

## Lower muscle strength gains in older men with type 2 diabetes after resistance training

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### Abstract

This investigation compared the effects of a twice-weekly whole-body supervised progressive resistance training program in older men with type 2 diabetes with those in healthy older men. Twenty sedentary older men participated in a 16-week progressive resistance training study. They were assigned either to a control group ( $n=11$ ) or to a type 2 diabetes group ( $n=9$ ). Lower as well as upper body maximal strength (one repetition maximum) and power testing and blood draws to determine basal hormone concentrations (total as well as free testosterone and cortisol) were conducted 4 weeks before training and then at Weeks 0 and 16. The training program consisted of intensities ranging from 50% to 80% of one repetition maximum, 5 to 15 repetitions per set, and three to four sets of each exercise. Baseline maximal muscle strength was not significantly different between groups. After training, significant differences were observed in the magnitude of increments in maximal arm strength and leg strength between the control and type 2 diabetes groups ( $36.7\% \pm 12.9\%$  vs.  $24.2\% \pm 4.1\%$ ,  $P=.04$ , and  $35.6\% \pm 12.2\%$  vs.  $17.0\% \pm 3.8\%$ ,  $P<.01$ , respectively), whereas no significant difference was observed between groups in the power output increments of the arm and leg extensor muscles ( $22.5\% \pm 21.3\%$  vs.  $23.8\% \pm 18.3\%$  and  $34.2\% \pm 32.0\%$  vs.  $33.0\% \pm 21.2\%$ , respectively). At baseline, significant differences were observed in the concentrations of total testosterone and cortisol between the control subjects and the patients with type 2 diabetes ( $20.3 \pm 6.0$  vs.  $10.6 \pm 2.9$  nmol/l,  $P<.001$ , and  $546.5 \pm 114.7$  vs.  $343.2 \pm 98.4$  nmol/l,  $P<.001$ , respectively). However, no systematic change was observed during the 16-week strength training period in the basal concentrations of serum total as well as free testosterone and cortisol in both groups. In contrast, statistically significant correlations were observed in a combined group of healthy older men and older men with type 2 diabetes (H+D group) between the mean levels of individual serum total testosterone and cortisol (averaged for the entire training period) and the individual changes in maximal leg strength and arm strength ( $r=0.85-0.51$  and  $0.63-0.70$ , respectively,  $P<.05$ ). In summary, it would appear that older subjects with type 2 diabetes are equally trainable for muscle power output but not for maximal strength as their healthy counterparts.

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**Keywords:** Muscle power; Cortisol; Hypogonadism; Disability

### 1. Introduction

Normal biological aging is associated with declines in muscle mass, neural motor drive, and blood concentrations

of circulating androgenic hormones (e.g., testosterone and insulin-like growth factor 1), resulting in decreases in maximal strength and muscle power output (Häkkinen et al., 1998a, 1998b; Izquierdo et al., 2001). Progressive loss of strength and power is an important factor in disability as well as loss of independence in the elderly population. In this context, it is known that disability is two to three times higher among older adults with diabetes than among those who do not suffer from the condition

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(Gregg et al., 2000; Mayfield, Deb, & Whitecotton, 1999). Indeed, it has been shown that in older men with type 2 diabetes, there are declines in the functional capacity of the neuromuscular system, a lower androgenic environment (Andersen, Nielsen, Mogensen, & Jakobsen, 2004; Andersson, Marin, Lissner, Vermeulen, & Bjorntorp, 1994; Corrales et al., 2004; Goodman-Gruen & Barret-Connor, 2000), and muscle weakness, with the magnitude being related to the severity of the neuropathy (Andersen et al., 2004). These findings are important because physical disability predicts future declines in health status, institutionalization, and health services use, as well as serious reductions in quality of life (Gregg et al., 2000).

On the other hand, exercise interventions that improve neuromuscular performance in older adults are becoming recognized as an effective strategy to increase functional independence (Izquierdo et al., 2001; Izquierdo et al., 2004). Recently, we showed that a twice-weekly whole-body progressive resistance training (PRT) program is effective in eliciting improvements in maximal strength and peak power output in healthy older men and older men with type 2 diabetes (Ibáñez et al., 2005; Izquierdo et al., 2001) and in insulin sensitivity and glucose tolerance in older men with type 2 diabetes (Ibáñez et al., 2005). To date, no study has compared the effects of a whole-body PRT program on changes in maximal strength and muscle power performances between healthy older men and older men with type 2 diabetes. We hypothesized that older men with type 2 diabetes would obtain less gains in strength and power of the upper and lower body extremity muscles in response to a strength training program as compared with healthy older men. Accordingly, the purpose of this study was to compare the effects of a twice-weekly whole-body supervised PRT program in older men with type 2 diabetes with those in healthy older men.

## 2. Methods

### 2.1. Subjects

Twenty untrained and sedentary older men participated in a 16-week supervised PRT study. They were assigned to one of two training groups: a control group ( $n=11$ ) or a type 2 diabetes group ( $n=9$ ). Before inclusion in the study, all candidates were thoroughly screened using extensive medical history recording, resting and maximal exercise electrocardiography, and blood pressure measurements. Cardiovascular, neuromuscular, arthritic, pulmonary, and other debilitating diseases as determined via one or all of the screening tools were reasons for exclusion from the study. Subjects with type 2 diabetes had fasting plasma glucose concentrations consistent with type 2 diabetes mellitus criteria as established by the American Diabetes Association (2004). All subjects were carefully informed about the possible risks and benefits of the project and then asked to

sign a written consent form before participating in the study. This project was approved by the ethics committee of the regional health department. The baseline characteristics of the subjects are shown in Table 1.

### 2.2. Experimental design

The subjects were tested on three occasions using identical protocols (Weeks  $-4$ , 0, and 16). Baseline testing was completed during the first 4 weeks of the study (between the measurements at Week  $-4$  and Week 0), during which no strength training was carried out, although the subjects maintained their customary recreational physical activities (e.g., walking). This was followed by a 16-week period of supervised experimental strength training.

Table 1  
Characteristics of and pretraining (Week 0) as well as posttraining (Week 16) values among the study subjects

Variable	Control subjects ( $n=11$ )	Diabetic patients ( $n=9$ )
Age (years)	64.8±2.6	66.6±3.1
Height (m)	1.65±3.2	1.66±3.1
Body mass (kg)		
Pretraining	81.7±11.8	80.3±10.02
Posttraining	80.2±10.8	79.8±10.1
Body fat (%)		
Pretraining	23.13±5.4	23.7±3.7
Posttraining	21.3±4.0*	22.5±3.7
Body mass index (kg/m <sup>2</sup> )		
Pretraining	29.4±4.0	28.1±2.7
Posttraining	28.8±4.6	28.2±2.7
Fasting plasma glucose level (mg/dl)		
Pretraining	96.4±7.9	146.6±28.3 <sup>a</sup>
Posttraining	96.3±15.2	135.0±29.3*
Total testosterone (nmol/l)		
Pretraining	20.3±6.0	10.6±2.9 <sup>a</sup>
Posttraining	19.5±5.7	10.2±4.3
Free testosterone (pm/ml)		
Pretraining	54.6±15.5	45.7±15.6
Posttraining	51.7±15.2	43.2±23.4
Cortisol (nmol/l)		
Pretraining	546.5±114.7	343.2±98.5 <sup>a</sup>
Posttraining	498.5±64.5	315.8±69.2
1RM bench press (kg)		
Pretraining	47.8±12.4	45.9±6.5
Posttraining	64.1±10.8***	54.1±5.8 <sup>b,***</sup>
1RM half-squat (kg)		
Pretraining	103.1±25.9	106.3±8.3
Posttraining	135.0±32.5***	124.1±8.0 <sup>b,***</sup>
Power output (W) with 30% of 1RM bench press		
Pretraining	245.0±63.2	186.0±27.9
Posttraining	291.6±46.8**	220.3±18.5*
Power output (W) with 30% of 1RM half-squat		
Pretraining	323.5±122.1	239.5±53.9
Posttraining	394.4±147.2***	312.3±52.8**

Data are expressed as mean±S.D.

<sup>a</sup> Baseline difference between groups,  $P<.001$ .

<sup>b</sup> Significantly different from the relative changes at pretraining between the groups,  $P<.01$ .

\*  $P<.05$ , versus pretraining values.

\*\*  $P<.01$ , versus pretraining values.

\*\*\*  $P<.001$ , versus pretraining values.

### 2.3. Strength and power testing

Maximal strength and power were examined because it has been postulated that age-related decreases in maximal strength and power output are associated with frailty, disability, and loss of muscle mass (Häkkinen & Pakarinen, 1994). Before testing, each subject was carefully familiarized with the testing procedure of voluntary force production during several submaximal and maximal actions. In addition, several warm-up contractions were recorded before the actual maximal test actions. Lower body maximal strength and upper body maximal strength were assessed using one repetition concentric maximum (1RM) half-squat and bench-press actions, respectively. A detailed description of the 1RM testing procedure can be found elsewhere (Izquierdo et al., 2001). Basically, in the half-squat test, the subjects began by lifting a bar in contact with the shoulders with weight plates added to both ends of the bar. On command, they performed concentric knee and hip extensions (as fast as possible) of the leg muscles starting from a knee angle of 90° to reach the full extension of 180°. In the bench-press test, the bar was positioned 1 cm above the subjects' chest and supported by the bottom stops of the measurement device. The subjects were instructed to perform from the starting position a purely concentric action maintaining the shoulders in a 90° abducted position to ensure consistency of the shoulder and elbow joints throughout their testing movement. Four to five single attempts were performed until the subjects were unable to extend their legs/arms to the required position. Those incremental increases of weight were made according to the difficulty with which the subjects executed the previous lift. Maximal half-squat strength and bench-press strength were defined as the maximum weight that could be lifted through a full range of motion with the proper lifting technique.

Lower body muscle power output and upper body muscle power output were assessed using 30% of their 1RM in a half-squat position and that in a bench-press position, respectively, because this rate has been reported as the optimal load to produce maximal power output (Izquierdo et al., 2001). In this case, the subjects were instructed to move the load as fast as possible. Two testing actions were recorded, and the best reading trial (with the best highest velocity) was taken for further analyses. During the lower extremity test actions, bar displacement, average velocity (meters per second), and mean power (watts) were recorded by linking a rotary encoder to the end of the bar. The rotary encoder (Computer Optical Products, Chatsworth, CA, USA) recorded the position and direction of the bar within an accuracy of 0.2 mm as well as time events with an accuracy of 1 ms. A customized software (JLML I+D, Madrid, Spain) was used to calculate the power output for each repetition of half-squat performed throughout the whole range of motion. Average velocity and power were calculated through the whole range of motion used to

perform a complete repetition as the most representative mechanical parameters associated with a contraction cycle of each muscle group. In the half-squat performance, the subjects were instructed not to try jumping with the weight.

In all tests of neuromuscular performance, strong verbal encouragement was given to the subjects to motivate them to perform each test action as maximally and rapidly as possible. The period of rest between the actions was always 1.5 min. Maximal strength and muscle power variables showed reliability coefficients ranging from 0.80 to 0.99, and the coefficients of variation ranged from 2% to 7%.

### 2.4. Training protocol

The twice-weekly strength training program was a combination of heavy resistance and explosive strength training by also emphasizing higher action velocities of the exercises performed. This has been reported as an effective strategy to minimize age-related decreases in muscle mass, maximal strength, and muscle power output (Häkkinen et al., 1998b) in older men without diabetes mellitus. The strength training program intensities, which ranged from 50% to 80% of the 1RM, used in this study were similar to those reported previously (Häkkinen et al., 1998a). The subjects were asked to report to the training facility two times a week for 16 weeks to perform dynamic resistance exercises for 45 to 60 min per session. A minimum of 2 days elapsed between two consecutive training sessions. Each training session included two exercises for the leg extensor muscles (bilateral leg press and bilateral knee extension exercises), one exercise for the arm extensor muscle (the bench press), and four to five exercises for the main muscle groups of the body (chest press, lateral pull down, and/or shoulder press for the upper body; abdominal crunch and/or rotary torso and/or another exercise for the trunk extensors; and standing leg curl and/or adductor–abductor exercises). Only resistance machines (Technogym, Gambettola, Italy) were used throughout the training period. All the exercises were performed using concentric muscle actions followed by eccentric actions during the lowering phase of a movement. The training loads prescribed in this study were determined during the training sessions every week for the 16-week training period using an RM approach.

During the first 8 weeks of the training period, the subjects trained with loads of 50% to 70% of the individual 1RM, 10 to 15 repetitions per set, and three to four sets of each exercise. During the last 8 weeks of the training period, the loads were 70% to 80% of the 1RM, 5 to 6 repetitions per set (higher loads), and three to five sets. In addition, from Week 8 to Week 16, the subjects performed part (20%) of the leg extensor and bench-press sets with loads ranging from 30% to 50% of the 1RM. On these training occasions, the subjects then performed 6 to 8 repetitions per set and three to four sets of each exercise but executed all of the repetitions as rapidly as possible. In all the individual

exercise sessions performed, one of the researchers was present to direct and assist each subject toward performing the appropriate work rates and loads. To be considered compliant, subjects had to attend a minimum of 90% of the exercise sessions organized.

### 2.5. Biological variables

Resting blood samples were drawn at Week  $-4$  (4 weeks before the start of training) and then at Weeks 0 and 16. The subjects reported to the laboratory and sat quietly for 10 to 15 min before giving a blood sample. Venous blood samples were obtained at rest between 8 and 9 a.m. from the antecubital vein to determine hormone concentrations of serum total testosterone, free testosterone, and cortisol. Blood samples were taken at the same time of day to reduce the effects of diurnal variation on hormone concentrations. Blood was drawn after 12 h of fasting and 1 day of minimal physical activity. Basal glycemia was analyzed using an enzymatic hexokinase method (Roche Diagnostics, Mannheim, Germany). The samples for hormone analysis were centrifuged, and the serum was removed and frozen at  $-20^{\circ}\text{C}$  for subsequent analysis. The assays of serum cortisol and testosterone were performed by radioimmunoassay. Serum total as well as free testosterone and cortisol concentrations were measured using reagent kits from Diagnostic Product and INCSTAR (Coat-A-Count Total/Free Testosterone TKTT11CS, Los Angeles, CA, USA, and GammaCoat Cortisol Radioimmunoassay Kit, Stillwater, MN, USA, respectively). The sensitivity of the total testosterone assay was 0.14 nmol/l, whereas that of the free testosterone assay was 0.15 pmol/l. The sensitivity of the cortisol assay was 0.21 nmol/l. All samples were analyzed

in the same assay for each hormone according to the manufacturer's instructions.

### 2.6. Statistical analysis

Standard statistical methods were used for the calculation of the mean values, standard deviations, and Pearson's product-moment correlation coefficients. Statistical comparisons during the control period (from Week  $-4$  to Week 0) were performed using Student's paired  $t$  test. A  $t$  test for independent samples determined any difference between the two groups' pretraining and posttraining strength and biological measures. The training-related effects were assessed using a two-way analysis of variance with repeated measures (Group $\times$ Time). When a significant  $F$  value was achieved, Scheffé post hoc procedures were performed to locate the pairwise differences between the mean values. Statistical power calculations for this study ranged from 0.75 to 0.80. The  $P < .05$  criterion was used for establishing statistical significance.

## 3. Results

There was no statistically significant difference within the groups for any of the variables tested in the two measurements during the control period (from Weeks  $-4$  to 0). The results of absolute maximal strength and muscle power output and basal hormone concentration at baseline (Week 0) and after training are shown in Table 1. Baseline maximal voluntary muscle strength was not significantly different between the groups. After training, significant differences were observed in the magnitude of increments in

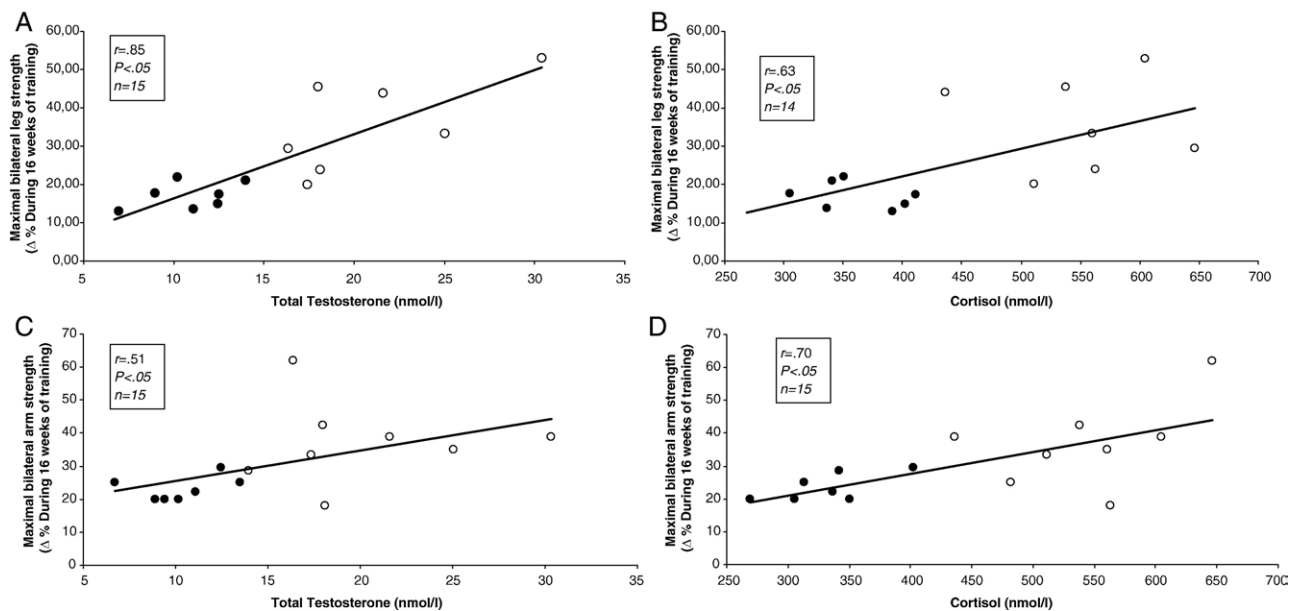


Fig. 1. Relationships between maximal bilateral leg strength and mean level of individual serum total testosterone (A) as well as that of cortisol (B) and between maximal bilateral arm strength and mean level of individual serum total testosterone (C) as well as that of cortisol (D) in the combined group of control subjects (white circles) and older men with type 2 diabetes (black circles).

maximal arm strength and leg strength between the control and type 2 diabetes groups ( $36.7\% \pm 12.9\%$  vs.  $24.2\% \pm 4.1\%$ ,  $P < .05$ , and  $35.6\% \pm 12.2\%$  vs.  $17.0\% \pm 3.8\%$ ,  $P < .01$ , respectively), whereas no significant difference was observed between groups in the power output increments of the arm and leg extensor muscles with 30% of their 1RM ( $22.5\% \pm 21.3\%$  vs.  $23.8\% \pm 18.3\%$  and  $34.2\% \pm 32.0\%$  vs.  $33.0\% \pm 21.2\%$ , respectively).

In contrast, baseline significant differences were observed in the concentrations of total testosterone and cortisol between the control subjects and the patients with type 2 diabetes ( $20.3 \pm 6.0$  vs.  $10.6 \pm 2.9$  nmol/l,  $P < .001$ , and  $546.5 \pm 114.7$  vs.  $343.2 \pm 98.4$  nmol/l,  $P < .001$ , respectively). However, no systematic change was observed during the 16-week strength training period in the basal concentrations of serum total as well as free testosterone and cortisol in both groups (Table 1). After 16 weeks of PRT, fasting plasma glucose levels significantly decreased in the older men with type 2 diabetes by 7.1% (from  $146.6 \pm 28.3$  to  $135.0 \pm 29.3$  mg/dl,  $P < .05$ ) but remained unchanged in the control group (Table 1). However, no significant relationship was observed between individual changes in fasting glycemia and individual strength or body composition.

Statistically significant correlations were found in a combined group of healthy older men (control) and older men with type 2 diabetes (H+D group) between the mean levels of individual serum total testosterone (averaged for the entire training period) and the individual changes in maximal bilateral leg strength and maximal bilateral arm strength ( $r = 0.85$  and  $0.51$ , respectively,  $P < .05$ ) (Fig. 1A and C). Moreover, statistically significant correlations were observed in a combined group of control and H+D subjects between the mean levels of individual serum total cortisol (averaged for the entire training period) and the individual changes in maximal bilateral leg strength and maximal bilateral arm strength ( $r = 0.63$  and  $0.70$ , respectively,  $P < .05$ ) (Fig. 1B and D).

#### 4. Discussion

The novel findings of this study are that the twice-weekly whole-body supervised PRT program led to similar gains in the muscle power output of the upper and lower body musculature in both groups but that the relative gains in maximal strength were greater in the control group as compared with the type 2 diabetes group. Moreover, in both groups, no systematic change was found during the 16-week strength training period in the basal concentrations of serum free as well as total testosterone and cortisol. It was also interesting to observe that the mean levels of individual serum total testosterone and cortisol and the individual changes in maximal bilateral arm strength and bilateral leg strength correlated significantly during the entire 16-week training period in the H+D group.

As far as we know, only one published comparative study assessed the influence of a resistance training program in the maximal strength of older men with type 2 diabetes (Holten et al., 2004). In the study by Holten et al., the subjects participated in a 6-week strength training program in which only one leg was trained three times a week, with the other leg remaining untrained. Training-induced increases in maximal leg muscle strength were similar between the diabetic and healthy older men. On the contrary, in our study, a unique approach was used to compare the effects of a total whole-body resistance training program in the maximal strength and muscle power performances of the upper and lower extremity muscles between healthy older men and older men with type 2 diabetes. In the patients with type 2 diabetes, resistance training led to a similar muscle power increase but a smaller strength gain relative to the healthy older men. In both groups, the greatest increase in muscle contraction velocity (e.g., muscle power output with submaximal loads) was mainly related to the submaximal loading approach more frequently used during the strength training sessions (50%–80% of the 1RM). This agrees well with the principle of the specificity of the training and seems to be true also in older adults. The discrepancies of our results with those of Holten et al. may be explained in part by training protocol differences related to the intensity and volume used, the dependent variable selection, and the muscle groups tested. Holten et al. performed a short-term (6 weeks) training program using a one-legged training model with lightweights and single-joint training/testing devices to measure the 3RM; in contrast, we compared the effects of a 16-week whole-body heavy and explosive training program using dynamic multijoint variable resistance training/testing devices to test muscle power output and the 1RM strength of the upper and lower body musculature.

In our study, it was interesting to observe that differences achieved in the maximal strength of the arms and legs by the groups were already present at 8 weeks, whereas a similar response in the muscle power output was observed between both experimental groups. Thus, it would appear that older men with diabetes are less trainable for maximal strength (i.e., they are more sensitive to the duration and/or the intensity of training) but have equal responsiveness to strength training for muscle power output relative to their healthy counterparts. The similar increase in muscle power output in older men with type 2 diabetes observed in this study is even more interesting considering the tendency ( $P = .08$ ) toward an initial lower level of muscle power output of the upper and lower body musculature as compared with the control group. Therefore, further studies on training frequency and intensity are warranted to optimize maximal strength and muscle power development of arm and leg extension actions in healthy subjects and patients with type 2 diabetes. Nevertheless, one might speculate that the unique finding of limitation in maximal strength gains after strength training in these patients with type 2 diabetes may also be attributed to some extent by

differences in the maximal voluntary neural drive of the involved muscles.

Furthermore, a potential physiological mechanism that explains these differences in our study could be associated with the greater declines observed in the functional capacity of the neuromuscular and/or neuroendocrine systems in older men with type 2 diabetes (Andersen et al., 2004; Andersson et al., 1994; Corrales et al., 2004; Goodman-Gruen & Barret-Connor, 2000). In this context, muscle weakness in type 2 diabetes has been related to the severity of the neuropathy (Andersen et al., 2004). However, the neuromuscular system does not seem to be significantly affected in this group of older men with newly diagnosed type 2 diabetes. Indeed, after the training period, the patients with type 2 diabetes showed an ability of the upper and lower extremity muscles to develop submaximal power output, similar to the control strength-trained subjects. This finding, and the fact that diabetes neuropathy seems to affect only 8% of newly diagnosed patients (Partanen et al., 1995), should indicate that the voluntary neural drive to muscles and qualitative characteristics of the muscle tissue itself in the diabetic subjects of this study are not different from those observed in control subjects.

On the other hand, consistent with previous studies, the older men with type 2 diabetes in this study had lower testosterone levels at pretraining as compared with the healthy older men (e.g., six of nine subjects were hypogonadal). However, no systematic change was observed in this study during the 16-week strength training period in the basal concentrations of serum testosterone and free testosterone in both treatment groups. These observations are in agreement with those of prior studies on healthy middle-aged and older men (Izquierdo et al., 2001) who also failed to observe changes in resting serum testosterone using a strength training program over a few months. Kraemer et al. (1999) also observed this similar nonresponse with 10 weeks of training in 62-year-old healthy men despite the enhanced adaptational ability to acute exercise-induced response after resistance exercise. However, the lower basal concentration of testosterone and the diminished rate of increase in maximal dynamic strength observed in older men with type 2 diabetes suggest that the overall loading of the training program during the 16 weeks of training in the older group with chronic illness may have been near the limit of the physiological range. It is possible that the increase in the overall intensity of the training and/or the target for maximal strength and power development became too stressful for the older men with type 2 diabetes and led to their diminished maximal strength responsiveness as well as similar muscle power gains despite the initial low levels observed at pretraining. Unfortunately, because only chronic changes in resting hormone concentrations were measured in this study, one may not speculate on an attenuated acute response after resistance training in the older men with type 2 diabetes.

Finally, it was also interesting to observe that statistically significant correlations were observed in the H+D group among the mean levels of the individual serum total testosterone and individual serum total cortisol (averaged for the entire training period) and the individual changes in maximal bilateral leg strength and bilateral arm strength. These kinds of correlation are similar to those previously observed in healthy older men and women during prolonged heavy resistance strength training (Häkkinen & Pakarinen, 1994; Häkkinen, Pakarinen, Kraemer, Newton, & Alen, 2000). These results suggest that a low level of the anabolic hormone testosterone may be a limiting factor in strength development during strength and/or power training in older adults with type 2 diabetes. Thus, one might speculate on the importance of the basal concentration of testosterone in older men by the potent influence on neuromuscular adaptations (e.g., in muscle hypertrophy and/or increased neurotransmitter synthesis, release, or neurotransmitter receptor density, thus altering tissue responsiveness) for strength development (Gray, Feldman, McKinlay, & Longcope, 1991; Häkkinen & Pakarinen, 1994; Kraemer et al., 1999). It is possible that although the blood testosterone levels would remain unaltered, strength and power training can induce changes, at the receptor level, for instance (Inoue, Yamasaki, Fushiki, Okada, & Sugimoto, 1994).

On the other hand, it was somewhat surprising that the mean levels of the individual serum total cortisol (averaged for the entire training period) were positively related to the individual changes in maximal bilateral arm strength and bilateral leg strength in the H+D group. It indicates that those older men with lower basal serum cortisol concentrations (e.g., older men with type 2 diabetes) may be able to produce minor strength gains as compared with those with higher levels. This observation also suggests that the impairment in the basal hypothalamic–pituitary–adrenal axis function may be a limiting factor in strength development during prolonged strength training, especially in older adults with type 2 diabetes. These positive correlations observed between serum catabolic hormone concentrations and changes in the individual gains in maximal strength during the strength training period could be considered as unexpected findings because it is known that testosterone activates the anabolic phase of skeletal muscle protein metabolism acting against the proteolytic effect of cortisol. In general, the data indicate that in those older subjects with type 2 diabetes who have demonstrative very low basal testosterone concentrations and a mild cortisol deficiency, the individual gains in maximal strength during the strength training period may be minor as compared with those in age-matched healthy counterparts with higher testosterone and cortisol concentrations.

In summary, the results suggest that older men with type 2 diabetes may have lower strength gains but similar muscle power enhancement in response to strength training relative to healthy older men. Thus, it would appear that older

subjects with type 2 diabetes are equally trainable for muscle power output but not for maximal strength as their healthy counterparts.

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