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Force-time characteristics during sustained maximal handgrip effort according to age and clinical condition

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ABSTRACT

Background: Muscle fatigue, a prominent symptom in older patients, can be assessed by sustained maximal handgrip testing. The force decline during sustained maximal contraction is described for young adults, but data for elderly persons are scarce. The aim of this study was to investigate force-time characteristics during a sustained maximal handgrip effort according to age and clinical condition.

Methods and materials: Force-time data were continuously recorded during sustained maximal grip effort in 91 elderly patients (aged 83 ± 5 years), 100 elderly controls (aged 74 ± 5 years) and 100 young controls (aged 23 ± 3 years). The force-time curve was divided in 4 parts per 25% strength drop observed. Time (representing fatigue resistance (FR)) was measured during which grip strength (GS) dropped to 75% (FR_{75}), 50% (FR_{50}), 25% (FR_{25}) of its maximum and to exhaustion ($FR_{exhaustion}$). Grip work ((GW), the area under the force-time curve) was measured for the 4 parts as well as for the first 20 and 30 s of the fatigue protocol test. Strength decay (GW_{decay}), defined as the difference between the area under the curve (% GW) and a theoretical maximal area under the curve (assuming there's no strength drop), was also studied. In the elderly participants, relationships (controlling for age and sex) of GS, FR and GW with circulating IL-6 and TNF-α were analyzed.

Results: $FR_{exhaustion}$ was similar for all groups, whereas the duration of each of the 4 parts was significantly different between the 3 groups. FR_{75} was shortest in old patients ($p = 0.004$), $FR_{75\text{-}50}$ was almost twice as long in old community-dwelling compared to old patients and young controls ($p < 0.001$). This contrast was inverted for $FR_{50\text{-}25}$ which was significantly shorter in old community-dwelling compared to the other groups ($p = 0.013$). $FR_{25\text{-}exhaustion}$was significantly longer in young controls compared to the groups of older participants ($p = 0.017$). Old patients showed lower GW for the first 2 parts compared to old community-dwelling and young controls. Also, GW_{decay} values during the first 20 and 30 s were significantly higher in old patients compared to old community-dwelling and young controls (both $p < 0.001$). IL-6 was significantly related to lower GS_{max}, FR_{75}, FR_{50}, FR_{25}, $FR_{exhaustion}$, $GW_{75,}$ GW_{50} and $GW_{75\text{-}50}$.

Conclusion: This is the first study reporting differences in strength decay during a sustained maximal handgrip effort according to age and clinical condition. Old patients showed a particularly rapid decline in GW during the first part of sustained handgrip. GW was also significantly related to circulating IL-6. Future studies should confirm whether a shorter FR test protocol (i.e. until FR_{75}) but using a continuous registration of the strength decay could be more informative in a clinical setting compared to the classical FR test (measuring only FR_{50}).

Abbreviations: BMI, body mass index; FR, fatigue resistance; FR_{75}, FR_{50} and FR_{25}, time during grip strength dropped respectively to 75% of its maximum, 50% of its maximum and 25% of its maximum; $FR_{exhaustion}$, the total time from maximal grip strength to exhaustion; $FR_{100\text{-}75}$, $FR_{75\text{-}50}$, $FR_{50\text{-}25}$ and $FR_{25\text{-}fatigue}$, time during which grip strength drops respectively from GS_{max} to 75% GS_{max}, from 75% GS_{max} to 50% GS_{max}, from 50% GS_{max} to 25% GS_{max}, and from 25% GS_{max} to exhaustion; GS_{max}, maximal grip strength; GS, grip strength; GW, grip work; $GW_{75\text{-}50}$, $GW_{50\text{-}25}$, $GW_{25\text{-}fatigue}$, grip work delivered when grip strength drops respectively from 75% GS_{max} to 50% GS_{max}, from 50% GS_{max} to 25% GS_{max}, and from 25% GS_{max} to exhaustion, calculated by integrating the actual GS at each time interval (i.e. 1 s); GW_{decay}, grip work decay; $GW_{decay20}$ and $GW_{decay30}$, the difference between the area under the curve and a theoretical maximal area under the curve (assuming there's no strength drop) respectively after the first 20 and 30 s during the FR test; % GW, area under the curve; IL-6, interleukin 6; TNF-α, tumor necrosis factor alpha

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1. Introduction

Fatigue, muscle weakness and low-grade inflammation are considered as key-elements for physical frailty at higher age (Fried et al., 2001). Frailty is a major geriatric syndrome defined as "a condition that results from a multisystem reduction in reserve capacity, to the extent that a number of physiological systems are close to, or pass, the threshold of symptomatic clinical failure". By the year 2025, 26 countries will have a life expectancy at birth of above 80 years, which is the age group with the highest prevalence of frailty. According to the World Health Organization, it will be highest in Iceland, Italy, Japan and Sweden (82 years) followed by Australia, Canada, France, Greece, Netherlands, Singapore, Spain and Switzerland (81 years).

Previously, we introduced a new assessment method for muscle fatigue resistance (FR), which is known to be a direct and objective outcome parameter of the exhaustion component of frailty in elderly persons (Bautmans and Mets, 2005). During the test subjects are instructed to sustain maximal handgrip effort as long as possible, and FR is expressed as the time during which grip strength (GS) drops to 50% of its maximum (Bautmans and Mets, 2005). In a series of original studies, we have further validated the FR test, and portrayed the dramatic impact of complex inflammatory processes on muscle fatigue. In fact, our previous work showed that GS and muscle endurance - the latter expressed as FR or grip work (GW) - were significantly related to dependency in basic ADL, self-perceived fatigue and circulating markers of inflammation in community-dwelling elderly persons (Bautmans et al., 2007; Bautmans et al., 2011), in frail elderly nursing home residents (Bautmans et al., 2008), in hospitalized geriatric patients (Bautmans et al., 2011; Bautmans et al., 2005; Beyer et al., 2012; Mets et al., 2004) and following abdominal surgery (Bautmans et al., 2010). Muscle endurance in geriatric hospitalized with acute infections recovered by > 60% following treatment with celecoxib, a COX-2 selective non-steroidal anti-inflammatory drug (Mets et al., 2004), which was confirmed in another study using piroxicam treatment (Beyer et al., 2011).

FR allows for the calculation of grip work ($GW = 0.75 * GS_{max} * FR$) (Bautmans et al., 2007; Bautmans et al., 2011), a parameter reflecting the work output delivered by the muscles during the test. When graphically represented, GW is the area under the curve with GS in the vertical and time in the horizontal axis. The calculation of GW starts from the assumption that GS drops linearly during the FR test. This linear approach was shown to be a fair estimation of the real area under the curve ($r = 0.98$, $p < 0.001$) (Bautmans et al., 2011), and is - given its simplicity and easiness to compute - excellent for clinical use. The FR test is now internationally accepted (Theou et al., 2008) and several researchers as well as clinicians are using it (Elmahgoub et al., 2009; Theou et al., 2011; Calders et al., 2011; Alkurdi and Dweiri, 2010; Elmahgoub et al., 2011; D'Hooge et al., 2011; Drey et al., 2011). In several studies involving adolescents (with or without diabetes, obesities or mental retardation), researchers used the FR test to investigate if exercises training improved the muscle endurance (Elmahgoub et al., 2009; Calders et al., 2011; Elmahgoub et al., 2011; D'Hooge et al., 2011). Not only in studies with young adults, but also in studies acting on frailty is the FR test an often used measurement method (Theou et al., 2011). In the literature review of Drey et al. (Drey et al., 2011), they affirm that the FR test is a valuable method to evaluate exhaustion and the test can be applied in a practical manner without overtly interfering with depression.

In the literature, the pattern of force decline during sustained maximal muscle contraction has been described in young adults (Yamaji et al., 2006a; Yamaji et al., 2006b; Yamaji et al., 2002; Hermansen et al., 1967; Nilsson and Ingvar, 1967), to our best knowledge data for elderly persons are scarce. In young adults it is known that isometric muscle strength, regardless of continuous or intermittent force exertions, decreases markedly in the initial part, and then reaches an almost steady state (nearly 15–20% of the maximal voluntary contraction) within about 150 s (Yamaji et al., 2002). The initial strength drop is assumed to be caused by a lack of oxygen supply by blood flow obstruction due to an increase in intramuscular pressure during sustained GS. During the steady state phase, a resumption of blood flow has been reported (Hermansen et al., 1967; Nilsson and Ingvar, 1967). However, muscle fatigue patterns might differ according to age and clinical condition (Kent-Braun, 2009).

The aim of this study was to compare force-time characteristics during a sustained maximal handgrip effort in old community-dwelling, old patients and young controls. In addition, for aged participants (old patients and old community-dwelling) we also examined the relationship between force-time characteristics and levels of circulating markers of inflammation.

2. Materials and methods

A secondary data-analysis was performed on continuously recorded force-time data during sustained maximal grip effort until exhaustion that was obtained in a previous study involving 291 subjects of different age categories and clinical conditions (Bautmans et al., 2011).

2.1. Subjects

A detailed description of the participants and their recruitment is published elsewhere (Bautmans et al., 2011). Briefly, 291 persons among which 91 hospitalized geriatric patients (30 male and 61 female, aged 60 years or over); 100 physically independent old community-dwelling (49 male and 51 female, aged 60 years or over); and 100 young healthy (49 male and 51 female, aged 20–30 years) persons participated in the study. The two groups of elderly participants were not age-matched since the aim was to recruit a large and diverse sample of elderly subjects ranging from healthy, physically independent and fit (often younger) seniors to very old, frail and ill geriatric patients. Subjects were screened for exclusion criteria by interview and excluded when unable to understand or perform (due to cognitive or physical impairments) the test instructions and procedures and when presenting functional disability of the dominant upper extremity (paresis/paralysis, tremor or recent surgery). The main diagnosis for hospitalization of the hospitalized geriatric patients were infectious disease (N = 18), cardio-vascular disease (N = 16), neuro-psychological disease (N = 11), cancer (N = 10), musculo-skeletal disease (N = 11), gastro-intestinal disease (N = 9), hematological disease (minor or transient, N = 4), rheumatological disease (N = 2), diabetes For the young controls and old community-dwelling, co-morbidity was not an exclusion criterion, except for acute or uncontrolled conditions, and chronic inflammatory pathology. The study protocol was approved by the local ethical committee and written informed consent was obtained from all subjects.

2.2. Measurements

If subjects participated in sports, measurements were performed at least 12 h after the last intensive physical activity (Bautmans et al., 2011). Old patients were assessed within the first 5 days after admission at the hospital (2.4 ± 1.5 days) in order to limit bias due to aggravation or resolution of the infection by the treatment of the patients.

2.2.1. Serum levels of inflammatory mediators

Peripheral venous blood was collected from the non-dominant arm prior to the GS and FR tests and left undisturbed at room temperature for 30 min. Next, the samples were centrifuged, and serum was obtained and frozen for later simultaneous determination of cytokines for the whole group. The levels of IL-6 and TNF-α in the serum samples were determined using ELISA Immunoassay kits (Invitrogen, Merelbeke, Belgium). Intra-assay precision expressed as a coefficient of variance as determined by the manufacturer for low (L), normal (N) and