Effects of resistance training on protein utilization in healthy children

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ABSTRACT
PIKOSKY, M., A. FAIGENBAUM, W. WESTCOTT, and N. RODRIGUEZ. Effects of resistance training on protein utilization in healthy children. Med. Sci. Sports Exerc., Vol. 34, No. 5, pp. 820–827, 2002. Purpose: Public health initiatives promote increased physical activity in children. More specifically, resistance training has recently received attention as an important component of youth fitness programs. The study examined the effect of this mode of exercise on protein utilization in young boys and girls. Methods: Healthy children (N = 11, 8.6 ± 1.1 yr, 33.7 ± 9.9 kg, 33.1 ± 9.6 cm, BMI = 19.1 ± 3.4) participated in a supervised resistance-training program 2 times wk⁻¹ for 6 wk. Amino acid methodology was used to assess nitrogen flux (Q), protein synthesis (PS), protein breakdown (PB), and net turnover ([NET] = PS − PB) before (PRE) and after (POST) resistance training. Percent body fat (%BF), fat-free mass (FFM), fat mass (FM), and energy and protein intakes were also determined. PRE/POST measurements of 1RM for the chest press and leg extension were used to examine strength gains. Results: Gains associated with the chest press and leg extension were 10% and 75% (P < 0.001), respectively. Significant decreases (P < 0.05) were noted for weight, height, FFM, and FM. Energy and protein intake remained constant. Significant decreases (PRE vs POST) were observed for Q (1.22 ± 0.1 vs 0.75 ± 0.05 gN·kg⁻¹·d⁻¹, P < 0.001), PS (6.48 ± 0.47 vs 3.55 ± 0.30 g·kg⁻¹·d⁻¹, P < 0.001), and PB (6.24 ± 0.41 vs 2.96 ± 0.30 g·kg⁻¹·d⁻¹, P < 0.01) after 6 wk of resistance training. NET was also reduced (P = 0.07, 1.24 ± 0.31 vs 0.59 ± 0.20 g·kg⁻¹·d⁻¹). Conclusions: Resistance training resulted in a downregulation in protein metabolism, which may be energy based. Future studies are needed to clarify energy, as well as protein, needs in young children participating in this form of exercise. Key Words: STRENGTH TRAINING, GLYCINE, NUTRIENT PARTITIONING, ENERGY.

In the past, the focus of promoting an active lifestyle, and the research documenting its benefits, has dealt primarily with adults. However, recent health initiatives outlined by the International Consensus Conference on Physical Activity, and in Healthy People 2010, have expanded this focus to include children and adolescents (26,29). Expanding the focus of health promotion through physical activity to include children and adolescents is beneficial for two reasons. Many of the same health-related benefits that are seen in adults hold true for this age group as well (i.e., improvements in aerobic fitness, reduced risk of osteoporosis and increased bone mass, prevention of obesity and hypertension, increased high-density lipoprotein cholesterol (HDL-C), and improved psychological health) (23). Also, physically active children are more likely to become physically active adults (26). Therefore, it would be advantageous to make children who already enjoy free play and physical activity the focus of health promotion programs.

Resistance training has recently received attention as an important component of youth fitness programs. In the past, youth resistance training was viewed to be both ineffective and unsafe. More recently, however, the American College of Sports Medicine, the American Orthopedic Society of Sports Medicine, the American Academy of Pediatrics, and the National Strength and Conditioning Association support children’s participation in resistance-training activities, provided that the programs are appropriately designed and competently supervised (2,3,1,13). In fact, increasing the number of children who regularly participate in activities that maintain and/or enhance muscular strength and endurance is one of the public health objectives discussed in a report by the Surgeon General (30).

The benefits of participating in youth resistance-training programs include increased strength, cardiovascular fitness, and flexibility, as well as improvements in body composition and motor-fitness performance. In addition, enhanced mental health, well-being, and a more positive attitude toward incorporating fitness into a healthy lifestyle result. Another potential benefit of resistance training is a reduction in sports-related injuries (15).

Specific scientific studies have been conducted which provide evidence for these proposed benefits. Studies by Faigenbaum et al. have shown significant increases in muscular strength (14–16), local muscular endurance (14), and body composition (16) in children who participated in a supervised resistance-training program compared with controls. Hejna et al. (19) reported that strength-trained athletes (13–19 yr) had a lower injury rate and required less time for rehabilitation as compared with their teammates who did not strength train. Furthermore, strength training has been shown to reduce the incidence of shoulder pain in 13- to 18-yr-old swimmers (9), and decrease the number and severity of knee injuries in high-school football players (8).
Although resistance training has been shown to be a safe and effective mode of physical activity in children, it is important to consider the effect of this form of activity on nutrient utilization in young boys and girls. Because of the rapid rate of growth and development in this age group, this question becomes more critical. To date, studies exploring the changes in whole-body protein metabolism in young children subsequent resistance exercise have not been executed. Therefore, this investigation was designed to examine the effect of a 6-wk resistance-training program on whole-body protein utilization in boys and girls aged 7–10 yr.

METHODS

The study design consisted of a 2-wk baseline period followed by 6 wk of resistance training. Criterion measures were assessed during the baseline period (PRE) and after the exercise intervention (POST). Subjects were encouraged to maintain their usual eating and activity patterns throughout the investigation. The specific protocol utilized was approved by the Institutional Review Board for Studies Involving Human Subjects at the University of Connecticut. Before the beginning of the investigation, informed written consent and assent was obtained by the parents and their children, respectively.

Subjects

Seven boys and four girls volunteered to participate in this investigation. All subjects were healthy children with no prior resistance-training experience. Parents completed medical histories pertaining to the health of their children. Prospective subjects who 1) suffered from acute or chronic diseases or had an orthopedic limitation, 2) suffered from gastrointestinal disorders which impair absorption, 3) were taking medications known to alter protein metabolism, or 4) exhibited evidence of growth failure were excluded from the study. Medical clearance was obtained from each child’s pediatrician before the initiation of the protocol.

Criterion Measures

Food and nutrient intakes. Beginning during the baseline period, subjects kept 7-d food records during alternate weeks of the study to document and monitor their nutrient intake. A registered dietician instructed both the subjects and their parents on how to keep thorough records. Throughout the investigation, these records were routinely checked for accuracy and completeness. In addition, 24-h recalls were periodically conducted to validate food records. Nutrient intakes were analyzed using Nutritionist IV software (N-squared Computing, Salem, OR).

Body composition. Subjects removed shoes and all clothing with the exception of shorts and a light T-shirt for anthropometric measurements. Body mass and height were determined using a balance-beam scale equipped with a measuring rod (Health-o-meter, Bridgeview, IL). Triceps and subscapular skinfolds were measured on the right side of the body with Harpenden calipers (British Indicators, West Sussex, U.K.). All anthropometric measurements were taken according to procedures specified in the Anthropometric Standardization Reference Manual (22). In addition to anthropometry, bioelectrical impedance analysis (BIA) was conducted with an RJL analyzer (RJL Systems, Detroit, MI; Model BIA-101Q) by using an established protocol (21). Body composition measures were obtained by the same investigator throughout the study.

The regression equation of Goran et al. (18) was used to calculate fat mass (FM), and subsequently fat-free mass (FFM; i.e., weight – FM) and relative body fat (i.e., FM/weight × 100%). This equation was selected given that it 1) was generated using dual-energy x-ray absorptiometry (DEXA), which is currently emerging as the “gold standard” for assessment of body composition in children; 2) was developed specifically for young children; and 3) incorporates a resistance index obtained from BIA (i.e., height2·R−1) in addition to triceps and subscapular skin-fold thickness, body mass, and gender as independent variables.

Modified nitrogen balance. Subjects collected a 24-h urine sample for determination of nitrogen excretion. The total nitrogen content of the sample was measured in duplicate using the micro-Kjeldahl technique. Urinary nitrogen excretion (E) and nitrogen intake (I), determined from a food record for the 24 h corresponding to the urine collection period, were used to calculate modified nitrogen balance (NB = I – E).

Protein turnover. Whole-body protein turnover was assessed using stable isotope methodology, according to the protocol utilized by Ebbeling et al. (10). Studies were conducted overnight rather than during the day to eliminate any potential confounding effects of physical activity on nutrient metabolism, to minimize imposition on subjects, and to promote adherence (20). In addition, assessment of protein turnover was conducted at least 48 h post training. Specifically, the selected methodology incorporated a single dose of 15N-glycine (2 mg·kg−1, 98 atom percent enrichment; Cambridge Isotope Laboratories, Inc., Andover, MA) dissolved in fruit juice. Protein-turnover studies were conducted at the homes of respective children in the evening when they were at least 2 h postabsorptive. Immediately preceding administration of the isotope by an investigator, subjects provided baseline spot urine samples for determination of background 15N-ammonia enrichments and then emptied their bladders. For approximately 10 h after the dose (i.e., 9 p.m. to 7 a.m.) subjects collected cumulative urine samples having refrained from consumption of foods and beverages.

Urinary nitrogen excretion (E) during the 10-h study and 15N-ammonia enrichments (i.e., ratios of tracer/tracer, t:t) were determined in duplicate using the micro-Kjeldahl technique (Tecator Kjeltec Systems, Hoganas, Sweden) and isotope ratio mass spectrometry (IRMS, Metabolic Solutions, Nashua, NH), respectively. The t:t ratio for the cumulative sample was corrected for background 15N-ammonia enrichment. Nitrogen intake (I) during the evening meal was determined based on the analysis of food records and recalls. Nitrogen flux (Q), protein synthesis (PS), protein
breakdown (PB), and net protein turnover (NET) were calculated as presented below where d denotes the oral dose of $^{15}$N ($d = g$ glycine $\times 0.1972$).

$$Q[g N/(kg d)^{-1}] = \frac{[d\text{corrected t/d}]}{10 h \times 24 h / \text{body weight}}$$

$$PS[g (kg d)^{-1}] = [Q - E / (10 h \times 24 h / \text{body weight})] \times 6.25 g \text{ protein/g N}$$

$$PB[g (kg d)^{-1}] = [Q - (I/10 h \times 24 h / \text{body weight})] \times 6.25 g \text{ protein/g N}$$

$$NET[g (kg d)^{-1}] = PS - PB$$

**Exercise Intervention**

**Testing procedures.** After receiving medical clearance, all subjects participated in two introductory training sessions during a 1-wk period before the testing procedures. During this time, the children were taught the proper technique (i.e., controlled movements and proper breathing) on each exercise, and any questions they had were answered. A warm-up session consisting of at least 10 min of low-intensity aerobic exercise and stretching preceded all tests. Measurements were made with identical equipment positioning using child-size dynamic, constant external resistance (DCER) equipment (Schnell Equipment, Peutenhausen, Germany).

**Performance strength.** Each subject’s 1-RM strength was determined on the vertical chest press and leg extension exercises at baseline and after the 6-wk exercise intervention. For the vertical chest press exercise, children were standing erect with their back against the support pad and both hands in a neutral grip position grasping the handles located at chest level. Children were instructed to extend their arms in front of them until their elbows were approximately 5° short of full extension (to prevent locking at the elbow joint), then return to the starting position. For the leg extension exercise, children were seated upright with both ankles behind the ankle pad. Children were instructed to extend their knees as fully as possible, from 90° of flexion to full extension, then return to the starting position. The 1-RM was determined as the maximum resistance that could be lifted throughout the full range of motion (determined in the unweighted position) using the proper form, one attempt.

Before attempting a 1-RM, subjects performed six repetitions with a relatively light load, followed by three repetitions with a heavier load, and finally a single repetition with 95% of their predicted 1-RM. Subjects then attempted a single repetition with the perceived 1-RM load. If this weight was lifted with the proper form, the weight was increased by approximately 1–2.5 kg, and the subject attempted another repetition. The increments in weight were dependent on the effort required for the lift and became progressively smaller as the subjects reached the 1-RM. Failure was defined as a lift falling short of the full range of motion on at least two attempts spaced at least 2 min apart.

The 1-RM was typically determined within four to five trials. Throughout all testing procedures, an instructor to subject ratio of 1:1 was maintained, and uniform verbal encouragement was provided to all subjects. Faigenbaum et al. (17) have determined a test-retest reliability for 1-RM testing in children to vary from 0.93 to 0.98 depending on the type of exercise.

**Resistance-training program.** During the 6-wk exercise intervention, subjects strength trained twice per week on nonconsecutive days. Before each strength training session, all subjects participated in 10–15 min of low-intensity aerobic exercise and stretching. During this time, instructors would also discuss and demonstrate proper resistance-training procedures. Instructional sessions gave the children an opportunity to understand the importance of proper form as well as to appreciate the potential benefits and risks associated with resistance training. Children were taught how to record their data on workout logs and did so during the training period. The instructors reviewed the workout logs daily and made appropriate adjustments in training loads for the subsequent session when needed. The resistance-training segment of each session lasted approximately 30–40 min. After the resistance training, there was an additional 10–15 min of various structured games that were fun for the children. Throughout the exercise intervention, an instructor-to-subject ratio of 1:4 was kept at all times to ensure adequate supervision.

The resistance-training program consisted of two exercises that used each child’s own body weight as resistance (abdominal curl and lower back extension) and 7 DCER exercises (leg extension, leg curl, pullover, vertical chest press, seated row, abdominal flexion, and front pull down). On the body weight exercises, subjects performed one set of up to 15 repetitions to provide a general conditioning effect. The vertical chest press and leg extension were considered the primary exercises, and subjects progressively increased from one to two sets of these two exercises at week 4 of the 6-wk intervention period. The remaining five DCER exercises were considered secondary exercises, and subjects performed one set of each throughout the intervention period. Subjects were instructed to perform 10–15 repetitions on all of the exercises, with the last repetition of each set being representative of momentary muscular fatigue. During the first week of training, the exercise loads were titrated on all DCER exercises to elicit volitional fatigue within the prescribed repetition range. When subjects were able to perform 15 repetitions utilizing proper form, the weight was increased by 5–10%, and the repetitions were decreased to 10. If a subject missed a training session, the training load was not increased at the returning session.

The order of exercises was changed every session to maximize subject enjoyment. Resistance training outside of the research setting was prohibited. All children were permitted to participate in sports and other recreational physical activity throughout the intervention period. Attendance was strictly monitored throughout with an allowance for missing no more than two sessions during the 6-wk period. Average attendance for the exercise classes was 95%. A total of 13 children enrolled in the resistance-training program; however, two subjects were excluded from the data analysis due to poor attendance and incompletedness of data collection.
**Statistical Analysis**

Group means for all criterion measures were compared PRE versus POST by using paired Student’s *t*-test to evaluate the effects of resistance training (Excel, Microsoft Office). The alpha level was set at $P < 0.05$.

**RESULTS**

**Macronutrient Intake**

Descriptive data for macronutrient intakes were obtained via analysis of 7-d food records. Energy and protein consumption remained constant throughout the investigation (Table 1). On average, the macronutrient breakdown was comprised of 55% carbohydrate, 29% fat, and 16% protein. All subjects consumed a sufficient amount of protein to meet their daily requirement (i.e. $>1.5 \text{ g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$).

**Protein Utilization**

On average, nitrogen balance was positive with a significant increase from PRE to POST testing ($P < 0.05$) (Fig. 1). A significant decrease in nitrogen flux ($Q = 1.22 \pm 0.29 \text{ gN} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}, P < 0.001$) (Fig. 2) with corresponding decreases in protein synthesis ($\text{PS} = 6.48 \pm 0.47 \text{ vs } 3.55 \pm 0.30 \text{ g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}, P < 0.001$) and protein breakdown ($\text{PB} = 5.24 \pm 0.41 \text{ vs } 2.96 \pm 0.30 \text{ g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}, P < 0.01$) was observed (Fig. 3). NET protein turnover also decreased following 6 wk of resistance training ($1.24 \pm 0.31 \text{ vs } 0.59 \pm 0.20 \text{ g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$), but these results were not statistically significant ($P = 0.07$) (Fig. 3).

**Body Composition**

During the investigation, significant increases in weight, height, FFM, FM, and body mass index were noted (Table 2). When plotted on the physical growth charts adapted from the National Center for Heath Statistics, the girls ranged from the 10th to 90th percentile for weight for age, and 5th to 95th percentile for height for age. The boys ranged from 25th to 95th and 10th to >95th on weight for age and height for age, respectively. No changes in percentiles were noted for individual children from PRE to POST. There was no significant change in percent body fat.

**Exercise Intervention**

Significant strength gains were made in both the 1 RM chest press and 1 RM leg extension over the 6-wk resistance-training protocol ($P < 0.001$). Specifically, the mean 1 RM chest press increased from $22.7 \pm 1.5 \text{ kg}$ to $25.1 \pm 1.7 \text{ kg}$, and the mean 1 RM leg extension increased from $18.6 \pm 2.4 \text{ kg}$ to $31.1 \pm 3.2 \text{ kg}$. The percent increases in strength for the chest press and leg extension were 10% and 73%, respectively.

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**TABLE 1. Average macronutrient intakes.*

<table>
<thead>
<tr>
<th></th>
<th>Energy (kcal)</th>
<th>Protein (g)</th>
<th>Carbohydrate (g)</th>
<th>Fat (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1852 ± 90</td>
<td>72 ± 5</td>
<td>260 ± 14</td>
<td>61 ± 6</td>
</tr>
<tr>
<td>Week 2</td>
<td>1833 ± 115</td>
<td>73 ± 5</td>
<td>265 ± 18</td>
<td>58 ± 6</td>
</tr>
<tr>
<td>Week 3</td>
<td>1804 ± 109</td>
<td>77 ± 5</td>
<td>246 ± 19</td>
<td>59 ± 6</td>
</tr>
<tr>
<td>Week 4</td>
<td>1776 ± 109</td>
<td>78 ± 5</td>
<td>242 ± 8</td>
<td>58 ± 7</td>
</tr>
</tbody>
</table>

*Mean ± SE. (Food records were kept every other week, beginning at the 2 week baseline period, and throughout the 6 week exercise intervention)
**DISCUSSION**

This investigation examined the effects of a 6-wk resistance-training program on whole-body protein utilization in healthy children aged 7–10 by utilizing $^{15}$N-glycine methodology. To date, this research provides the first evidence of changes in whole-body protein utilization subsequent to programmed resistance exercise in this population.

Our findings regarding strength gains are in accordance with previous research in this area and show that preadolescent children are able to make significant gains in strength. Although control group data were not available in our investigation, other researchers have shown strength gains with similar training protocols to be above and beyond those occurring as a result of normal growth and development in young children (14–16,25). Indeed, the increase in upper body strength achieved in the present study is similar to those made in a previous investigation by Faigenbaum et al. (14), where a similar protocol was utilized (10% vs 16.3%). However, the gains made in the leg extensors are much more significant in our investigation (73% vs 40.9%). This difference may likely be due to the fact that the number of sets performed was increased from one to two at the midpoint of our exercise protocol. However, this additional workload did not result in greater gains in upper body strength. Strength gains reported in other studies involving prepubertal children have ranged from 20 to 35% (24,25,28).

Resistance training also had a distinct effect on protein utilization in our subjects. Mean modified nitrogen balance significantly increased from PRE to POST, which indicates a state of anabolism and supports the indices of growth noted in our subjects. Therefore, this form of exercise does not appear to be contraindicated in young children. However, the fact that the increase in modified nitrogen balance was accompanied by significant decreases in nitrogen flux (Q), protein synthesis (PS), and protein breakdown (PB) is thought provoking and has potential nutritional implications. That is, the changes noted in protein utilization reflect a downregulation in protein turnover that may be energy based.

Currently there are few studies in the literature with which to compare our findings. In examining the investigations that have been completed, it is evident that this is an area that requires further attention. A study by Ebbeling and Rodriguez (10) examined the effect of a reduced calorie diet and subsequent programmed walking (5 d-wk$^{-1}$, 2–3 miles-d$^{-1}$) on protein utilization in obese children aged 8–10. The methodology used to assess protein metabolism was identical to that used in our investigation. With diet only, NET protein turnover (synthesis – breakdown) decreased due to a reduction in protein synthesis from baseline values. Although protein synthesis increased with walking, NET was still significantly below baseline levels due to a concurrent increase in protein breakdown. Nitrogen flux (Q), which is a measure of amino acid cycling between the protein and free amino acid pools, also significantly increased in response to exercise. Indeed, these data suggest an influence of programmed exercise on protein metabolism in young children.

A follow-up investigation in our laboratory utilized the same exercise protocol in healthy children consuming an ad libitum diet. Significant reductions in protein synthesis, protein breakdown, and nitrogen flux were noted as a result of programmed aerobic exercise when compared to baseline values (7). These findings are consistent with those in the present study.

The changes in protein utilization observed in the present investigation, as well as with the walking study involving healthy children, were not anticipated given what was observed with the addition of programmed exercise in the study by Ebbeling. Based on those initial findings, the expected change in response to resistance training was an upregulation of protein turnover that would mandate energy and protein intake considerations. However, when one examines the findings of Ebbeling and Rodriguez more closely, some similarities are apparent. During the initial phase of that investigation (i.e., initiation of hypocaloric therapy alone) a downregulation in protein turnover did occur as evidenced by the decrease in NET. The authors concluded that this change in protein utilization likely resulted from the energy deficit caused by the decrease in energy intake. Interestingly, with the addition of programmed exercise, no additional energy deficit was incurred as evidenced by the fact that energy expenditure associated with physical activity (assessed via Trictrac accelerometer) and resting energy expenditure remained constant during both phases of the intervention. From these results, it is possible to speculate that the children adapted over time to the lower calorie intake (i.e., after week 6) and then with exercise there was a stimulation to upregulate protein turnover, given no additional energy deficit was noted.

Indeed a consistent factor that appears to have similar affects on protein utilization across these investigations is the existence of an energy deficit. In the study by Ebbeling and Rodriguez (10), an energy deficit resulted via the dietary intervention. In the present investigation, evidence for the existence of a potential energy deficit is based on results obtained from the dietary data, and the possible effect of resistance training on resting metabolic rate (RMR).
Although the diets of the children in the present study provide more than adequate amounts of protein, an examination of energy intake suggests a possible energy deficit. According to the recommendation of 70 kcal-kg\(^{-1}\)d\(^{-1}\) outlined in the 10th edition of the Recommended Dietary Allowances, the study participants potentially were at a caloric deficit of approximately 536 kcal-d\(^{-1}\). More specifically, only two of the subjects were not in an energy deficit when individual mean energy intakes were examined.

One might argue the validity of this conclusion based on a question of the accuracy of the food records provided by the children, especially because of the fact that they did not experience any weight loss during the investigation. However various steps were taken to minimize the amount of error associated with this data. Before baseline data collection, a registered dietitian met individually with each child and their parents to provide detailed instructions regarding the recording of food records. These records were checked for accuracy and completeness by that registered dietitian throughout the data collection period. In addition, children were given a small monetary reward each week if their food records were complete from the previous week. Also, a majority of the parents were extensively involved in assisting their children with this record keeping. Finally, the intermittent collection of 24-h recalls provided data consistent with that generated from the 7-d food records.

The potential for increased energy needs subsequent to consistent participation in resistance training is another important consideration in support of an occurrence of a slight yet possibly physiologically significant, energy deficit in the present study. A study by Van Etten et al. (31) assessed the effect of an 18-wk resistance-training program on average daily metabolic rate (ADMR) in healthy, sedentary men aged 33 ± 6 yr, utilizing the doubly labeled water technique. Their results showed that ADMR increased 9.3% from baseline to week 8 (12.4 ± 1.2 to 13.5 ± 1.3 MJ-d), with no further increase at week 18. Because of the fact that there was no change in nontraining physical activity, as measured by an accelerometer, the authors concluded that the change in energy expenditure was attributed to the weight-training program.

Treuth et al. (28) examined the effect of a low volume resistance-training program on strength, physical fitness, and energy expenditure in obese, prepubertal girls aged 7–10 yr. There were significant increases in weight, height, and FFM in both the exercise and control groups. Resistance training resulted in significant strength gains in both the 1-RM bench press and leg press (19.6%, 20.0%, respectively). Both the exercise and control groups had significant increases in RMR. However, when RMR was adjusted for the changes in FFM or weight, the changes were no longer significant. Therefore, the authors concluded that although a low-volume resistance-training program can elicit positive changes in strength, energy expenditure is not significantly improved in obese prepubertal girls. The increase in RMR that occurred was a result of the changes in FFM and weight that accompany normal growth and development. Based on the fact that the children in the present investigation experienced significant increases in height, weight, FM, and FFM, it is reasonable to conclude that a concurrent increase in RMR may have developed. As shown by Treuth et al., general growth and development in prepubescent children can impact energy expenditure. In sum, these data would support the existence of a potential energy deficit in our subjects. That is, an increase in energy expenditure subsequent to resistance training and growth was not accommodated for by an increase in energy intake.

One theory that may help to explain the coexistence of a potential energy deficit and downregulation of protein turnover along with significant increases in muscular strength, modified nitrogen balance, and various growth indices can be derived from the concept of nutrient partitioning. This concept is used to describe a state in which “absorbed nutrients are partitioned differently among metabolic organs and tissues to accommodate successful execution of the dominant productive function” (6) (p. 13925). Growth, pregnancy, and lactation are three physiologic as well as anabolic states in which nutrient partitioning is believed to occur (4–6). Bauman et al. (5) proposed that growth hormone, prolactin, and somatomammotropin (placental hormone) provide some form of higher regulation of endocrine control over the usual homeostatic mechanisms to support this partitioning of nutrients. Bauman and Currie defined this regulatory phenomenon as homeorrhesis, “the orchestrated or coordinated changes in metabolism of body tissues necessary to support a physiologic state” (4) (p. 1515).

When the concept of nutrient partitioning is extended to the present investigation, the observed protein-related metabolic changes can be integrated with the physiological response to resistance training. First and foremost, nutrients were partitioned in support of growth in the children as evidenced by the positive modified nitrogen balance and increases in height, weight, FM, and FFM. The fact that protein turnover was downregulated suggests that whole-body protein utilization may have slowed in response to an energy-deficit situation. Because the \(^{15}\)N-glycine methodology is not truly tissue specific, one might speculate that other nongrowth-directed protein utilization pathways were effected during the study. Similar protocols of longer duration are needed to fully characterize these observations. It may also be necessary to employ other stable isotope techniques in a more controlled setting such as a Clinical Research Center (CRC) where nutritional intake can be more closely monitored.

Although hormonal measurements were not made in the present investigation, neuroendocrine adaptations observed in children and adolescents in response to both acute and chronic exercise have been characterized and can be cautiously extended to findings in the present investigation. In two separate studies, the relationship between physical fitness and circulating components of the GH-insulin like growth factor I (IGF-I) system were examined in adolescent male and female subjects (11,12). In both of these investigations, 5 wk of endurance-type training, anabolic adaptations occurred despite the presence of what the authors characterized as a catabolic hormonal profile. Similar hormonal responses
have been reported in prepubertal children (27). The potential connection between this research and the present investigation lies in this paradox of what might be considered a catabolic environment being accompanied by the expected fitness gains resulting from training.

The training program utilized in this investigation proved to be a safe, effective, and enjoyable mode of exercise with which to elicit positive changes in strength and body composition in healthy children aged 7–10. However, the nutritional adequacy of the diets, specifically energy intake, in children engaging in this type of activity may be of a concern, as evidenced by the downregulation in protein metabolism that resulted in our subjects. Evaluation of dietary intake suggests that the observed changes in protein utilization were energy based. Although the children’s diets contained more than adequate amounts of protein, their total energy intake suggests a potential energy deficit of approximately 500 kcal·d−1, given the current RDA for energy in this population. When the additional energy demands of resistance training were superimposed on the increased needs for growth, changes in protein utilization occurred.

Interestingly, these changes did not compromise the positive gains in strength, body composition and growth in the children participating in our investigation. The specific mechanisms underlying these changes in protein utilization are unclear but may be a result of some form of nutrient partitioning. Additional investigations are necessary in which prolonged protocols are utilized in order to longitudinally characterize the relationships between the protein metabolic response, neuroendocrine adaptations, and nutritional adequacy in children participating programmed resistance training.

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