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Dynamic Strength Training Improves Insulin Sensitivity without Altering Plasma Levels and Gene Expression of Adipokines in Subcutaneous Adipose Tissue in Obese Men

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Context: Obesity is characterized by a low-grade inflammatory state, which could play a role in insulin resistance. Dynamic strength training improves insulin sensitivity.

Objective: The objective of this study was to investigate, in obese subjects, whether the insulin sensitizing effect of dynamic strength training is associated with changes in plasma levels and gene expression of adipokines potentially involved in the development of insulin resistance.

Design: Twelve obese male subjects were investigated before and at the end of 3 months of dynamic strength training. Insulin sensitivity was evaluated using euglycemic-hyperinsulinemic clamp. Blood samples and needle biopsy samples of sc abdominal adipose tissue were obtained. The plasma levels and adipose tissue mRNA levels of adiponectin, leptin, IL-1β, IL-6, and TNF-α were determined.

Results: The training induced an increase in the whole-body glucose disposal rate by 24% ($P = 0.04$). The body weight was not altered during the training. Plasma levels of leptin decreased during the training (16.6 ± 6.3 *vs.* 13.1 ± 5.7 ng/ml) by 21% ($P < 0.02$), whereas no change in plasma levels of other adipokines and C-reactive protein was observed. Gene expression of the investigated adipokines was not changed in sc adipose tissue during the training.

Conclusions: In obese subjects, the dynamic strength training resulted in an improvement of whole-body insulin sensitivity. The increase in insulin sensitivity was not associated with training-induced modifications of plasma levels or adipose tissue gene expression of adipokines supposedly involved in the development of insulin resistance. **(*J Clin Endocrinol Metab* 91: 5107–5112, 2006)**

REGULAR PHYSICAL ACTIVITY is recognized as an effective nonpharmacological intervention with beneficial effect on insulin sensitivity and glucose tolerance in healthy, obese (1), insulin resistant (2), and type 2 diabetic individuals (3). Strength training (also called resistance training) is known to improve insulin sensitivity as is aerobic exercise training, although potentially via different mechanisms (4).

Obesity, as generally accepted now, is characterized by a low-grade inflammatory state that leads to insulin resistance and development of metabolic diseases such as diabetes and cardiovascular diseases (5). Chronic low-grade systemic inflammation is characterized by a 2- to 3-fold increase of TNF-α, IL-1, IL-6, IL-1 receptor antagonist, soluble TNF-α receptors (sTNF-Rs), and C-reactive protein plasma concentrations (6). Higher plasma IL-6 and TNF-α mRNA and protein secretion from adipose tissue are associated with obesity and/or insulin resistance (7). They are assumed to play a role in the mechanism of insulin resistance. Adiponectin and leptin are secreted by adipocytes and may act like physiological insulin sensitizers. The suggested mechanisms of insulin sensitizing action of adiponectin are the suppression of hepatic glucose production (8) and the increase of fatty acid oxidation by skeletal muscle, thereby reducing plasma free fatty acid levels (9). Adiponectin stimulates fatty-acid oxidation and glucose uptake in adipocytes and muscle by activating 5′-AMP-activated protein kinase (10). Leptin also operates through activation of 5′-AMP-activated protein kinase and improves fatty acid oxidation in muscle (11). Little is known about the peripheral physiological effects of adiponectin and leptin in humans. Stefan *et al.* (12) suggested that physiological concentrations of fasting plasma adiponectin are not related to fat oxidation or energy expenditure in resting conditions in humans. A recent study of Blaak *et al.* (13) showed that serum leptin was negatively related to

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Abbreviations: BMI, Body mass index; hsCRP, high-sensitivity C-reactive protein; qPCR, quantitative PCR; 1-RM, one-repetition maximum strength; SCAAT, sc abdominal adipose tissue; SI_{Clamp}, clamp-derived index of insulin sensitivity; sTNF-R, soluble TNF-α receptor; VO_2max, maximal oxygen consumption.

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fasting fat oxidation. As shown recently, there is an increased amount of macrophages in the stroma vascular fraction of adipose tissue in obese subjects (14, 15). A substantial number of inflammatory genes in the stromavascular fraction of adipose tissue are expressed in macrophages, and it is hypothesized that the presence of resident macrophages is a reason for the inflammatory profile observed in sc (14) or visceral (15) adipose tissue of morbidly obese subjects.

The effects of strength training on insulin sensitivity in different populations have been examined already in a number of studies (16–18). There are a few studies indicating that exercise training might reduce the overall inflammatory state (19). However, as recently emphasized, the type and extent of physical activity necessary for antiinflammatory and insulin sensitizing effects are not clear. Strength training is an increasingly popular type of exercise in obese subjects and type 2 diabetic patients as it may be easily practiced in growing numbers of fitness centers. Moreover, strength training is a good model to investigate the effects of exercise while maintaining stable body weight.

To our knowledge, no study has investigated the effects of dynamic strength training simultaneously on gene expression and plasma levels of the adipokines with a suggested role in insulin resistance. Therefore, the aim of the present study was to investigate whether long-term dynamic strength training induces improvement in insulin sensitivity in obese middle-aged men and exerts antiinflammatory and insulin-sensitizing effects by altering plasma and mRNA levels of adiponectin, leptin, IL-1β, IL-6, and TNF-α in sc abdominal adipose tissue (SCAAT).

Subjects and Methods

Subjects

Twelve obese, middle-aged, sedentary males [age 50.4 ± 2.3 yr, mean body mass index (BMI) 33.6 ± 1.2 kg/m^2] were recruited for the study. Five subjects were previously diagnosed as type 2 diabetic, based on the World Health Organization criteria (20). Three of them were drug free; the two others were on hypotensive (amlodipin) therapy. The latter medication was not changed during the study. Among the remaining seven nondiabetic subjects, four of them had impaired oral glucose tolerance test, whereas the three remaining subjects had normal oral glucose tolerance test (20). None of the subjects had any disease other than those mentioned above. All patients had a stable weight for at least 3 months before inclusion. The sedentarity of patients was assessed during an interview. They were instructed to maintain their habitual diet throughout the whole study period. Dietary regimen was assessed using a 3-d food record in the beginning, at the sixth week, and at the end of the study. According to this evaluation, no changes in calorie intake and macronutrient composition of the diet were detected. The study was approved by the Ethical Committee of the 3rd Faculty of Medicine, Charles University, and all subjects gave their informed consent after detailed explanation.

Experimental protocol

The participants followed a program of dynamic strength training for 12 wk. The subjects were investigated twice: before and at the end of the intervention. On each occasion, they were investigated at 0800 h after an overnight fast. The second investigation was performed 48–72 h after the last exercise session to eliminate the effect of the last acute bout of exercise on insulin sensitivity. Anthropometric and body composition measurements and blood sampling for subsequent analysis were performed. Thereafter, hyperinsulinemic euglycemic clamp was carried out. Two days after this investigation at 0900 h, after an overnight fast, a needle microbiopsy of adipose tissue was performed under local anesthesia (1% Xylocaine) from the abdominal region (14–20 cm lateral to the umbilicus) for subsequent gene expression analysis. In addition, 4–5 d before the clamp, the maximum exercise test for determination of maximum aerobic capacity was carried out. At the beginning of the dynamic strength training program, the test of maximum muscular strength was performed [see *maximal oxygen consumption (VO_2max) and maximum muscle strength determination* paragraph].

Training program

The dynamic strength training program started after completion of entry examinations. Based on the test of muscular strength, the individual prescription of physical activity (intensity, number of repetitions) was recommended according to conventional guidelines (21). Participants exercised in fitness centers three times a week, for 1 h, including warm-up and stretching. The training was performed using equipment (Technogym, Gambettola, Italy), with the minimum duration of 30–45 min of strength training itself. It consisted of 17 different single-joint and multijoint exercises (one set) involving large muscle groups. The intensity was set at 60–70% of their maximum muscle strength [one repetition maximum (1-RM)] for each exercise (*i.e.* for each muscle group), and 12–15 repetitions were performed. The subjects completed one set during the initial week. Afterward the number of sets was gradually adapted to the progression of fitness. To assess progress in muscle strength, maximum strength on upper (bench press) and lower body (leg press) was determined. Participants were supervised by professional fitness instructors twice a week during the initial period and once a week later on. All participants kept an exercise diary. The participants were instructed to limit other regular physical activity besides the dynamic strength training during the study.

Anthropometric measurements

Body weight and waist and hip circumference were measured regularly throughout the study. Body composition (fat mass, fat free mass) was assessed in the fasting condition by bioimpedance (QuadScan 4000; Bodystat, Douglas, UK). Coefficients of variation of fat mass, fat-free mass, and impedance were, respectively, 1.7, 0.8, and 1.5%.

VO_2max and maximum muscle strength determination

The maximum exercise test was performed on a bicycle ergometer (Ergoline 800) to determine VO_2max in each subject. An initial workload of 50 W was followed by a sequential increase in workload of 25 W every minute until exhaustion. Oxygen uptake was measured using Vmax Sensor Medics (Yorba Linda, CA), and attention was paid to reach one of the criteria for VO_2max as defined (22). The highest VO_2 achieved was taken as the VO_2max. Verbal encouragement was given to reach maximal performance. Heart rate was continuously monitored.

To determine maximal muscle strength (1-RM) on upper body (bench press) and lower body (leg press), the subjects performed, after warm-up and stretching, three to five initial exercises on 60–80% of their estimative 1-RM. Afterward, weight-balance was increased, and they performed one more lift. If they were successful in lifting, they continued the same way with 3- to 5-min breaks in between exercises until their maximum. The weight of the weight-balance of the last successful lift was taken as the maximal muscle strength (1-RM). Three to five attempts were allowed to reach the maximum.

Euglycemic-hyperinsulinemic clamp

The euglycemic-hyperinsulinemic clamp was performed according to the method of de Fronzo *et al.* (23). A catheter for insulin and glucose infusion was inserted into an antecubital vein, and a second catheter for blood sampling was placed in a dorsal vein of the ipsilateral hand. The hand was kept in a warm box (60 C) to provide arterialization of venous blood. Priming plus continuous infusion of crystalline human insulin (Actrapid Human; Novo A/S, Bagsvaerd, Denmark), 40 mU/m^2 body area/min, was given for 210 min. Euglycemia (the fasting blood glucose concentration) was maintained by a variable 20% glucose infusion. The infusion rate was determined by measuring arterialized plasma glucose every 5 min (glucose analyzer; Beckman Instruments, Fullerton, CA). Glucose consumption was calculated from the exogenous glucose in-

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fusion rates during the last 30 min of the clamp and corrected for kilogram of fat-free mass ($mg \cdot min^{-1} \cdot kg^{-1}$ fat-free mass). Glucose clamp-derived index of insulin sensitivity (SI_{Clamp}) was defined as $M/(G \times \Delta I)$ corrected for body weight (24). M is the steady-state glucose infusion rate (milligram per minute), G is the steady-state blood glucose concentration (milligram per deciliter), and ΔI is the difference between basal and steady-state plasma insulin concentrations (microunits per milliliter).

mRNA quantification

The biopsies of SCAAT (about 1 g) were used for mRNA quantification. The samples were washed, homogenized in RLT lysis buffer (QIAGEN, Courtaboeuf, France) and stored at −80 C until analysis. Total RNA was extracted using the RNeasy minikit (QIAGEN). Integrity of RNA was checked on agarose gel, and RNA concentration was determined using a fluorometric assay (Ribogreen, RNA Quantification Kit, Invitrogen, Cergy Pontoise, France; Fluoroskan Ascent, Labsystem, Cergy Pontoise, France; Thermo Electron Corp., Waltham, MA). Reverse transcription was performed with 1 μg of total RNA using random hexamers as primers and SuperScript II reverse transcriptase (Invitrogen). Real-time quantitative PCR (qPCR) was performed on ABI PRISM 7000 sequence detection system (Applied Biosystems, Foster City, CA). A set of primers was designed for adiponectin and leptin using the software Primer Express 1.5 (Applied Biosystems) and used at a final concentration of 300 nmol/liter with SYBR-Green-based chemistry. For each primer pair, a standard curve was obtained using serial dilutions of human adipose tissue cDNA prior mRNA quantification. To verify that genomic DNA was not amplified, qPCR was performed on reverse transcription reactions with no addition of reverse transcriptase. Primers and probes for IL-1β, IL-6, and TNF-α were obtained from Applied Biosystems using TaqMan probe-based assays. The probes were labeled with a reporter dye (FAM) on the 5′ end. We used 18S rRNA (Ribosomal RNA Control TaqMan assay kit; Applied Biosystems) as control to normalize gene expression. Each sample was performed in duplicate, and 10 ng cDNA was used as a template for real-time PCR. When the difference between the duplicates was above 0.5 Ct, qPCR was performed again.

Determination of plasma levels

Plasma glucose was determined with a glucose oxidase technique (Biotrol kit, Paris, France). Plasma insulin was measured using an insulin Irma kit (Immunotech, Prague, Czech Republic). Plasma triglycerides were determined by spectrophotometry. Plasma high-sensitivity C-reactive protein concentrations were assessed by immunoturbidimetry using an ultrasensitive kit (Orion-Diagnostica, Espoo, Finland) and Cobas Mira Plus analyzer (Roche, Stockholm, Switzerland). Adiponectin and leptin plasma levels were determined using RIA kits from Linco Research (St. Charles, MO) according to the manufacturer's recommendations. IL-6, IL-1β, and TNF-α plasma levels were determined using quantikine IL-6, quantikine high sensitivity IL-1β, and TNF-α kits (R&D Systems, Minneapolis, MN), respectively.

Statistical analysis

Data are presented as means ± SD. Statistical analysis was performed using SPSS 12.0 for Windows (SPSS Inc., Chicago, IL). The differences in the responses to the training were analyzed using a Wilcoxon's signed rank test. Correlations were assessed by Spearman's correlation. The level of significance was set at $P < 0.05$.

Results

Clinical data

The training did not produce a significant change in body weight or other anthropometric variables (fat mass, fat free mass, waist and hip circumference) or VO_2max (Table 1). However, it did lead to a marked increase of indices of muscle strength represented by bench press and leg press (by 33.4 and 31.7%, respectively).

Effect of strength training on metabolic variables and insulin sensitivity

Metabolic and hormonal variables of the subjects before and after the training are shown in Table 2. Plasma insulin, blood glucose concentrations, and indices of lipid metabolism remained unchanged. No change in high-sensitivity C-reactive protein (hsCRP) concentration in blood was detected. Glucose disposal rate corrected for kg of fat-free mass increased after training by 24.4%. As shown in Fig. 1 and Table 2, the insulin sensitivity calculated by SI_{Clamp} also significantly increased by 30.8%.

Effect of strength training on plasma adipokine levels

Training did not induce changes in plasma levels of adiponectin, IL-1β, IL-6, or TNF-α (Table 3). The plasma leptin level decreased by 21%. This decrease in leptin concentration was present in all but one subject, whose leptin levels increased after intervention (Fig. 2). The training-induced plasma leptin reduction remained significant after adjustment of plasma values to BMI (by 20%, $P = 0.02$).

Effect of strength training on gene expression of adipokines in SCAAT

The training did not induce changes in relative mRNA levels for any of the investigated adipokines in SCAAT (Table 4).

TABLE 1. Anthropometric and clinical characteristics of subjects before and after strength-training period

	Before training	After training	95% CI	*P* value
Body weight (kg)	109.2 ± 12.6	109.5 ± 12.9	−1.76, 2.08	0.878
BMI (kg/m^2)	33.6 ± 3.9	33.7 ± 4.0	−0.54, 0.66	0.799
Fat mass (%)	31.6 ± 4.9	30.1 ± 4.2	−0.23, 5.31	0.139
Fat-free mass (%)	68.5 ± 4.8	69.9 ± 4.2	−5.28, 0.50	0.139
Waist circumference (cm)	115.7 ± 7.9	115.7 ± 8.0	−2.75, 2.95	0.905
Hip circumference (cm)	112.2 ± 7.4	112.4 ± 4.7	−2.85, 3.05	1.000
Waist to hip ratio	1.03 ± 0.1	1.03 ± 0.04	−0.04, 0.04	0.905
Systolic blood pressure (mm Hg)	140.0 ± 10.8	127.7 ± 19.4	0.54, 24.12	0.002
Diastolic blood pressure (mm Hg)	92.5 ± 9.2	81.3 ± 9.8	3.57, 18.93	0.002
Heart rate (bpm)	66.6 ± 7.4	65.7 ± 7.6	−2.04, 3.81	0.552
VO_2max (ml/kg·min)	21.4 ± 2.9	22.9 ± 4.1	−3.86, 0.96	0.358
Bench press 1-RM (kg)	51.8 ± 8.9	69.1 ± 8.7	−26.28, −11.50	0.005
Leg press 1-RM (kg)	174.9 ± 46.8	230.4 ± 56.9	−103.57, −21.98	0.005

Values are means ± SD. CI, Confidence interval.

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TABLE 2. Metabolic and hormonal characteristics of obese men before and after 12 wk of dynamic strength training

	Before training	After training	95% CI	*P* value
Fasting glucose (mmol/liter)	7.1 ± 3.1	6.6 ± 1.8	−7.44, 2.48	0.260
Fasting insulin (mU/liter)	10.9 ± 10.6	4.8 ± 4.78	−4.57, 15.77	0.237
Total cholesterol (mmol/liter)	5.2 ± 0.7	5.2 ± 1.0	−0.41, 0.44	0.646
HDL cholesterol (mmol/liter)	1.1 ± 0.2	1.07 ± 0.2	−0.16, 0.18	0.878
Triglycerides (mmol/liter)	1.8 ± 0.9	1.8 ± 0.8	−0.50, 0.43	0.878
Norepinephrine (pg/ml)	307.6 ± 66.1	320.9 ± 73.2	−47.72, 21.12	0.507
Epinephrine (pg/ml)	39.9 ± 14.3	40.6 ± 11.3	−6.37, 4.97	0.540
hsCRP (mg/liter)	3.3 ± 2.2	2.9 ± 1.7	−0.92, 1.68	0.929
Glucose disposal (mg·min^{-1}·kg $^{-1}$ fat-free mass)	4.5 ± 2.1	5.6 ± 1.8	−2.11, −0.09	0.04
SI_{Clamp}	5.2 ± 2.3	6.8 ± 3.1	−2.75, −0.43	0.01

Values are means ± SD. CI, Confidence interval; HDL, high-density lipoprotein.

Relationship between insulin sensitivity and adipokine levels

Marked association between the glucose disposal rate and TNF-α mRNA ($r = -0.697$, $P = 0.03$) was apparent before the training program. No relations between the indices of insulin sensitivity and plasma level and gene expression in SCAAT for other cytokines were observed.

Relationship between adipokine plasma levels and/or gene expression in SCAAT and anthropometric and metabolic variables

Plasma leptin was positively related to BMI at the beginning ($r = 0.683$, $P = 0.04$) but not at the end of the intervention. hsCRP was positively correlated with waist circumference as at baseline as after dynamic strength training ($r = 0.572$, $r = 0.628$, respectively, $P < 0.05$). No correlations between mRNA levels of adipokines before or after the training and anthropometric or metabolic variables were observed.

Discussion

The aim of the present study was to investigate the associations between the effects of dynamic strength training on insulin resistance/sensitivity and modifications of the cytokines produced in adipose tissue and supposedly related to the pathogenesis of insulin resistance in obese individuals. In the present study, the 3 months of dynamic strength training induced an improvement in insulin sensitivity as assessed by the euglycemic-hyperinsulinemic clamp. We investigated a sustained effect of exercise on plasma levels of relevant adipokines as well as the effect on gene expression of the cytokines in SCAAT. The study did not reveal any significant changes, except the decrease of plasma leptin, in the measured variables induced by the training.

The positive muscular effects of dynamic strength training in the present study were demonstrated by a marked improvement in muscular strength (as evaluated by bench press and leg press tests). The improvement of insulin sensitivity in our subjects is in accordance with results of other studies investigating effects of strength training (18, 25). The training did not induce any significant change in total body weight or body adiposity evaluated by the bioimpedance method. We cannot exclude training-induced changes in the amount of visceral fat because no specific measures of visceral fat were performed in this study.

Obesity and/or type 2 diabetes mellitus are associated with low-grade inflammatory state characterized by altered levels of C-reactive protein and several cytokines produced and released from adipose tissue (adipokines). Compared with lean individuals, mRNA and plasma levels are found to be lower for adiponectin (26) and higher for leptin (27) in obese subjects. This corresponds to the findings of pretraining values in this study. The circulating levels of IL-6 have been reported to be higher in patients with obesity (27). The insulin stimulation of IL-6 gene expression in adipose tissue might play a role in this process (28). In obese subjects, TNF-α levels are found to be elevated (29). Circulating levels of IL-1β in type 2 diabetic patients (30) were not found to be different from lean subjects. No reports concern obese individuals. Adipokines act as autocrine, paracrine, or endocrine substances and are thought to contribute to the pathogenesis of insulin resistance as well as the development of the low-grade inflammatory state observed in obese or diabetic subjects. In this regard, we also measured hsCRP as a classical inflammatory marker. In our study, base-

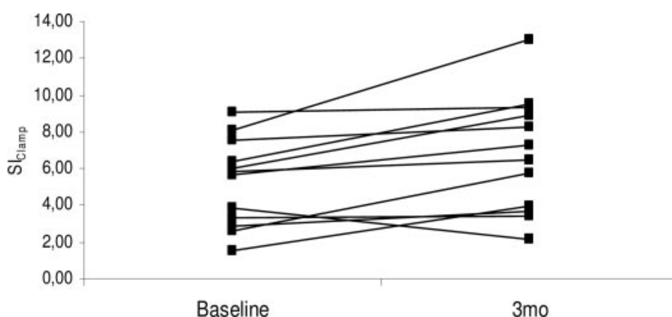

FIG. 1. Individual changes in insulin sensitivity in response to dynamic strength training. The mean of SI_{Clamp} is 5.2 ± 0.7 at baseline and 6.8 ± 0.9 after 3 months (3mo) of dynamic strength training in 12 subjects.

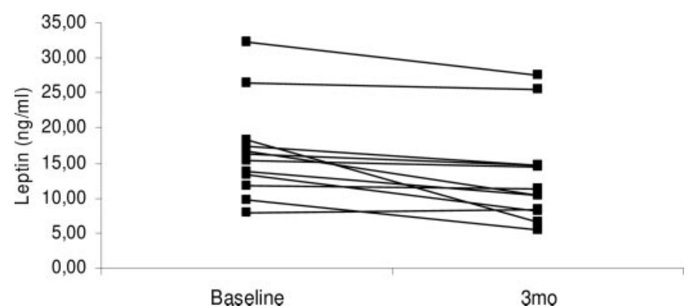

FIG. 2. Individual plasma leptin variations of 12 subjects in response to dynamic strength training.

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TABLE 3. Plasma levels of adipokines before and after 12 wk of dynamic strength training

	Before training	After training	95% CI	*P* value
Adiponectin (μg/ml)	5.6 ± 3.9	5.05 ± 3.1	−0.67, 1.35	0.683
Leptin (ng/ml)	16.6 ± 6.3	13.1 ± 5.7	0.59, 6.36	0.02
IL-1β (pg/ml)	1.6 ± 1.2	1.0 ± 0.5	−0.46, 2.58	0.063
IL-6 (pg/ml)	1.4 ± 0.7	1.5 ± 0.6	−0.97, 0.68	0.859
TNF-α (pg/ml)	2.0 ± 1.5	2.3 ± 2.2	−0.13, 0.37	0.261

Values are means ± SD. CI, Confidence interval.

line hsCRP level corresponded to the reference range for indication of chronic low-grade inflammation state and high cardiovascular risk (31).

It may therefore be hypothesized that the training-induced changes in insulin sensitivity could be associated with modifications of adipokine production or release. However, in the present study, no training-induced modifications of either plasma levels (except of plasma leptin diminution) of adipokines or mRNA levels in SCAAT were found. To date, few studies have investigated the effect of strength training on plasma levels of adipokines, and no data on the effect of training on gene expression of adipokines in SCAAT are available. The absence of training-induced effects on plasma adipocytokines found in this study is in agreement with the results of previous studies (25, 32–34). A 4-month resistance training program was reported to increase glucose disposal and lean body mass independently of plasma levels of TNF-α, sTNF R1, and sTNF R2 in old hypertensive subjects (25). No change in plasma IL-6 or TNF-α levels was observed in a 12-wk resistance training program in the oldest of the aged study population, despite the improvement in muscle strength (32). A 12-wk high-intensity progressive resistance training program did not induce changes in plasma IL-1β, TNF-α, or IL-6 in healthy young or elderly individuals or subjects with rheumatoid arthritis (33). In healthy obese males, 12 wk of resistance training did not produce a change in serum levels of TNF-α (34). The lack of effect on IL-1β, TNF-α, and IL-6 plasma levels observed in this study was supported by the lack of change in adipose tissue mRNA. It is to be noted that the training-induced response of cytokine mRNA levels could be different in visceral adipose tissue. This might be relevant in respect to the insulin sensitivity changes (given the higher expression of some of the investigated adipokines in visceral adipose tissue as compared with the sc one, *e.g.* IL-6) (35).

We found a significant inverse association of TNF-α mRNA and insulin sensitivity in the beginning of the study. Although this could support the hypothesis of the role of TNF-α in the pathogenesis of whole-body insulin resistance, the relevance of TNF-α produced in adipose tissue is still not clear. No net release of TNF-α from the SCAAT bed was observed (36). TNF-α possibly acts in an autocrine and paracrine manner, thus playing a local role in the regulation of adipose tissue metabolism, namely in the control of lipolysis (37).

Reduction of plasma leptin without any modification of mRNA SCAAT levels was found in this study. Decrease of plasma leptin was also demonstrated in the only study using resistance training (38). Importantly, we found that the reduction was independent of BMI changes, suggesting a direct effect of the training on leptin release, independent of changes in body weight. An alternative possibility for leptin diminution could be its enhanced removal from the blood. The lack of effect on fat mass may explain the discrepancy between leptin plasma levels and SCAAT mRNA expression and suggest a regulation at the level of leptin secretion or protein turnover. Such a discrepancy has been reported before (39).

Adiponectin mRNA and plasma levels have not been investigated in the context of dynamic strength training. Studies on the effect of aerobic exercise training on plasma adiponectin have provided conflicting results (40–42). The reported training-induced changes in adiponectin levels may be related to training-induced weight loss. However, in the present study, the adiposity of the participants remained unchanged and may explain the absence of changes in adiponectin expression. It is noteworthy that during very low-calorie diet-inducing weight loss and an improvement in insulin sensitivity, no change in plasma or mRNA levels of adiponectin was found (43).

In conclusion, the present study demonstrates that 3 months of dynamic strength training improves insulin sensitivity in obese middle-aged males. This confirms the beneficial effect of this type of training in obese individuals. In a search for mechanisms underlying the training-induced change in insulin sensitivity, the indices of proinflammatory state of the body, namely plasma cytokine levels and their expression in adipose tissue, were investigated. Because no training-induced changes of these variables were observed, it is suggested that the adipokines investigated are not mediators of the change in insulin sensitivity induced by dynamic strength training.

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TABLE 4. Relative mRNA levels before and after strength training period in SCAAT

	Before training	After training	Fold change	95% CI	*P* value
Adiponectin	$7.1 \times 10^{-4} \pm 2.2 \times 10^{-4}$	$7.7 \times 10^{-4} \pm 2.8 \times 10^{-4}$	1.08	-2.2×10^{-4}, 2.0×10^{-4}	0.859
Leptin	$2.6 \times 10^{-3} \pm 7.0 \times 10^{-4}$	$2.6 \times 10^{-3} \pm 9.1 \times 10^{-4}$	1.01	-8.8×10^{-4}, 6.7×10^{-4}	0.859
IL-1β	$2.1 \times 10^{-6} \pm 2.0 \times 10^{-6}$	$4.4 \times 10^{-6} \pm 6.6 \times 10^{-6}$	2.10	-9.1×10^{-6}, 3.3×10^{-6}	0.953
IL-6	$3.1 \times 10^{-7} \pm 1.9 \times 10^{-7}$	$4.5 \times 10^{-7} \pm 5.0 \times 10^{-7}$	1.47	-6.2×10^{-7}, 2.5×10^{-7}	0.594
TNF-α	$6.2 \times 10^{-7} \pm 2.5 \times 10^{-7}$	$8.3 \times 10^{-7} \pm 4.8 \times 10^{-7}$	1.34	-7.2×10^{-7}, 1.9×10^{-7}	0.208

Values are means ± SD. Relative amounts of mRNA are expressed as arbitrary units obtained after normalization by the 18S rRNA subunit. Fold change was calculated by dividing gene expression values after the treatment by values before the intervention. CI, Confidence interval.

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