The role of metabolites in strength training

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I. A comparison of eccentric and concentric contractions

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Abstract This study examined the role of high forces versus metabolic cost in the adaptations following strength training. Ten young, healthy male and female subjects trained one leg using concentric (CL) and the other using eccentric (EL) contractions of the quadriceps muscle for 20 weeks. EL used weights which were 35% higher than those used for CL. Isometric strength, and the length-tension and force-velocity relationship of the muscle were measured before and after training. Muscle cross-sectional area (CSA) was measured near the knee and hip using computed tomography. Increases in isometric strength were greater for CL compared to EL, the difference being significant with the knee at 1.57 rad (90°) [mean (SD), 43.7 (19.6)% vs 22.9 (9.8)%, respectively; \( P = 0.01 \)]. Increases in isokinetic strength tended to be larger for EL, although the differences were not significant. Significant increases in CSA occurred near the hip for both EL and CL. These results suggest that metabolic cost, and not high forces alone, are involved in the stimuli for muscle hypertrophy and strength gains following high-resistance training.

Key words Muscle strength • Hypertrophy • Concentric contractions • Eccentric contractions • Strength training

Introduction

Despite considerable research interest, the stimulus for muscle hypertrophy and strength gains following high-resistance training remains unknown. Evidence suggests that high-force contractions are required for adaptations to occur; this type of contraction will have several consequences for the muscle and the endocrine system. Several hormones are known to be released during and after high-resistance training. These include growth hormone (GH), testosterone, catecholamines and cortisol (Kraemer 1992a). Their release varies depending on several factors including the intensity, length of rest periods and level of training of the subject. The muscle specificity of the training effect requires a mechanism by which systemic hormone release can interact with an individual muscle to result in protein synthesis. This may involve receptor regulation and/or the release of local growth factors in the working muscle in response to hormonal stimulation (Kraemer 1992b). Growth factor release may also occur in the muscle independently of endocrine stimulation and exert autocrine or paracrine actions on the muscle.

Apart from placing high mechanical stresses on the fibres and connective tissue, the high forces used in strength training will also cause metabolic changes within the muscle. Although the majority of strength training regimes utilise low numbers of repetitions, the metabolites may accumulate because the blood supply is occluded during the high-force contractions. These changes may directly, or indirectly via growth factor release, stimulate protein synthesis. In order to differentiate the roles of high mechanical stress versus metabolic cost, use can be made of eccentric and concentric contractions. In the former, high forces can be generated at a relatively low metabolic cost compared to either isometric or concentric contractions (Bigland-Ritchie and Woods 1976). Comparison of the changes resulting from high-force, low-metabolic cost (eccentric) contractions and lower-force, high-metabolic cost (concentric) contractions may provide further insight into the relative importance of stress versus metabolite levels. The purpose of this study was to compare the strength changes and hypertrophy resulting from concentric or eccentric contractions. A preliminary report
of this work has been presented (Carey Smith and Rutherford 1994).

**Methods**

**Subjects**

Ten, young healthy adults (five males) took part in the study. Anthropometric details for the group are given in Table 1. None of the subjects had previously taken part in regular strength training exercise and all maintained their normal level of activity. The study was passed by the Parkside Ethical Committee and all subjects gave their written, informed consent.

**Training**

Subjects trained the quadriceps muscle three times per week for 20 weeks on the leg extension station of a multigym. The right leg was trained using concentric contractions (CL) and the left with eccentric contractions (EL), both contractions being controlled and lasting approximately 3 s each. Each training session consisted of four sets of ten contractions with a 1-min rest between each set. The weight was assessed as that which could just be lifted (CL) ten times and adjusted as performance improved. The design of the multigym station was such that the load could be varied depending on the position of the foot on the foot plate. The difference in leverage meant that with the foot on the top of the plate, the weight was 35% greater than with the foot on the bottom of the plate. Subjects therefore lifted the weight (CL) with the foot on the bottom of the plate and then lowered (EL) the weight with the other foot on the top of the plate, the latter weight being 35% greater.

**Quadriceps strength**

Strength was assessed as the maximum voluntary isometric contraction force in a conventional strength testing chair. The percutaneous superimposition technique was used to test for full muscle activation during the contraction (Rutherford et al. 1986). Using an adapted isokinetic dynamometer (Cybex II) the length: tension and force: velocity relationship of the muscle was also measured. The adaptation involved bonding a strain gauge on to the lever arm of the dynamometer from which the undamped force trace was taken and recorded for analysis. For the length : tension relationship the muscle was tested at 0.17 rad (10°) intervals between 0.35 and 1.92 rad (20° and 110°) of knee flexion (from the horizontal). Knee angle was measured using a manual goniometer. The velocities of isokinetic testing were 0.52, 1.05, 1.57, 2.09, 2.62 rad·s⁻¹ (30, 60, 90, 120, 150, 180, 240 and 300° s⁻¹). Velocities were selected in a random order, with a 3-min rest period between each. The order was the same for each testing occasion.

**Quadriceps cross-sectional area**

The cross-sectional area (CSA) was measured at two levels on the quadriceps using computed tomography. The levels chosen were one-quarter and three-quarters femur length measured from the knee joint space. For re-scanning the height of these levels were measured from the knee with the subject lying flat. The scanner (Phillips Tomoscan 350) was set to a scan time of 4.8 s and a slice thickness of 9 mm. Images were analysed off-line using an interactive image analysis package (Sun).

**Statistics**

Changes with training were analysed using Student's paired t-test. Differences between eccentric and concentric training were compared using Student's unpaired t-test.

**Results**

All subjects successfully completed all 20 weeks of training. On average, the group improved by 65% in the weights lifted during training.

**Isometric strength**

The group mean increase for CL was 43.7 (19.6)% [Mean (SD); P < 0.0001] and for EL, 22.9 (9.8)%. The increase for CL was significantly greater than for EL (P = 0.01). All subjects were able to maximally activate the quadriceps during the testing manoeuvre.

**Length: tension**

For CL there were significant increases in strength at 0.87, 1.22, 1.40, 1.57 and 1.74 rad of flexion. The increase at 1.57 rad was similar in magnitude (48.4%) to that found in the strength testing chair where the knee was also held at 1.57 rad. For EL there were significant increases in strength at 1.22 and 1.57 rad only. Again the change at 1.57 rad was similar between the chair and dynamometer. Group mean percentage changes and significance values are given in Table 2 and the length: tension relationships illustrated in Fig. 1. There were no significant differences between the changes in strength at any angle between the two legs. The changes, however, were consistently greater over the mid-range for the CL.

**Force: velocity**

There were significant increases in the forces generated at 0.52 and 1.05 rad·s⁻¹ for CL and at 0.52, 1.05, 1.57, 2.09, 2.62 rad·s⁻¹ for EL (Table 3). There were no significant differences between the changes for the two legs. The force: velocity relationships for each leg are illustrated in Fig. 2.

<p>| Table 1 Anthropometric details of subjects [mean (SD)] |
|-------------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Mass (kg)</th>
<th>Height (m)</th>
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<tbody>
<tr>
<td>Men (n = 5)</td>
<td>20.6 (0.9)</td>
<td>79.6 (13.8)</td>
</tr>
<tr>
<td>Women (n = 5)</td>
<td>20.2 (1.3)</td>
<td>55.6 (6.2)</td>
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