Effect of Exercise Intervention on Thigh Muscle Volume and Anatomical Cross Sectional Areas – Quantitative Assessment Using MRI

INTRODUCTION: In vivo assessment of human muscle morphology is important for evaluating to what extent growth, aging, training, or disease affect muscle function, and for modeling load transmission in human joints. It has been shown that for isometric and slow-speed contraction, muscle volume displays a slightly higher correlation with the actual joint moments than the anatomical or physiological cross sectional area (ACSA, PCSA), the fascicle length, or the tendon moment arm. Other work has suggested that muscle volume is more reliable than ACSA to monitor the effect of strength training on the quadriceps and total thigh musculature.

The current gold standard for in-vivo measurement of muscle volume is three dimensional reconstruction of contiguous transverse magnetic resonance imaging (MRI) scans, and this technique has been validated using cadaver muscles. Assessment of muscle volume by MRI, however, requires imaging and segmentation of the entire muscle(s) of interest and is thus time consuming. Therefore, it would be more ideal if for monitoring the response to training (or other anabolic factors) a single MRI slice could be used to evaluate the changes occurring during the intervention.

Whether the thigh muscles display different magnitudes of response and sensitivity to change at different (proximal-to-distal) levels, and whether the levels with maximal response differ between the extensors, flexors, and adductors, however, is currently unknown.

The objectives of this study were therefore:
1) to assess correlations of the anatomical cross sectional areas (ACSA) with the thigh muscle volume at baseline
2) to test the hypothesis that the effect of a 3-month supervised exercise intervention in peri-menopausal, untrained adult women can be monitored quantitatively with MRI
3) to identify whether strength, endurance, and autogenic (control) training induce different magnitudes of response and whether the effects differ between extensors, flexors, adductors, and the sartorius
4) to determine at which proximal-to-distal anatomical level the exercise induced increase in the ACSA is most pronounced in each of the muscle groups studied.

METHODS: 41 untrained peri-menopausal women, aged 45-55 years, were randomly assigned to three groups: strength training of the leg (n=16), endurance training [cycling](n=19), and autogenic training (n=6). Fully supervised training was performed 3 times per week for 60 min over a period of 12 weeks, respectively.

MRIs of the thigh were acquired before and after the training intervention period on a 1.5 Tesla magnet (NT Inter, Philips Medical Systems, Netherlands), employing a T1 weighted Turbo Spin Echo (TSE) sequence (TR=1541ms, TE=15ms, FA=90°, section thickness=10mm, in-plane resolution=0.78mm², acquisition time=1.57min).

A region of interest (ROI) was defined between the femoral neck proximally (Fig. 1 top left) and the vastus intermedius tendon distally (Fig. 1 bottom left), in which the extensors (quadriceps = magenta), flexors (green), adductors (red) and sartorius (blue) were segmented manually (Fig. 1). Muscle volumes were determined by numerical integration of the segmented voxels, and the anatomical CSA derived from the 3D reconstruction.

Pearson correlation coefficients were used to assess the association between ACSA at different levels and muscle volume. The response to training was expressed in percent (% versus baseline) and the level of statistical significance determined using a paired t-test. The sensitivity to change was assessed by determining the standardized response mean [SRM], i.e. the mean change divided by the standard deviation of the change between participants.

RESULTS: At baseline, the extensors occupied 50%, the flexors 19 %, the adductors 28%, and the sartorius 3% of the total thigh muscle volume. Maximal correlations of ACSA and muscle volumes were observed at the 30% level in the adductors (r²=0.82), at 40% in the flexors (r²=0.73), and at 70% in the flexors (r²=0.72) and sartorius (r²=0.85). ACSA at the 50% level displayed the highest overall correlations (r²≥0.69) with the muscle volumes of each muscle group.

With strength training, the volume and mean CSA of the quadriceps increased by 3.1% (standardized response mean [SRM] = 1.3, p<0.0001), that of the flexors by 3.5% (SRM 0.9; p<0.01), that of the adductors by 3.9% (SRM 1.2; p<0.0001). The largest increases were seen at the 30% level from proximal to distal (5.3%, 9.2%, and 5.6%, respectively). With endurance training, the volume and mean CSA of the quadriceps increased by 3.8% (SRM = 1.4, p<0.01), the greatest effect being at the 20% and 30% level. No significant effect was observed in the flexors and adductors in the endurance group. No effect in any muscle group was seen in the controls (autogenic training).

DISCUSSION: The results show that 1) anatomical cross sectional areas display high correlations with muscle volume at baseline in this relatively uniform group of untrained adult women, but the proximo-distal level with the highest correlation varies between muscle groups.

2) The effect of exercise intervention can be effectively monitored using MRI-based muscle volume measurement.

3) Whilst strength training had a significant effect on all muscle groups of the thigh, endurance training (cycling) only induced measurable effects in the extensors (quadriceps)

4) Measurement of anatomical CSA at a 30% (proximal to distal) level between the femoral neck and the rectus femoris tendon was most effective in demonstrating exercise-based changes in all muscle groups, whereas changes in the distal half of the thigh was much less pronounced.

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