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Validation of handgrip strength and endurance as a measure of physical function and quality of life in healthy subjects and patients

Lene H. Jakobsen, M.Sc.[a,*], Ingeborg K. Rask, M.Sc.[a], and Jens Kondrup, M.D.[a,b]

[a]Department of Human Nutrition, Faculty of Life Sciences, University of Copenhagen, Copenhagen, Denmark
[b]Clinical Nutritional Unit, Rigshospitalet, Copenhagen, Denmark

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Abstract

Objective: Handgrip strength (HGS) is often used as a bedside measurement of muscle function in the hospital setting. The aim of this study was to investigate the extent to which HGS, endurance, and work (force during endurance × time) are related to physical function as measured by mobility and physical activity (PA) in young, healthy volunteers. Further, the relations between HGS, mobility, PA and quality of life (QoL) in patients were investigated.

Methods: Ninety-two healthy subjects (45% men, mean age 30 y) and 45 patients (56% men, mean age 55 y) were assessed for HGS, handgrip endurance, and handgrip work, mobility (timed up-and-go test), and PA (Baecke questionnaire or Bouchard activity diary). The patients were further assessed for QoL (SF-36).

Results: There was a correlation between HGS and mobility in healthy subjects ($r = -0.31$, $P = 0.0028$) and patients ($r = -0.59$, $P < 0.0001$). Further, HGS and mobility were related to physical and mental component summary scores of QoL in patients. There was also a relation between HGS and PA in healthy female subjects and male patients.

Conclusion: Handgrip strength is a valid measurement of mobility and QoL in patients and of PA in healthy female subjects and male patients. Handgrip endurance and work were not found to be valid measurements of mobility and PA in healthy subjects or of QoL in patients.

Keywords: Physical function; Handgrip strength; Handgrip endurance; Handgrip work; Mobility; Physical activity

Introduction

Malnutrition is a common problem in hospitalized patients, found at a prevalence of about 40% [1,2], and related to increased morbidity and mortality [3]. Nutritional therapy has been shown to improve nutritional status and functional recovery and reduce complications and mortality [4]. Detection and treatment of malnutrition are therefore important parts of daily clinical practice. Simple and rapid screening tools (e.g., based on body mass index, recent weight loss, recent food intake, and severity of disease) are available for detection [5]. However, monitoring of nutritional support is more complex. Adequacy of nutritional intake is traditionally monitored by body weight, which has its limitations such as in the presence of edema. Functional measurements could be of potential value in this context and a systematic review has suggested that intervention trials should include functional measurements, such as muscle strength, mobility, and quality of life (QoL), in addition to clinical outcome variables [6].

Malnutrition leads to wasting of skeletal muscle [7,8] and thereby results in impaired muscle function [8,9]. Handgrip strength (HGS) is a sensitive measurement of short-term response to nutritional therapy [10]. It correlates with outcome from surgery and clinical improvement [11] and improves concomitantly with outcome in intervention trials [11,12], such as being positively related to changes in QoL [13]. HGS is related to clinical outcome more closely than nutritional status and/or body composition [14,15]. Still, a better understanding of the relations among HGS, mobility, physical activity (PA), and eventually QoL is required to appreciate the validity of HGS as a simple bedside tool.

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* Corresponding author. Tel.: +45-3533-3281; fax: +45-3533-2483.
E-mail address: lhj@life.ku.dk (L. H. Jakobsen).

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A few studies have investigated the relation among HGS, mobility, and PA, primarily in healthy elderly subjects, but the results differ as to the extent to which HGS is related to mobility [16,17] or habitual PA [18–23] and this relation has not been investigated in patients.

Handgrip strength is a test of maximal force produced by muscle. However, most activities of daily living occur at submaximal force levels. Therefore, a measurement of the ability to sustain a given submaximal force (i.e., endurance) may provide additional information for assessment of disability in patients with wasting conditions [24]. Coronell et al. [24] showed that dysfunction of the quadriceps muscle in patients with chronic obstructive pulmonary disease is underestimated if measured by strength only. Russell et al. [25] found that HGS was more sensitive to nutritional deprivation than handgrip endurance (HGE). It has been suggested that strength and endurance change independently and their values may depend on the nature and duration of nutritional deprivation [25].

This study examined the relations between simple bedside methods, including HGS, HGE (duration of 70% maximal grip strength in seconds), and handgrip work (HGW; force during endurance × seconds), and more global health indicators such as mobility and PA in healthy subjects and patients. Further, the study examined the relation among HGS, HGE, HGW, and QoL to evaluate whether HGS, HGE, and HGW relate to the patients' subjective well-being.

Materials and methods

The study was conducted in two parts. Part I was carried out in healthy subjects validating HGS, HGE, and HGW by measuring mobility (timed up-and-go test [TUG]) and habitual PA (Baecke questionnaire). Part II was carried out in hospitalized patients validating HGS, HGE, and HGW by measuring mobility (TUG), PA (Bouchard activity diary), and QoL (SF-36v2).

Healthy subjects

Ninety-two healthy subjects (41 men, 51 women) were studied. Subjects were within an age range of 20–65 y and were recruited among students and employees from the Faculty of Life Sciences, University of Copenhagen (Copenhagen, Denmark), by advertisement by an internal mail portal, and posters at the Faculty of Life Sciences.

Patients

Forty-five patients (25 men, 20 women) were recruited by daily visits to departments of surgery, gastroenterology, oncology, and internal medicine. These departments had given consent to participate in the study. All newly admitted patients were included if the nurse responsible for the patient considered the patient to be eligible and if the patient fulfilled the in- and exclusion criteria. The nutritional risk screening (NRS)-2002 [5] was used to determine if patients were at risk for nutrition-related complications.

Subjects with neuromuscular or joint disease were excluded. The study design was approved by the local ethics committee and verbal or written consent was obtained when recruiting healthy subjects or patients, respectively.

Measurements

Measurement sequence

All evaluations were performed on the same day in the following order: HGS, HGE, HGW, TUG, and PA. Further, QoL was assessed in patients. Body mass index was calculated from reported body weight and height.

Handgrip performance tests

Handgrip strength was measured with a Jamar 5030J1 Hydraulic Hand Dynamometer (Sammons Preston Rolyan, Bolingbrook, IL, USA) according to methods described by Bohannon et al. [26] and Mathiowetz et al. [27,28]. In contrast to Bohannon et al. and Mathiowetz et al., we measured HGS only in the right hand because the right hand is significantly stronger in right-handed subjects and there is no significant difference between the two sides in left-handed subjects [29,30]. Subjects were encouraged to perform maximal contractions three times with a 15-s interval and the average value was recorded.

Handgrip endurance was measured by the ElectroFluidGraph (EFG; Akern/RJL Systems, Florence, Italy), which is ordinarily used for bioelectrical impedance analysis. A handgrip device with a handle connected to two steel springs is connected to the EFG and the force produced is measured as a resistance (ohms) by the EFG. The HGE test started with measuring the participant's maximal force when pressing the EFG handle. A force equivalent to 70% of this maximal force was then shown on a display on the EFG. The subjects were then instructed to press the handle until they reached a level within the range of 65–75% of their own maximal force ($HGE_{70\%\ own\ max}$), as seen on the EFG display and to hold the handle at this level for as long as possible. The time (seconds) and resistance (ohms) against time were recorded by the EFG. Seventy percent of maximal force was chosen because it is known to induce anaerobic conditions during a prolonged contraction [8]. It is believed that if the stores of substrates for anaerobic glycolysis (i.e., glycogen/glucose) are decreased in malnourished patients, there will be a more rapid loss of force during a sustained contraction compared with well-nourished individuals [8]. HGE was subsequently measured at 70% of a standard maximum handgrip strength ($HGE_{70\%\ std\ max}$) specific for gender and age as based on data provided by Mathiowetz et al. [28]. The normative data [28] (in kilograms) were translated to the EFG handgrip device (in ohms) according to a prestudy in 40 healthy volunteers comparing Jamar to EFG, which produced a standard curve with $r^2 = 0.89$ (unpublished data).

Handgrip work was described by Bautmans et al. [31] as a measurement of the total work produced during the

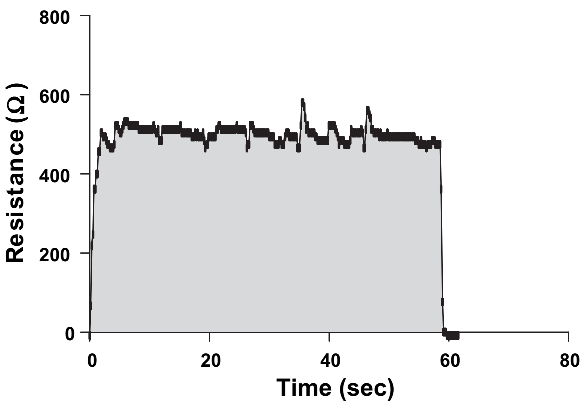

Fig. 1. An example of handgrip endurance and handgrip work. The subject/patient is asked to maintain 70% of his maximum grip strength for as long as possible. In this case, the subject kept a force of about 500 Ω for 58 s. Handgrip work (70% handgrip strength × seconds) is calculated as the area under the curve (gray filling) of handgrip force against time.

endurance test (HGW = 70% grip strength × seconds; Fig. 1). In our study, the area under the curve of the handgrip force against time was calculated. We see this as a more precise calculation than the one used by Bautmans et al. [31] in which they used the time elapsed until a 50% decrease from maximal force was reached and calculated work assuming a linear decrease in force against time. Our results clearly showed that the decrease in force is not linear against time.

Mobility

Mobility was assessed by TUG [32], which was modified for our young subjects. The original TUG [32] was developed for testing mobility in elderly people and included a total walking distance of 6 m. We increased the distance to 8 m because our subjects were expected to perform the test faster than the elderly. This modified TUG was also used in patients. As fast as possible, the participant rose from an ordinary armchair (45 cm high), walked 4 m to a spot, turned around, returned to the chair, and sat down. The time in seconds was recorded. The subject was requested to perform the test twice and the first trial was considered a rehearsal in which only the time of the second trial was used.

Physical activity

In healthy subjects, the Baecke questionnaire [33] was used to assess habitual PA. Its validity has been advocated based on a high correlation to PA as measured by doubly labelled water [34], although this was not confirmed in another validation study [35]. Studies have found a good test–retest reliability of the Baecke questionnaire [36,37], which is commonly used in epidemiologic studies [38–40]. The Baecke questionnaire evaluates the subjects' PA over the previous year and consists of 16 questions each with a 5-point scale [33]. The results are grouped under a work index, a sports index, and a leisure time index. A total activity score is calculated as the sum of these three indices.

In patients, PA was assessed by the Bouchard activity diary [41] as modified by Bratteby et al. [42]. This was decided based on the disappointing results we obtained with the Baecke questionnaire in part I in healthy subjects (see RESULTS). Also, the Baecke questionnaire measures PA retrospectively, whereas the Bouchard activity diary measures the subjects' current level of PA, which may be more closely related to an individual's muscle function than the PA over the previous year. Validity has been documented by relating total energy expenditure estimated by the Bouchard activity diary, as modified by Bratteby et al., to total energy expenditure measured by the doubly labelled water method [42]. $PA_{Bouchard}$ is determined by stratifying each activity, or intensity of activity, according to one of nine categories of PA. Each category of PA is given a value of physical activity ratio (PAR) representing multiples of basal metabolic rate from the lowest category of 1, representing sleep in bed, to the highest category of 9, reflecting very intense manual work or maximal sport activity. For category 1, Bratteby et al. [42] combined the PAR for lying sleeping in bed and lying awake in bed to a single PAR = 0.95 in their study of healthy subjects. However, hospitalized patients spend proportionally much more time lying awake in bed (watching television, being nursed, etc.) than healthy subjects and therefore we used separate PARs for lying asleep in bed (PAR = 0.9) and lying awake in bed (PAR = 1.2) as in Kondrup et al. [43] In the activity diary, a day is divided into 96 periods of 15 min each. For each 15-min period, the patient marked the category corresponding to the dominant activity of that period in the corresponding field on the activity diary form. A list of common activities and their categories is printed on the form [41]. With this method, the average 24-h PA level is estimated by dividing the sum of PAR values by 96 [42].

Quality of life

Quality of life was assessed in patients by the Short-Form Health Survey [44] (SF-36v2), consisting of 36 questions for which the answers are grouped under eight multi-item scales: physical function, perception of physical role, vitality, general health, mental health, perception of emotional role, social function, and bodily pain [44]. The standard (US) scoring algorithms, as described by Ware et al. [45] were used. The scales of the SF-36v2 are summarized into two dimensions: physical component summary (PCS) and mental component summary (MCS). The SF-36 has been shown to be valid in discriminating between physical and mental health status in cross-sectional and longitudinal tests [45] and it has been validated in a healthy Danish population [46].

Data analysis

Data were evaluated for Gaussian distribution by Shapiro-Wilks test for normality, and for clarity all results are presented as mean ± standard deviation. To determine statistical significance of differences between groups, Student's unpaired t test or the Mann-Whitney U test was used in accordance with the distribution of the variables (specified in the tables). For correlation analyses, Pearson's or Spearman's correlation coefficients were calculated depending on the distribution of the variables (specified in the tables and figures). To compare the various variables between healthy subjects and patients, multivariate analysis adjusted for age, height, weight, and gender was performed using a general linear model (GLM). To investigate the role of nutritional status and length of stay before examination in patients, the various correlations were adjusted for NRS and length of stay before examination, respectively, by GLM.

An acceptable level of statistical significance was established at $P < 0.05$. The area under the curve was calculated using GraphPad Prism 5.00 for Windows, (GraphPad Software, San Diego, CA, USA). Statistical analysis was carried out using SAS 9.1 for Windows (SAS Institute, Cary, NC, USA).

Results for men and women are combined in the tables and figures because we wanted to evaluate possible universal relations between the variables (HGS, HGE, HGW, TUG, PA, and QoL). Separate analyses for each gender are given in the text. Data are presented in absolute terms, although some variables clearly have extensive properties, e.g., HGS, which is dependent on body size [47], whereas other variables have intensive properties, e.g., PA and QoL, which are not expected to depend on body size. These incommensurabilities are discussed in the text.

Results

Part I: Healthy subjects

Nine subjects were taking medication for hypertension or allergies. Statistical analyses were done with and without these subjects and, since the results were not different, these subjects were included in the results presented.

Table 1 summarizes the characteristics of the healthy subjects together with data on muscle function, mobility, and habitual PA. The male subjects were able to hold a sustained effort for a longer time during HGE and to produce a larger HGW compared with the female subjects. The male subjects were also slightly faster in performing the TUG compared with the female subjects.

There was a positive correlation between HGS and height ($r = 0.730$, $P < 0.0001$) and weight ($r = 0.642$, $P < 0.0001$) for both genders combined. There was a negative correlation between HGS and age in women ($r = -0.32$, $P < 0.05$), but not in men. Details of these results are not shown.

Correlations among muscle function, mobility, and habitual PA are presented in Table 2.

There was a negative correlation between HGS and TUG combined for both genders. Figure 2 shows a relation between HGS and mobility. $HGE_{70\%\ std\ max}$ and $HGW_{70\%\ std\ max}$ were, surprisingly, negatively related to work index combined for both genders.

When analyzed separately for each gender, there were several significant correlations for women only. A significant correlation between HGS and TUG (Table 2, Fig. 2) was only seen in women ($r = -0.36$, $P < 0.01$; men: $r = -0.15$, $P > 0.05$). Furthermore, in women, there were significant relations between HGS and work index ($r = -0.37$, $p < 0.01$), sport index ($r = 0.47$, $P < 0.001$), leisure time index ($r = 0.28$, $P < 0.05$), and total score for the Baecke questionnaire ($r = 0.31$, $P < 0.05$). Also, only in women, $HGE_{70\%\ own\ max}$ and $HGW_{70\%\ own\ max}$ were negatively related to work index ($r = -0.28$, $P < 0.05$, and $r = -0.37$, $P < 0.01$, respectively). $HGW_{70\%\ own\ max}$ was positively related to leisure time index ($r = 0.29$, $P < 0.05$) in women. Furthermore, there was a negative correlation between TUG and sport index in women

Table 1
Characteristics of healthy subjects and their muscle function*

	All	Men	Women	P
Subjects	92	41	51	
Age (y)	33.9 ± 10.6	37.3 ± 10.8	31.1 ± 9.7	<0.0001†
Weight (kg)	71.5 ± 11.8	79.9 ± 9.1	64.6 ± 8.3	<0.0001†
Height (m)	1.76 ± 0.09	1.84 ± 0.06	1.70 ± 0.06	0.0306‡
Body mass index (kg/m^2)	23.0 ± 3.0	23.7 ± 2.1	22.4 ± 3.4	<0.0001‡
HGS (kg)	42.9 ± 12.0	54.0 ± 8.0	34.4 ± 5.4	<0.0001‡
$HGE_{70\%\ std\ max}$ (s)	33.3 ± 17.3	38.0 ± 18.4	29.8 ± 15.1	0.0130‡
$HGW_{70\%\ std\ max}$ ($\Omega \times$ s)	14 044 ± 9975	20 459 ± 9847	7649 ± 4437	<0.0001‡
$HGE_{70\%\ own\ max}$ (s)	38.5 ± 18.6	46.7 ± 15.5	31.8 ± 15.9	<0.0001‡
$HGW_{70\%\ own\ max}$ ($\Omega \times$ s)	16 700 ± 12 101	26 267 ± 10 882	8800 ± 5417	<0.0001†
Baecke total	8.49 ± 1.10	8.47 ± 1.07	8.51 ± 1.14	NS
Work index	2.13 ± 0.52	2.10 ± 0.56	2.16 ± 0.49	NS
Sport index	2.87 ± 0.76	2.89 ± 0.77	2.85 ± 0.77	NS
Leisure time index	3.49 ± 0.71	3.49 ± 0.78	3.49 ± 0.65	NS
Timed up-and-go test (s)	6.11 ± 1.03	5.87 ± 1.00	6.31 ± 1.01	0.0424‡

$HGE_{70\%\ own\ max}$, handgrip endurance at 70% of a subject's maximal force; $HGE_{70\%\ std\ max}$, handgrip endurance at 70% of a standard maximum handgrip strength; HGS, handgrip strength; $HGW_{70\%\ own\ max}$, handgrip work at 70% of a subject's maximal force; $HGW_{70\%\ std\ max}$, handgrip work at 70% of a standard maximum handgrip strength

* Results are presented as mean ± SD.

† Mann-Whitney U test.

‡ Student's t test.

Table 2
Correlation coefficients (r) among HGS, HGE, HGW, mobility, and physical activity in healthy subjects

	TUG (s)	Baecke total	Work index	Sports index	Leisure time index
HGS (kg)	−0.309[†,‡]	NS	NS	NS	NS
$HGE_{70\%\ own\ max}$ (s)	NS	NS	NS	NS	NS
$HGW_{70\%\ own\ max}$ ($\Omega \times$ s)	NS	NS	NS	NS	NS
$HGE_{70\%\ std\ max}$ (s)	NS	NS	−0.290[*,‡]	NS	NS
$HGW_{70\%\ std\ max}$ ($\Omega \times$ s)	NS	NS	−0.272[*,‡]	NS	NS
TUG (s)		NS	NS	NS	NS

$HGE_{70\%\ own\ max}$, handgrip endurance at 70% of a subject's maximal force; $HGE_{70\%\ std\ max}$, handgrip endurance at 70% of a standard maximum handgrip strength; HGS, handgrip strength; $HGW_{70\%\ own\ max}$, handgrip work at 70% of a subject's maximal force; $HGW_{70\%\ std\ max}$, handgrip work at 70% of a standard maximum handgrip strength; TUG, timed up-and-go test

* $P < 0.05$.

† $P < 0.01$.

‡ Pearson's correlation.

($r = -0.32$, $P < 0.05$), but not in men. A significant negative correlation between $HGW_{70\%\ std\ max}$ and work index was found in both genders (women: $r = -0.33$, $P < 0.05$; men: $r = -0.39$, $P < 0.05$; Table 2).

When data were analyzed adjusted for body weight and height, respectively, no other statistically significant relations appeared, but some showed a stronger relation, e.g., a correlation between HGS adjusted for body weight and TUG (both genders combined: $r = -0.35$, $P < 0.001$; women: $r = -0.42$, $P < 0.01$) and a correlation between HGS adjusted for height and TUG (both genders combined: $r = -0.27$, $P < 0.05$; women: $r = -0.36$, $P < 0.01$).

Part II: Patients

Characteristics of the patients and data on muscle function, mobility, PA, and QoL are presented in Table 3. The patients had significantly lower HGS, $HGE_{70\%\ own\ max}$, $HGE_{70\%\ std\ max}$, $HGW_{70\%\ own\ max}$, and $HGW_{70\%\ std\ max}$ and were slower in performing the TUG test ($P < 0.0001$ for all variables) compared with the healthy subjects. These differences in the various handgrip performance tests and TUG between healthy subjects and patients persisted after adjusting for differences in age, height, weight, and gender by GLM. Results are not shown.

Table 3
Characteristics of patients and their muscle function and quality of life*

Patients	45
Women/men	20/25
NRS-2002 (<3/≥3)	24/21
Length of stay before application of tests	8 (1, 26)
Age (y)	54.9 ± 16.1
Weight (kg)	74.0 ± 17.1
Height (m)	1.72 ± 0.09
Body mass index (kg/m^2)	24.9 ± 4.9
HGS (kg)	31.7 ± 11.3
$HGE_{70\%\ own\ max}$ (s)	18.9 ± 10.1
$HGW_{70\%\ own\ max}$ ($\Omega \times$ s)	6174 ± 4400
$HGE_{70\%\ std\ max}$ (s)	16.8 ± 9.3
$HGW_{70\%\ std\ max}$ ($\Omega \times$ s)	6061 ± 4483
$PA_{Bouchard}$	1.32 ± 0.16
TUG (s)	9.68 ± 4.07
Physical component summary	36.8 ± 10.5
Mental component summary	41.5 ± 14.7

$HGE_{70\%\ own\ max}$, handgrip endurance at 70% of a subject's maximal force; $HGE_{70\%\ std\ max}$, handgrip endurance at 70% of a standard maximum handgrip strength; HGS, handgrip strength; $HGW_{70\%\ own\ max}$, handgrip work at 70% of a subject's maximal force; $HGW_{70\%\ std\ max}$, handgrip work at 70% of a standard maximum handgrip strength; NRS-2002, nutritional risk screening-2002; $PA_{Bouchard}$, physical activity measured by the Bouchard activity diary; TUG, timed up-and-go test

* Results are presented as number of patients, median (quartile 1, quartile 3), or mean ± SD.

Correlations among muscle function, mobility, and PA are presented in Table 4. HGS was negatively related to TUG in both genders combined (Fig. 2) and positively related to the PCS and MCS of QoL (Fig. 3). $HGW_{70\%\ std\ max}$ was negatively related to TUG in both genders combined, but less significantly than the relation with HGS. The TUG was also negatively related to the PCS and MCS of QoL (Fig. 4). When analyzed separately for each gender, there was a significant difference in HGS, but not in PA. Furthermore, there was a correlation between HGS and PA for men (r = 0.57, $P < 0.05$) but not for women. Twenty-one patients (14 men, 7 women) were nutritionally at risk according to the NRS-2002. The at-risk patients had a significantly lower body mass index (23.4 ± 3.9 versus 26.3 ± 5.4 kg/m^2, $P < 0.05$), lower PA (1.50 versus 1.63, $P < 0.05$), and a lower

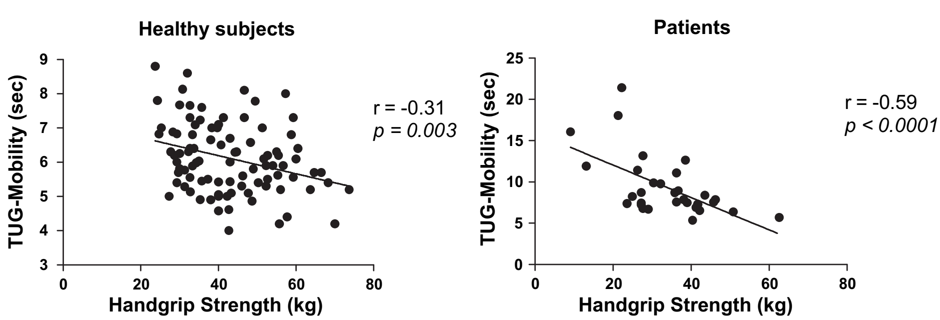

Fig. 2. Correlation between handgrip strength and mobility in healthy subjects and patients. TUG, timed up-and-go test.

Table 4
Correlation coefficients (r) among HGS, HGE, HGW, mobility, and PA in patients

	TUG (s)	$PA_{Bouchard}$	Physical component summary	Mental component summary
HGS (kg)	$-0.591^{\dagger,\S}$	NS	$0.384^{*,\ddagger}$	$0.326^{*,\S}$
$HGE_{70\%\ own\ max}$ (s)	NS	NS	NS	NS
$HGW_{70\%\ own\ max}$ ($\Omega \times$ s)	NS	NS	NS	NS
$HGE_{70\%\ std\ max}$ (s)	NS	NS	NS	NS
$HGW_{70\%\ std\ max}$ ($\Omega \times$ s)	$-0.429^{*,\ddagger}$	NS	NS	NS
TUG (s)		NS	$-0.566^{\dagger,\ddagger}$	$-0.432^{*,\S}$
$PA_{Bouchard}$			NS	NS

$HGE_{70\%\ own\ max}$, handgrip endurance at 70% of a subject's maximal force; $HGE_{70\%\ std\ max}$, handgrip endurance at 70% of a standard maximum handgrip strength; HGS, handgrip strength; $HGW_{70\%\ own\ max}$, handgrip work at 70% of a subject's maximal force; $HGW_{70\%\ std\ max}$, handgrip work at 70% of a standard maximum handgrip strength; $PA_{Bouchard}$, physical activity measured by the Bouchard activity diary; TUG, timed up-and-go test

* $P < 0.05$.

† $P < 0.001$.

‡ Spearman's rank correlation.

§ Pearson's correlation.

MCS score (38.5 versus 44.0, $P < 0.05$) compared with patients not at risk. The at-risk patients also had significantly lower HGS ($P < 0.0001$) and TUG ($P < 0.05$) after adjusting for sex by GLM. There were no differences in correlations among muscle function, mobility, and PA when adjusting for NRS or length of stay before examination by GLM.

Discussion

Handgrip strength is useful for diagnostic and monitoring purposes in the clinical setting. However, the result may be difficult for the patient and the investigator to relate to because its relation to physical function (mobility and PA) and QoL is unknown. This investigation has shown that HGS is associated with mobility in young, healthy subjects and patients. Furthermore, it was shown that HGS and mobility are related to QoL in patients. In clinical practice, recording of HGS may help to motivate patients to comply with nutritional therapy because rapid improvement may reflect improved mobility and QoL.

The healthy subjects in this study were of similar height and weight, but younger than the average Danish population [48]. HGS in the present study was in line with the range of reference values produced in the meta-analysis by Bohannon et al. [26].

The patients included were of similar weight, height, and body mass index and had a similar HGS as in a study of 287 consecutive patients with mixed medical and surgical diagnoses [49] and are therefore considered a representative sample.

HGS versus mobility

In healthy subjects, there was a negative correlation between HGS and mobility (TUG). This finding confirms observations by Samson et al. [16] who investigated the relation between HGS and ''get up and go'' (total distance 6 m) in 155 healthy men and women 20 to 90 y of age. Separate analyses of male and female data showed that HGS was significantly related to the mobility test in each gender [16]. When we analyzed male and female data separately, we did not find a relation between HGS and mobility in men. An explanation for this could be that our healthy subjects were only young individuals, and because there is a decline in mobility and strength with age, the data of Samson et al. probably had a wider span for both variables. Visser et al. [17] investigated the relation between HGS and lower-extremity performance tests including timed walking and repeated chair stands in healthy men and women 65 y and older. They found, after adjustment for age and height, that HGS was significantly associated with lower-extremity performance in men and women [17]. When adjusting HGS for body weight and height, respectively, our results for healthy subjects showed a stronger correlation between HGS and TUG for both genders combined and separately for women. This may reflect that HGS has a higher validity in relation to TUG when expressed per kilogram of body weight or height (intensive property). However, because it is the unadjusted HGS that was found to be related to clinical outcome, we decided to maintain the unadjusted format.

HGS versus PA

When analyzed for both genders combined, there was no relation between HGS and PA in healthy subjects or patients, with absolute HGS, with HGS per kilogram of body weight, or with HGS per meter. When analyzing separately for each

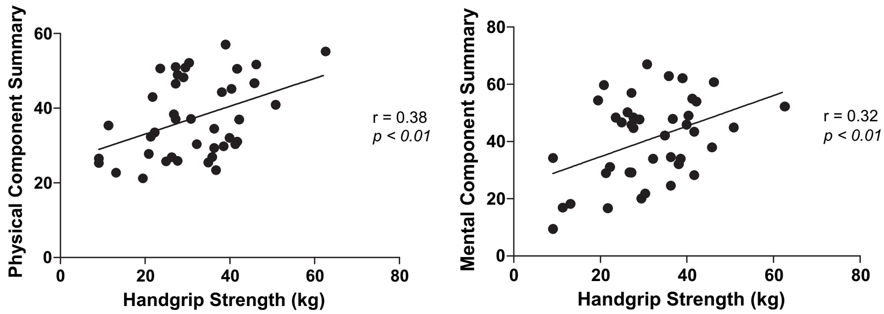

Fig. 3. Correlation between handgrip strength and quality of life in patients.

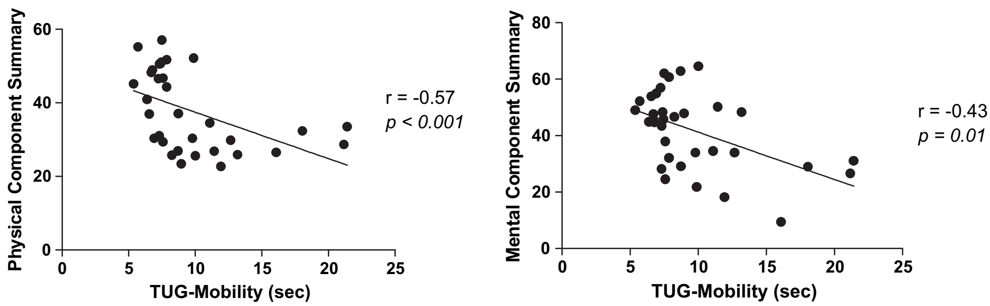

Fig. 4. Correlation between mobility and quality of life in patients. TUG, timed up-and-go test.

gender in healthy subjects, there were several significant correlations for women, but not for men, also when adjusting for body weight and height, respectively. The genders had similar Baecke indices and total scores despite different HGSs. These results probably reflect that a high HGS is not transformed into a higher PA in men with a sedentary lifestyle and that a given level of PA in women is closer to their maximum strength because of their relatively smaller muscle mass.

We replaced the Baecke questionnaire with the Bouchard activity diary in the part I study in patients to compare current PA with the other variables. Nevertheless, there was no relation with HGS when analyzed for both genders combined. When analyzing separately for each gender in the patient population, there was a weak significant correlation between HGS and PA for men but not for women. Too few patients were included to allow for an analysis of this finding. Both genders had similar PA levels despite different HGSs. It seems that the Baecke questionnaire and the Bouchard activity diaries describing prevailing activity are not strongly reflected in a challenge test such as HGS.

HGE and HGW

There were no relations between HGE and HGW (measured as 70% of own maximal force or 70% of a standard maximal force) and mobility in healthy subjects. There were also no relations between HGE and HGW (measured as 70% of a standard or own maximal force) and total PA in healthy subjects or patients. However, there were negative correlations between $HGE_{70\%\ own\ max}$ and $HGW_{70\%\ own\ max}$ and work index in healthy subjects. We had expected a positive correlation because occupational effort is sustained over much of an 8-h workday. Philippaerts et al. [37] showed a significant, but weak, positive relation between upper-body muscular endurance (measured by the bent-arm hang test) and the Baecke work index [37]. The mean value of the Baecke work index in the study by Philippaerts et al. and our study are similar. Possible explanations for this discrepancy are that the bent-arm hang test is a test of endurance at 100% maximal force and/or that the bent-arm hang test includes other muscle groups (the arm, shoulder, and dorsal muscles) than the HGE test.

A further consideration is that the procedure for measuring endurance turned out to be problematic in some individuals. Complaints were received regarding discomfort of the handle on the EFG device, and in such cases our test may reflect a pain threshold rather than fatigue. Among the healthy subjects, pain was most pronounced in subjects who could hold the handle for a long time. A study by Desrosiers et al. [50] also reported that subjects complained of pain during the endurance test using a Jamar hand dynamometer. If a painless test can be developed, HGE may prove to provide more representative information about muscle endurance and this should be considered in the future.

Difference between healthy subjects and patients

The patients had significantly lower handgrip performance tests and TUG compared with healthy subjects, even after adjusting for differences in age, height, weight, and gender. For the HGS test, the 29% decrease in patients compares well with the 26% decrease reported by Humphreys et al. [51] in a mixed group of patients hospitalized at medical and surgical wards compared with healthy subjects.

Muscle function, mobility, and QoL in patients

In patients, there was a negative correlation between HGS and mobility, which was also found in healthy subjects to a similar degree. Overall this correlation was the most consistent finding seen in healthy subjects and patients.

We found a positive relation between HGS and QoL. This is in accordance with the observations by Norman et al. [13] who investigated the effect of oral nutritional supplements on muscle function and QoL in a randomized trial. They reported that increases in HGS were significantly associated with increases in QoL, but very limited results were presented [13].

Moreover, we found negative relations between mobility and the PCS and MCS. The relations among HGS, mobility, and PCS and MCS may be interpreted as showing that patients with strong HGS experience relatively few physical limitations and therefore score a high PCS and MCS. Hence, it appears that PCS and MCS are indeed related to performance in challenges of physical function. Our results suggest that an indicator of physical function, such as HGS, provides useful information about a patient's mobility and QoL in the clinical setting. Thus, HGS could be useful in the assessment of individuals' ability to function well physically and may be useful in the monitoring of malnourished patients while being treated with nutritional therapy. Vestergaard et al. [52] found that fatigued (self-reported) men and women 65 y and older had weaker HGS, slower walking speed, and reduced mobility and activities of daily living than non-fatigued persons. because fatigue can be defined by ‘‘the awareness of a decreased capacity for physical and/or mental activity due to an imbalance in the availability, utilization, and/or restoration of resources needed to perform activity'' [52], it may be transferred to lower QoL scores in PCS and MCS. Thus, our results are compatible with this study.

Limitations of the study

There are some limitations to our study, such as the small number of patients. A study with a larger number of patients is essential to consolidate the results of this study. Because patients needed to be able to walk to perform the TUG test, the most fragile patients were excluded and this may have contributed to a selection bias. Thus, our results may not be extrapolated to bedridden patient populations. Furthermore, the finding that the patients had a lower HGS compared with the healthy population may be due to age differences, differences in gender composition, and the status as a patient. This was adjusted for in the GLM analyses, but directly comparable groups would have strengthened the observations.

Conclusion

Handgrip strength is a valid measurement of mobility and of QoL in patients. Furthermore, HGS is valid as a measurement of PA in healthy females and male patients. HGE and HGW were not found to be valid measurements of mobility and PA in healthy subjects or QoL in patients.

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