUT4 receptors on skeletal muscle, and improve insulin sensitivity and glucose tolerance in normal (44–46) and clinical populations (45,47–51). A single bout of resistance exercise lowered total insulin response to an oral glucose tolerance test in seven subjects with type 2 diabetes (45). Insulin sensitivity improved by 48% in nine subjects with type 2 diabetes after 4–6 weeks of moderate-intensity (40–50% 1RM) re-

Table 2—Randomized controlled trials examining the effects of PRT in type 2 diabetes

Author	Sample size and type	Training intensity	Training frequency	Training duration	Effect on HbA _{1c} (%)	Effect on oral glucose tolerance test
Dunstan et al. (51)	27 M = 17 F = 10 CWT = 15 CON = 12	50–55% 1RM, two sets for 2 weeks then three sets with 10–15 reps within 30 s, 30 s active rest	Three times weekly	8 weeks	Compared with baseline: CWT: -0.2 ± 0.5 (NS) CON: $+0.2 \pm 0.6$ (NS)	Decreased glucose AUC Decreased insulin AUC in CWT $P < 0.05$ (compared with control subjects)
Dunstan et al. (49)	29 PRT + WL = 16 WL = 11	75–85% 1RM Three sets of 8–10 reps	Three times weekly	26 weeks	Compared with baseline: PRT + WL: -1.21 ± 1.0 ($P < 0.01$) WL: -0.4 ± 0.8 (NS)	Not tested
Castaneda et al. (50)	43 M = 16 F = 27 PRT = 25 CON = 18	80% 1RM Three sets of eight reps	Three times weekly	16 weeks	PRT: -1.0 ± 1.1 vs. CON: 0.4 ± 1.2 ($P = 0.0001$)	Not tested

AUC, area under the curve; CON, nonexercising control group; WL, moderate weight loss.

sistance training and occurred despite no change in body composition (48).

Effects of PRT on lipid metabolism are equivocal. However, there is some evidence that it increases HDL cholesterol levels in normal subjects (40,52) and lowers triglyceride and LDL cholesterol levels in type 2 diabetic subjects (41).

Improvements in glycemic control have also been demonstrated after PRT (47–51,53). However, only three randomized controlled trials have examined long-term effects of PRT on glycemic control in older diabetic adults (Table 2). Six months of high-intensity PRT (75–80% 1RM) combined with moderate energy restriction in 29 older overweight sedentary subjects with type 2 diabetes induced a significant reduction in HbA_{1c} from baseline ($-1.21 \pm 0.2\%$) compared with no change in diet alone and control groups. These findings remained significant after adjustment for fat mass (49). In another study of 43 older Hispanic subjects with type 2 diabetes, 16 weeks of high-intensity PRT significantly improved HbA_{1c} when compared with a nonexercising control group (-1.0 ± 1.1 vs. $0.4 \pm 1.2\%$, respectively; $P = 0.0001$). Significant falls in fasting insulin levels and waist circumference as well as significant increases in muscle glycogen content and mean muscle strength were also noted after PRT when compared with control subjects (50). Even 8 weeks of CWT in 27 subjects with type 2 diabetes induced significant reductions in glucose and insulin areas under the curve relative to nonexercising control subjects (51).

Interpretation of available data on the effects of PRT on insulin sensitivity and glucose homeostasis in type 2 diabetes must be tempered in some cases by small sample sizes, uncontrolled study designs, inconsistent measurement of insulin action, short durations, and variable intensity of training used. Even though these data are not analogous, the magnitude of improvement in insulin sensitivity and glycemic control appears to be a function of PRT intensity. Small changes to these parameters have been noted even with CWT (41,51,53,54), and moderate to high intensities of PRT (60–90% 1RM) produced a more potent stimulus for change than aerobic training, given the results of the best-designed studies described above (45,47,48). Aerobic exercise does not have the same potential as PRT to increase muscle mass and is thus unlikely to provide benefit via this mechanism of action (Table 3).

Safety and feasibility of PRT in older obese people with type 2 diabetes

Detailed guidelines for safe, effective, and appropriate PRT regimens for elderly people with type 2 diabetes are well documented (5,32). However, PRT is not routinely used in the clinical management of diabetes, despite recommendations for this in recent position statements from the ADA (7) and the American College of Sports Medicine (5). In the past, PRT has been viewed as an inherently risky form of exercise and is still deliberately avoided by many clinicians in their physical activity recommendations to older adults and those with diseases such as diabetes, hypertension, and cardiovascular disease. A wealth of data demonstrates that PRT is indeed safe, effective, well accepted, and potentially more feasible than aerobic exercise in many complex patient groups including the elderly and individuals with disability or disease (32,34,42,43). More-

Table 3—Exercise modality, body composition, and glucose homeostasis

Variable	Aerobic exercise	Resistance exercise
Body weight	Small or no change	Small or no change
Total fat mass	Small change	Small change
Visceral fat	Moderate decrease	Moderate decrease
Bone density	Small increase	Small increase
Muscle mass	No change	Increased (not CWT)
HbA _{1c}	Moderate decrease	Moderate decrease
Insulin sensitivity	Moderate increase	Moderate increase
Basal insulin levels	Small decrease	Small decrease
Insulin response to glucose challenge	Moderate decrease	Moderate decrease

over, PRT is preferential to aerobic training in patients with some clinical scenarios common in older diabetic individuals, including foot ulceration or Charcot's joint, lower-extremity amputation without prosthesis, severe osteoarthritis, angina, and/or claudication, and in individuals at high risk of falling (32).

Feasibility and acceptability of supervised PRT to older people with type 2 diabetes is suggested by compliance rates of 90–100% documented in two of the three randomized controlled trials described above (49,50). Other compliance rates for PRT of 4 weeks to 6 months' duration are reported as 83–96% in subjects aged 65–98 years (34,55) including independent individuals (55) and very frail nursing home residents (34). Furthermore, no exercise-related injuries or complications were reported, attesting to the safety of supervised PRT in elderly clinical populations.

Medical contraindications to PRT are relatively few and are outlined in Table 4. Musculoskeletal injury is mostly preventable with proper technique, isolation of the targeted muscle group, and slow lifting speed without momentum or ballistic movements. Machines or chairs with good back support should be used with range of motion limited to the pain-free arc and rest periods between sets and sessions strictly observed (32) (Table 5). Acute injury is usually sharp localized pain felt during or immediately after training and should be treated immediately with rest, ice, compression, and elevation of the affected area. Acute injury is distinct from delayed-onset muscle soreness, which requires no treatment, is a normal response to initiation or increase in training intensity, and is due to muscle ultrastructure damage during loading, which causes an inflammatory response. Repair of this damage leads to desirable adaptations of increased protein synthesis and muscle fiber hypertrophy (31,32).

Cardiovascular Response to PRT

Cardiovascular responses to PRT remain an area of concern for many clinicians. Studies show large brief pulsatile swings in arterial blood pressure (BP) throughout each repetition at high intensities (56) and an associated increase in heart rate (HR). Peak arterial BP rises over a set of repetitions, with HR and BP response proportional to the load lifted. However, these effects are transient, returning to

Table 4—Medical contraindications to PRT

Cardiovascular contraindication

Unstable angina, untreated severe left main coronary artery disease
Angina, hypotension, or arrhythmias provoked by resistance training
Acute myocardial infarction
End-stage congestive heart failure (New York Heart Association Class IV)
Severe valvular heart disease
Malignant or unstable arrhythmias*
Large or expanding aortic aneurysm
Known cerebral aneurysm
Acute deep venous thrombosis
Acute pulmonary embolism or infarction
Recent intracerebral or subdural hemorrhage

Musculoskeletal contraindications

Significant exacerbation of musculoskeletal pain with resistance training
Unstable or acutely injured joints, tendons, or ligaments
Fracture within last 6 months (delayed union)
Acute inflammatory joint disease

Other contraindications

Rapidly progressive or unstable neurological disease
Failure to thrive, terminal illness
Uncontrolled systemic disease†
Symptomatic or large abdominal or inguinal hernias, hemorrhoids
Severe dementia/behavioral disturbance
Acute alcohol or drug intoxication
Acute retinal bleeding/detachment/severe proliferative diabetic retinopathy
Recent ophthalmic surgery‡
Severe cognitive impairment
Uncontrolled COPD/CAL
Prosthesis instability

*Ventricular tachycardia, complete heart block without pacemaker, atrial flutter, and junctional rhythms. †For example, uncontrolled diabetes (symptomatic hyper- or hypoglycemia; HbA_{1c} > 10%), hypertension (untreated systolic BP >170 mmHg), thyroid disease, congestive heart failure, sepsis, acute illness, and fevers. ‡Laser, cataract extraction, retinal surgery, glaucoma surgery, etc. (collated from Fatarone Singh [32]). COPD, chronic obstructive pulmonary disease; CAL, chronic airways limitations.

baseline values or below within 1–2 s after the final lift (57). Moreover, chronic PRT reduces acute systolic BP, diastolic BP, and rate-pressure product (RPP) responses to weight lifting by 17–27% (57).

Climbing 12 flights of stairs produced greater systolic BP, HR, and RPP responses in 17 older healthy men (mean age 64 years) than weight lifting. Stair climbing RPP was 50% greater than weight lifting RPP, suggesting greater myocardial oxygen demand. A total of 10–12 repetitions at 70–80% 1RM elicited higher systolic BP, diastolic BP, and lower HR responses than incline walking but similar RPP values, suggesting comparable myocardial oxygen demand (58). However, the higher diastolic pressure with PRT ensures a more prolonged coronary artery filling at a higher perfusion pressure than aerobic exercise (57), which is of potential benefit to older individuals, particularly those with diastolic

dysfunction or coronary artery disease. Consistent with this are reports of patients who exhibit ischemia or angina during treadmill work but not during PRT at similar elevations of RPP (57). Additionally, ischemic signs and symptoms are reduced after PRT in cardiac patients, attesting to its safety even in high-risk individuals (42,58,59), with no clinically significant nonfatal or fatal cardiovascular events reported in over 26,000 maximal strength tests performed (60). These studies support the safety of PRT in older adults, including those with coronary artery disease, suggesting that PRT may be preferable to aerobic training in many clinical population groups.

Precautions for use of PRT in older obese people with type 2 diabetes

Before prescribing any physical activity regimen, patients should be assessed for metabolic control, complications status,

Table 5—Recommendations for safe and effective PRT in type 2 diabetes

Modality
Machine and/or free weights training
Large muscle groups of upper and lower body and trunk
Dynamic lifting through full pain-free range of motion
Slow velocity during eccentric phase (3–4 s)
Intensity
Moderate-high (60–80% 1RM)
15–18 on Borg Scale of Perceived Exertion (32, 68)
Volume
Two to three set of eight repetitions; 1–2 min rests between sets
Frequency
Every 48–72 h
Precautions
Preactivity medical clearance
Avoid Valsalva
Avoid breath-holding
Avoid sustained isometric contractions
Take care with ankle cuffs because of risk of soft tissue injury
Ensure good posture and technique to avoid back pain

Collated from Fiatarone Singh (32).

and any other medical contraindications to exercise. Detailed guidelines for comprehensive preactivity assessment are well documented (5).

Cardiovascular disease

In individuals with cardiovascular disease, PRT is well-tolerated and complementary to an aerobic training regimen (42,43). In some cases, PRT may even be preferable to an aerobic exercise regimen because of its lower HR and RPP response. Given the increased risk of cardiovascular mortality in older diabetic subjects, even without coronary history, a graded cardiovascular stress test measuring HR, BP, and 12-lead electrocardiogram response is advisable for individuals with clinical markers or significant risk factors for coronary artery disease. Such testing may not directly predict cardiovascular responses to PRT but would identify individuals with exercise contraindications, including marked ischemia, severe arrhythmias, or an exaggerated hypertensive response to exercise (5,7) (Table 4).

Peripheral vascular disease and neuropathy

In individuals with lower-limb complications, including foot ulceration, Charcot's joint, severe peripheral vascular disease, and osteoarthritis, conventional forms of exercise may be hindered. A well-supervised PRT regimen could offer an effective alternative in these individuals. The risk of foot injury from the repetitive load-bearing on lower limbs associated with walking or other aerobic activities is likely to be far greater than that seen with PRT using a variety of weight machines targeting different muscle groups. The use of good footwear and routine pre- and postexercise preventative foot examination would reduce this risk further. Many PRT exercises can be performed seated in chairs with no pressure on the feet. Weight lifting is also an option for individuals with recent lower-extremity amputation, individuals awaiting peripheral bypass surgery, or when foot ulcers preclude weight-bearing exercise. Maintenance of upper- and lower-body strength will optimize recovery from surgery; transfer capability, functional independence, and adaptation to a prosthesis; or minimize debilitation from periods of bed or wheelchair confinement related to these conditions. Clinicians often wrongly assume that if aerobic exercise or walking cannot take place, then exercise must be abandoned. The potential role for PRT in just such situations is obvious and vastly underused.

Nephropathy

The rise in BP associated with PRT implies caution in individuals with nephropathy, but there is no evidence that exercise-induced BP changes exacerbate its progression (5). However, in the absence of definitive data, individuals with nephropathy may want to avoid activities that cause systolic BP elevation more than 200 mmHg, because this could potentially worsen the progression of disease (5). PRT has other benefits in individuals with renal disease. A recent study evaluated 12 weeks of high-intensity PRT in 26 older subjects with moderate renal insufficiency, 10 of whom had type 2 diabetes as the underlying cause. All were consuming a low-protein diet to slow progression of renal failure. In individuals randomized to PRT, there was significant improvement in muscle mass, nutritional status, and functional capacity compared with

individuals on a low-protein diet alone. PRT offset the wasting syndrome of uremia without adverse events or injuries. Moreover, urinary creatinine excretion decreased by 8% and glomerular filtration rate improved significantly compared with diet alone, suggesting that PRT does not cause short-term renal function deterioration (61).

Retinopathy

Exercise increases systemic and retinal BP (5), but there is no evidence that it accelerates diabetic retinopathy either acutely or with chronic training (62). In a study of diabetic subjects with proliferative retinopathy, subjects trained aerobically at increasing intensities until BP reached 50 mmHg over baseline levels or a maximum of 200 mmHg. No new retinal hemorrhages occurred in any subjects (63), suggesting that low-intensity training is safe for individuals with retinopathy as long as systolic BP is maintained below 200 mmHg (5). Changes in intraocular pressure (IOP) secondary to Valsalva maneuvers may be more critical than changes in systemic BP on retinal hemorrhage risk. IOP rose markedly during maximal isometric contraction in power-lifters (64), but pressure changes were transient, lasting 3–8 s (65), questioning whether short intermittent rises in IOP cause long-term sequelae. Chronic aerobic training reduces IOP (66), but it is unknown whether chronic PRT has similar effects. A large study of 606 people with type 1 diabetes followed over 6 years found no association between self-reported level of physical activity and progression or development of proliferative retinopathy. No association was found even in individuals who undertook PRT (67). No similar studies have been performed in older subjects with type 2 diabetes. Given the available data, older subjects with type 2 diabetes who do not have diabetic retinopathy, or have mild to moderate stable nonproliferative retinopathy, could safely undertake PRT as long as care is taken to avoid Valsalva maneuvers and BP is monitored regularly. Until evidence is provided to the contrary, individuals with severe proliferative retinopathy should avoid any activity that may increase IOP, including near-maximal isometric contractions or Valsalva maneuvers (62). There are no data to indicate when PRT may be resumed after cataract, laser, or glaucoma surgery, but most ophthalmol-

ogists recommend restriction of such activities for 1–2 months postoperatively.

SUMMARY — Despite the growing knowledge base supporting the use of PRT in insulin resistance and complex patient populations and its inclusion in physical activity guidelines by international expert committees (5,7), it is not routinely part of usual care for type 2 diabetes. Exploration of the benefits of PRT in diabetes, the mechanisms underlying its effect on insulin resistance, and its acceptability to patients and clinicians should be the basis for further research. The social and financial costs of caring for older obese diabetic individuals are substantial. Including PRT in their treatment regimen, if successful, should improve physiological and psychological function, change body composition, and improve glucose homeostasis, resulting in improved quality of life. The greater feasibility of using PRT over aerobic exercise in this population because of concomitant cardiovascular, arthritic, and other disease provides a solid rationale for further investigation into the global benefits of PRT in the clinical management of older diabetic subjects.

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