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Improved skeletal muscle mass and strength after heavy strength training in very old individuals

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ABSTRACT

Age-related loss of muscle mass and function represents personal and socioeconomic challenges. The purpose of this study was to determine the adaptation of skeletal musculature in very old individuals (83+ years) performing 12 weeks of heavy resistance training (3×/week) (HRT) compared to a non-training control group (CON). Both groups received similar protein supplementations. We studied 26 participants (86.9 ± 3.2 (SD) (83–94, range) years old) per-protocol. Quadriceps cross-sectional area (CSA) differed between groups at post-test ($P < 0.05$) and increased $1.5 \pm 0.7\ cm^2$ (3.4%) ($P < 0.05$) in HRT only. The increase in CSA is correlated inversely with the baseline level of CSA ($R^2 = 0.43$, $P < 0.02$). Thigh muscle isometric strength, isokinetic peak torque and power increased significantly only in HRT by 10–15%, whereas knee extension one-repetition maximum (1 RM) improved by 91%. Physical functional tests, muscle fiber type distribution and size did not differ significantly between groups. We conclude that in protein supplemented very old individuals, heavy resistance training can increase muscle mass and strength, and that the relative improvement in mass is more pronounced when initial muscle mass is low.

1. Background

The number of senior citizens in the Western world is increasing rapidly and demographic estimates reveal that the number of European citizens at least 80 years old will increase from 35 million (2015) to 71 million in 2050 (United Nations, 2015). This poses a socioeconomic challenge since between 30% (Janssen et al., 2002) and 50% (Baumgartner et al., 1998) of elderly individuals can be categorized as having low muscle mass, resulting in reduced physical capability. In turn, this may lead to a frail phenotype (Fried et al., 2001), care-dependency, increased risk of falling (Landi et al., 2012) and even death (Metter et al., 2002, da Silva Alexandre et al., 2014). Some studies on exercise in elderly individuals have been carried out but the literature on the effect of heavy strength training on muscle mass and strength in very old individuals over 80 is sparse, and only very few studies are controlled, contain a sufficient daily nutrient and protein intake, or have studied muscle mass in detail (Stewart et al., 2013).

Research has demonstrated, that heavy resistance strength training can induce muscle hypertrophy, strength gains and improved physical function, in both young (Phillips et al., 1997; Holm et al., 2008b; American College of Sports Medicine, 2009) and elderly individuals (Kryger and Andersen, 2007, Tieland et al., 2012b, Stewart et al., 2013). There is however some evidence indicating that the positive effects of heavy resistance exercise on muscle size and strength are somewhat blunted in old age (Welle et al., 1996; Kumar et al., 2009; Greig et al., 2011).

Supplementing with protein, either immediately after the training session (Esmarck et al., 2001) or simply by elevating the daily protein consumption (Tieland et al., 2012b) can improve the gains in muscle mass and strength. Even without heavy resistance training, protein supplementation can improve muscle mass (Houston et al., 2008; Beasley et al., 2013), where supplementing with protein at breakfast (Tieland et al., 2012a) and lunch (Paddon-Jones and Rasmussen, 2009; Bauer et al., 2013) in under-nourished elderly appears to improve muscle mass and function. Protein requirement is possibly increased with age

Abbreviations: 1 RM, one repetition maximum; ANOVA, analysis of variance; BMI, body mass index; CC, capillary contacts; CON, control group; CSA, cross-sectional area; DEMMI, Demorton mobility index; DXA, dual-energy X-ray absorptiometry; HbA1c, glycosylated hemoglobin; HRT, heavy resistance training group; LDL, low-density lipoprotein; MRI, magnetic resonance imaging; RFD, rate of force development; SD, standard deviation; SEM, standard error of the mean; VEGF, vascular endothelial growth factor.

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(Cermak et al., 2012; Deutz et al., 2014; Moore et al., 2014; Phillips et al., 2016) and, in addition, protein intake is often reduced in elderly (Landi et al., 2010). Thus, there is a need for studying strength training in very old individuals in conditions that control for protein intake.

The aim of the present study was to investigate the effect of 12 weeks of progressive heavy resistance training (3×/week) (HRT), versus no training (CON), on muscle mass and function in individuals of at least 83 years of age consuming a mixed nutrient supplementation including 20 g of milk protein at breakfast and lunch. We hypothesized that heavy resistance training would result in increased thigh muscle cross sectional area (primary outcome), thigh strength, and functional muscle performance.

2. Methods

2.1. Overview and location

In October 2013 we launched this single center, single blinded, randomized controlled trial at Institute of Sports Medicine Copenhagen, Bispebjerg Hospital, Denmark. Participants carried out the intervention at home and in training facilities at two nursing homes in the Municipality of Gladsaxe, Denmark. We performed all tests at our research institution or in participant's homes whenever settings complied with test instructions.

2.2. Ethics and data handling

The Danish Regional Ethical Committees of the Capital Region approved the protocol (J-no. H-4-2013-068) that was registered at ClinicalTrials.gov (ID: NCT01997320) and the Danish Data Protection Agency with journal no. 2007-58-0015, local no. BBH-2013-043, I-suite no. 02568.

2.3. Participants

A total of 30 participants at least 83 years old living in and approximately Gladsaxe Community – a middleclass suburb of Copenhagen – were recruited using direct approach and local advertisements. We excluded participants with surgical or medical diseases preventing participation in strength training, magnetic resonance imaging (MRI) scanning or strength testing. Further, persons with unstable cardiac arrhythmia, severe chronic obstructive pulmonary disease (GOLD 3–4), impaired kidney function (estimated glomerular filtration rate < 30 ml/min), diabetes mellitus, severe cognitive impairment or individuals taking systemic corticosteroid or anticoagulant treatment were not included.

2.4. Inclusion

Upon a brief introduction, we gave written and oral information about the project followed by informed participants' written consent in accordance with the Declaration of Helsinki II. Next, medical staff carried out a brief health examination consisting of heart auscultation, Orientation-Memory-Cognition test (Katzman et al., 1983; Goring et al., 2004), and blood samples as described in the Measurements section.

2.5. Randomization

The participants were randomized to either HRT (N = 15) or CON (N = 15) using biased coin minimization with the software program MinimPy v. 0.3 (Saghaei, 2011a, 2011b) with a base-probability score of 0.95 stratified for gender.

2.6. Interventions

After two weeks of familiarization, adjustments and a 3–6 repetition maximum (RM)-test, 12 weeks of supervised resistance training was performed 3×/week starting at 70% of 1 RM. The RM was calculated from the RM-test aiming for 3–6 repetitions (Abdul-Hameed et al., 2012) using Brzycki's formula (Brzycki, 1993). The leg exercises were knee extension, leg press and leg curl (MED Line, Technogym, Gambettola, Italy). The initial volume was 3 sets of 12 repetitions, gradually progressing to 5 sets of 6 repetitions in week 10 followed by two weeks of tapering consisting of 3 and 2 sets of 6 repetitions, respectively. Further, participants performed two upper-body exercises. If participants could perform more than one repetition after the final set, the physiotherapist increased the load at the next session.

All participants consumed a mixed nutrient supplement (Fresubin® Protein Energy Drink, Fresenius Kabi, Bad Homburg, Germany) at breakfast and lunch (i.e. immediately after training for HRT). Each supplement contained 1260 kJ including 20 g of milk protein (whey:casein 20:80), maltodextrin, sucrose, sunflower- and rapeseed oil.

2.7. Measurements

We consistently tested the participant's dominant extremity, except for handgrip strength and blood pressure, which were always measured on the right side.

2.7.1. Primary outcome

2.7.1.1. MRI-based cross sectional area of m. quadriceps femoris. 1–2 days after the final intervention day trained radiographs recorded the T1-weighted images in a Philips Ingenia scanner, with a 1.5 T magnetic field. Scans consisted of 8 slices, each 10 mm thick, separated by a 60 mm gap with the first slice placed on the tibial plateau. Due to occasional movement artifacts, we evaluated the overall quality of slice 4 (21–22 cm proximal from the tibial plateau) and 5 (28–29 cm proximal) and chose the best for analysis. Usually, slice 4 was selected. A blinded and experienced assessor measured each slice three times and we report the mean. The coefficient of variation for the determination of CSA was <2% based on three blinded separate measurements performed on different days.

2.7.2. Secondary outcomes

2.7.2.1. Isometric and isokinetic peak torque of the thigh. In a Kinetic Communicator (KinCom), model 500-11, Kinetic Communicator, Chattex, Chattanooga, TN (Farrell and Richards, 1986), we measured isometric peak torque, rate of force development (RFD) and impulse at 70° flexion (0° being full knee extension without hyperextension). The isokinetic peak torque was measured from 90° to 0° at 60°/s. The tester provided careful instruction followed by two test sweeps and three verbally encouraged maximal sweeps, each separated by at least 20 s. The tester discarded and replaced sweeps with odd-looking time/force development. A blinded investigator chose the sweeps with highest peak torque for analysis.

2.7.2.2. Thigh power. After the KinCom tests, we measured leg extensor power using a power-rig (Queen's Medical Centre, Nottingham University, UK) as described elsewhere (Bassey and Short, 1990), with the only difference being that participants performed a minimum of three explosive contractions, separated by 30s rest and testing continued until participants produced less power than the prior contraction.

2.7.2.3. Muscle fiber size and composition. Using 1% lidocaine as local anaesthetic, experienced staff extracted muscle biopsies from m. vastus lateralis as previously described (Bergstrom, 1975) using suction. Biopsies were taken in a proximal-distal direction 3–5 cm apart. After extraction, we removed connective tissue and fat before dividing the biopsy into one smaller raw piece (not reported here) and one larger piece embedded in Tissue-Tek®, which was immediately frozen in