ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

CHANGES IN NEUROMUSCULAR FUNCTION OF THE QUADRCEPS MUSCLE WITH AGING

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SUMMARY

The present study was designed to provide further insight into the neuromuscular mechanisms that determine the decrease in maximum strength and strength development of the quadriceps muscle with aging. Different neuromuscular tests were performed in order to assess the neural and muscular changes. The age-related decrease in isometric maximum voluntary torque (iMVT) was accompanied by a decline in voluntary activation and normalized surface electromyographic (EMG) amplitude. Mechanical parameters of explosive voluntary strength were reduced while the corresponding muscle activation remained primarily unchanged. The spinal excitability of the vastus medialis was not different while maximal M wave (M_{max}) latency was longer. Contractile properties and lean mass were reduced. In conclusion, the age-related decline in iMVT of the quadriceps muscle might be due to a reduced neural drive and changes in skeletal muscle properties. The decrease in explosive voluntary strength seemed to be more affected by muscular than by neural changes.

INTRODUCTION

The age-related decrease in muscle strength (dynapenia) and strength development is well-documented and might be caused by neural modulations and alterations of skeletal muscle properties [1, 2]. Despite the importance of knee extensor strength for physical function and mobility in the elderly [3, 4], studies focusing on the underlying neuromuscular mechanisms of quadriceps muscle weakness are limited. Moreover, the reported results are partially conflicting, particularly with regard to changes in neural drive to the quadriceps muscle [5-8]. The ability to voluntarily activate the knee extensors during an isometric contraction has been estimated using either the interpolated twitch technique or the central activation ratio. The inconsistent findings may be primarily related to methodological limitations and differences of these two techniques [9]. Thus, the simultaneous application of two different methods may provide greater insight into modulations of neural drive to the muscle.

It is further noteworthy that age-related changes in neural drive to the quadriceps during strength development have been less frequently investigated. Dynapenia of the quadriceps is a determinant of fall risk [10] and mortality [11]. Considering the fact that the capacity to activate the muscle quickly may be more essential for maintaining balance and preventing falls than maximum strength [12], neuromuscular modulations of the quadriceps muscle during strength development should be investigated more closely.

In summary, there is some lack of knowledge about the neuromuscular mechanisms behind the modulations of maximum strength and strength development of the quadriceps muscle with advancing age. The aim of the present study was to investigate the contributions of age-related neural and muscular changes to decreases in iMVT and explosive voluntary strength. It was hypothesized that iMVT and explosive voluntary strength were reduced with aging accompanied by changes in neural drive to the quadriceps muscle. It was further assumed that aging would affect spinal excitability, contractile properties and skeletal muscle mass.

METHODS

Thirty physically active and healthy subjects were assigned to two groups: (1) young, (2) elderly (Table 1). The subjects participated in three experimental sessions. The first session included the measurement of body composition using dual-energy X-ray absorptiometry (DXA) followed by two sessions of neuromuscular tests: (1) familiarization, (2) experiment (Figure 1).

Table 1: Subject characteristics. Values are presented as mean ± standard deviation (** < 0.01).

	Young (n = 15)	Elderly (n = 15)	p
Men, n (%)	8 (53.3)	8 (53.3)	
Age, yrs	25.3 (3.6)	69.6 (3.1)	<0.001**
Weight, kg	71.3 (11.6)	72.6 (9.9)	0.750
Height, m	1.75 (0.9)	1.69 (0.9)	0.058
Physical activity, h/week	4.6 (3.6)	3.7 (3.3)	0.134

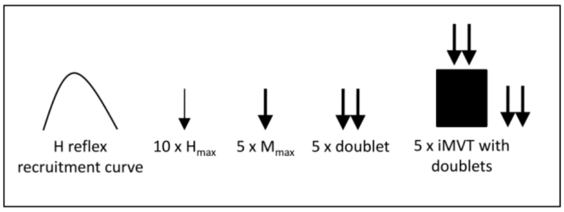
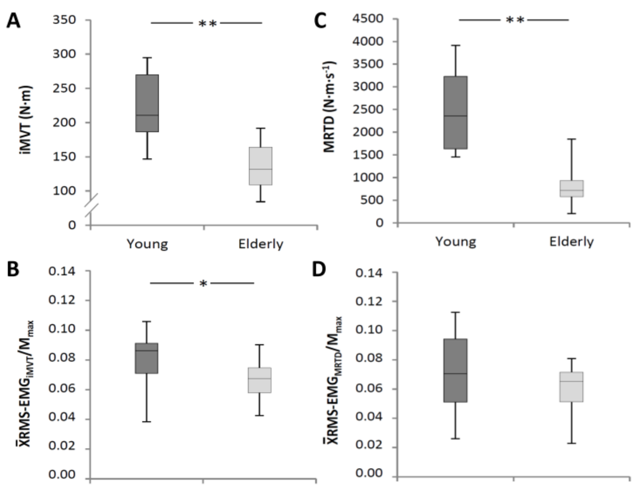


Figure 1: Schematic illustration of the neuromuscular tests. The *thin arrow* indicates single stimulation at maximum H reflex (H_{max}) intensity, the *thick arrow* indicates supramaximal single stimulation and *double thick arrow* indicates supramaximal doublet stimulation.

The neuromuscular tests were carried out on the quadriceps muscle of the dominant leg. Subjects were seated in a standardized position on a CYBEX NORM dynamometer. The iMVT was tested by asking the subjects to exert maximum isometric knee extensions. Explosive voluntary strength was analyzed by calculating the maximum rate of torque development (MRTD) as well as rate of torque development (RTD) and impulse (IMP) in the early phase of contraction in time intervals of 0-50 ms, 50-100 ms, 100-150 ms and 150-200 ms after torque onset. The neural drive to the muscle during iMVT was estimated using two approaches: the interpolated twitch technique and the root mean square of the EMG signal (RMS-EMG) normalized to M_{max}. The neural drive to the muscle during MRTD and RTD was assessed using the RMS-EMG normalized to M_{max} and normalized to the RMS-EMG during iMVT. Age-related changes in α-motoneuron excitability via Ia afferents were determined with the H reflex technique. Modulations at the skeletal muscle level were evaluated by analyzing the twitch torque signal induced by supramaximal electrical stimulation and by determining the lean mass of the leg.
Data were checked for normal distribution using a Shapiro-Wilk *W* test. Age-related differences between the groups were tested for significance by the unpaired Student's *t* test or Mann-Whitney *U* test. The level of significance was established at $p < 0.05$.

RESULTS AND DISCUSSION

IMVT and MRTD, as well as RTD and IMP in the early phase of contraction were reduced in elderly subjects (Figure 2A, 2C). Voluntary activation and normalized muscle activity during iMVT were decreased indicating a reduced neural drive to the muscle (Figure 2B, 2E). The decline in MRTD and RTD during the early phase of contraction might be more affected by modulations of muscle properties than neural changes, as corresponding muscle activity remained primarily unchanged (Figure 2D). There were no differences in the maximum H reflex (H_{max}) and H_{max}/M_{max}-ratio of the vastus medialis, but a longer normalized M_{max} latency was observed, indicating a decline in efferent conduction velocity. In addition, the age-related decreases in iMVT and explosive voluntary strength were accompanied by changes at the muscle level, as evidenced by a decline in twitch contractile properties and leg lean mass (Table 2).



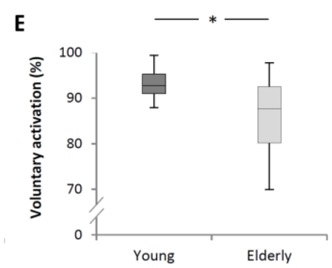


Figure 2: Comparisons between groups. A: isometric maximum voluntary torque (iMVT), B: normalized and averaged root mean square (RMS) of the EMG signal of vastus medialis, rectus femoris and vastus lateralis during iMVT, C: maximal rate of torque development (MRTD), D: normalized and averaged RMS of the EMG signal of the three muscles during MRTD and E: voluntary activation (* $p < 0.05$, ** $p < 0.01$).

Table 2: Lean mass of the leg and contractile properties. Contractile properties were evaluated by doublet stimulation at supramaximal intensity. Peak torque (PT), maximum rate of torque development ($MRTD_{TT}$), maximum rate of torque relaxation ($MRTR_{TT}$), twitch contraction time (TCT_{TT}), twitch half relaxation time ($THRT_{TT}$) and total twitch area (TTA_{TT}) of the resting twitch torque. Values are presented as mean ± standard deviation (* $p < 0.05$, ** $p < 0.01$).

	Young	Elderly	*p*
Lean mass, kg	9.27 (1.65)	7.79 (1.72)	0.028*
Contractile properties			
PT (Nm)	39.4 (10.6)	15.35 (7.20)	<0.001**
$MRTD_{TT}$ ($Nm·s^{-1}$)	1814.4 (449.7)	673.54 (359.21)	<0.001**
$MRTR_{TT}$ ($Nm·s^{-1}$)	828.1 (171.8)	292.97 (163.94)	<0.001**
TCT_{TT} (s)	0.06 (0.02)	0.07 (0.02)	0.101
$THRT_{TT}$ (s)	0.08 (0.02)	0.07 (0.02)	0.106
TTA_{TT} (Nm·s)	4.4 (0.6)	2.2 (0.4)	0.001**

CONCLUSIONS

The data from this study confirm that the age-related decline in iMVT of the quadriceps muscle might be due to modulations of the nervous system and changes in skeletal muscle properties. Surprisingly, the reduction in MRTD as well as RTD and IMP during the early contraction phases might be more affected by modulations at the muscle level than by neural changes.

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