Age-related change in handgrip strength in men and women: is muscle quality a contributing factor?

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Received: 29 December 2015 / Accepted: 9 February 2016 / Published online: 13 February 2016
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Abstract Age-related changes in muscle quality and muscle mass in the forearm, which relate to decline in handgrip strength (HGS), have not been reported. The purpose of this study was to investigate the relationships between age-related declines in HGS and loss of muscle thickness and/or muscle quality in the forearm of 613 adults (306 men and 307 women) aged 20–89. Anterior forearm muscle thickness (MT-ulna) and HGS were measured using an ultrasound and a hand dynamometer, respectively, in the dominant hand. Muscle quality (fMQ) was defined as a ratio of HGS to MT-ulna. HGS was similar among younger (ages 20–29, 30–39, and 40–49) groups and was progressively lower with increasing age in both sexes. MT-ulna was similar between ages 20–29 and 60–69 in men and between ages 20–29 and 70–79 in women. In men, MT-ulna was lower in ages 70–79 and 80–89 compared with other age groups. In women, MT-ulna was lower in ages 80–89 compared with ages 20–29 and 40–49. In both men

and women, fMQ was identical among younger (ages 20–29, 30–39, and 40–49) groups. After that fMQ was progressively lower with age in both men and women. The results indicated that age-related decline in HGS is associated with fMQ, but it appears to be accelerated after the seventh decade due to muscle loss.

Keywords Aging · Grip strength · Skeletal muscle mass · B-mode ultrasound

Introduction

Age-related decline in handgrip strength (HGS) is a simple and powerful predictor of future disability (Rantanen et al. 1999; Giampaoli et al. 1999) and mortality (Rantanen et al. 2000; Metter et al. 2002; Al Snib et al. 2002; Newman et al. 2006; Sasaki et al. 2007; Ruiz et al. 2008; Koopman et al. 2015). Recently, Leong and Teo (2015) investigated the association between HGS, cause-specific mortality, and incident disease using a large sample (139,691 participants) from 17 different countries. The study found that HGS predicted not only all-cause mortality but also cardiovascular mortality, non-cardiovascular mortality, myocardial infarction, and stroke. However, important questions remain such as the mechanism explaining the inverse association between HGS and morbidity and mortality in middle-aged and older adults (Leong et al. 2015).

In the aging process, loss of muscle mass is a cause of the age-related decline in muscle strength (Kallman et al. 1990; Doherty 2003). In some cases,

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muscle strength declines at a higher rate than muscle mass (Doherty 2003; Manini and Clark 2012). Thus, an age-related decline in muscle strength/mass ratio (i.e., muscle quality) would be expected. To understand the mechanism behind the relationship between HGS and morbidity or mortality, the contribution of muscle mass and muscle quality to the age-related decline in HGS may be useful to find solutions. Similarly, loss of muscle mass and/or muscle quality may be different factors to determine the strategy for preventing the decline in HGS. To the best of our knowledge, the age-related changes in muscle quality and muscle mass in the forearm, which relate to decline in HGS, have not been reported. Recent studies showed that the HGS is strongly associated with forearm muscle size in young adults (Abe et al. 2015a) but not in older adults (Abe et al. 2014b). The purpose of this study was to investigate the relationships between age-related decline in HGS and loss of forearm muscle size and/or muscle quality in men and women.

Methods

Subjects

Six hundred thirteen (50 % women) adults between the age of 20 and 89 years were recruited through printed advertisement and by word of mouth from the university campus and surrounding area. Prior to obtaining informed consent, a written description of the purpose of the study and its safety was distributed to potential subjects. All subjects were free of overt chronic disease (e.g., myocardial infarction, cancer, stroke, and neuromuscular disorders) and were not taking any medications known to affect muscle as assessed by self-report. The rate of regular sports activity (at least once a week) among the subjects was 66 % for men (young 57 %; middle-aged 47 %; old 84 %) and 69 % for women (young 51 %; middle-aged 46 %; old 94 %). Many old men and women performed ground golf which is very popular for older populations in Japan. The study was conducted according to the World Medical Association Declaration of Helsinki and was approved by the university's institutional review board. Written informed consent was obtained from all subjects before participation.

Muscle thickness measurement and anthropometry

Forearm muscle thickness (MT) was measured using B-mode ultrasound (Aloka SSD-500, Tokyo, Japan) on the anterior forearm (at 30 % proximal between the styloid process of the ulna and the head of the radius) of the dominant hand. After limb length measurements using anatomical landmarks described earlier, a measurement site was marked with a marker pen and then limb girth was measured. The measurements were made while subjects stood quietly with the elbow extended and relaxed and the forearm supinated. A linear transducer with a 7.5-MHz scanning head was coated with water-soluble transmission gel to provide acoustic contact and reduce pressure by the scanning head to achieve a clear image. The scanning head was placed on the skin surface of the measurement site using the minimum pressure required, and cross sections of each muscle were imaged. Two images were printed (Toshiba Super Sonoprinter TP-8010, Tokyo, Japan), and mean values were used for data analysis. MT was measured as the perpendicular distance between the subcutaneous adipose tissue–muscle interface and muscle–bone interface of the ulna (MT-ulna), as described previously (Abe et al. 2014b). The distance between the two interfaces was measured with a ruler. The precision and linearity of the image reconstruction have been confirmed and are described elsewhere (Abe et al. 2014a). Test–retest reliability of MT-ulna measurements using the intra-class correlation coefficient ($ICC_{3,1}$), standard error of measurement (SEM), and the minimal difference needed to be considered real (Weir 2005) was previously determined for data from 23 young and middle-aged adults (13 men and 10 women) scanned twice 24 h apart: 0.994, 0.06 cm, and 0.17 cm, respectively.

Body mass and standing height were measured to the nearest 0.1 kg and 0.1 cm, respectively, by using an electronic weight scale and a stadiometer. Body mass index (BMI) was defined as body mass/height² (in kilogram per square meter).

Handgrip strength measurement

Maximum voluntary HGS was measured for the dominant hand with a calibrated Smedley hand dynamometer (TKK 5401 Grip-D, Takei Scientific Instruments, Tokyo, Japan). All subjects were instructed to maintain an upright standing position, arms down by the side, holding the dynamometer in the hand without

squeezing. The width of the dynamometer's handle was adjusted to the hand size of the subjects (the middle phalanx rested on the inner handle). Hand dominance was ascertained by asking each subject which hand they used to perform well-learned skills such as writing, throwing a ball, and grasping a racket. Subjects were allowed to perform one test trial, followed by two maximum trials, and the highest value was used for analysis. Test–retest reliability of HGS measurements using ICC_{3,1}, SEM, and minimal difference (see above) was previously determined for data from the same 23 young and middle-aged adults described earlier, tested twice 24 h apart: 0.975, 2.5 kg, and 7.0 kg, respectively.

Forearm muscle quality

Muscle quality in the forearm (fMQ) was defined as a ratio of HGS to MT-ulna. In the forearm, three major flexor muscles (*flexor digitorum profundus* [FDP], *flexor digitorum superficialis* [FDS], *flexor pollicis longus*) are the prime movers of the digits, and the MT-ulna mainly includes two muscles (FDP and FDS), which produce flexion movement for the middle phalanges of the fingers. Although muscle strength per unit of muscle mass or of muscle cross-sectional area (CSA) may be a better indicator to determine muscle quality, HGS is strongly associated with MT-ulna in young men and women (Abe et al. 2015a). Therefore, the MT-ulna measurement appears to serve as a viable for CSA of forearm flexor muscles.

Definition of low forearm muscle quality

Low forearm muscle quality was defined as a fMQ value of 2 standard deviations (SDs) below the mean for young men and women. Because there are no published fMQ reference values for young adults, we used a mean and SD from the current study (aged 20–29 years) for diagnostic criteria of fMQ (12.1 [1.6] kg/cm for men and 9.7 [1.3] kg/cm for women). Therefore, the reference values for fMQ (2 SD below the sex-specific means) in men and women were 8.9 and 7.1 kg/cm, respectively.

Statistical analysis

Results are expressed as mean and SD. The differences between age groups for age, height, body mass, BMI, forearm length, forearm girth, HGS, MT-ulna, and fMQ

were tested for significance by one-way analysis of variance, followed by pairwise comparisons using Tukey's multiple comparison procedure if a significant *F* test was obtained. If variances were unequal, Dunnett's C procedure was performed. Pearson product correlations were performed to determine the relationships between HGS and MT-ulna in each age group.

Results

Age-related changes in anthropometric variables

BMI was similar among all age groups in men, although young and middle-aged groups were taller and heavier compared with older groups. Forearm girth was lower in ages 80–89 compared with middle-aged groups (ages 40–49, 50–59, and 60–69) (Tables 1 and 2). In women, BMI was also similar among age groups, except two age groups; ages 30–39 were lower than ages 60–69. Similarly, forearm girth was lower in ages 30–39 compared with middle-aged groups (ages 40–49, 50–59, and 60–69).

Age-related changes in HGS, MT-Ulna, and fMQ

HGS was similar among younger (ages 20–29, 30–39, and 40–49) groups and was progressively lower with increasing age in both sexes (Tables 1 and 2). MT-ulna was similar between ages 20–29 and 60–69 in men and between ages 20–29 and 70–79 in women. In men, MT-ulna was lower in ages 70–79 and 80–89 compared with other age groups. In women, MT-ulna was lower in ages 80–89 compared with ages 20–29 and 40–49. In both men and women, fMQ was identical among younger (ages 20–29, 30–39, and 40–49) groups. After that, fMQ was progressively lower with age in both men and women.

Relationship between HGS and MT-Ulna

There were moderate correlations between HGS and MT-ulna ($r = 0.606$ [$n = 83$] and $r = 0.536$ [$n = 80$], both $p < 0.001$) in young men and women (combined ages 20–29 and 30–39). However, a weak correlation coefficient was observed between HGS and MT-ulna in middle-aged (combined ages 40–49 and 50–59) and old (combined ages >60) men ($r = 0.373$ [$n = 93$] and

Table 1 Handgrip strength (HGS) and muscle thickness (MT) in the forearm of men ($n = 306$) in each age group

	Age group (years)							<i>p</i> value
	20–29	30–39	40–49	50–59	60–69	70–79	80–89	
<i>N</i>	42	41	43	47	46	47	40	
Age (years)	23 (3) ^{bcd} efg	35 (3) ^{acdefg}	44 (3) ^{abdefg}	54 (3) ^{abcefg}	65 (3) ^{abcedfg}	75 (3) ^{abcedeg}	82 (2) ^{abcdef}	<0.001
Height (cm)	172 (5) ^{efg}	171 (6) ^{efg}	172 (5) ^{efg}	169 (6) ^{fg}	167 (5) ^{abcefg}	162 (5) ^{abcde}	161 (5) ^{abcde}	<0.001
Body mass (kg)	67.7 (13.0)	68.7 (11.1)	70.7 (9.7) ^{fg}	70.3 (11.9) ^{fg}	66.3 (8.9)	63.2 (7.4) ^{cd}	61.7 (9.6) ^{cd}	<0.001
BMI (kg/m ²)	22.9 (3.7)	23.5 (3.0)	24.1 (3.4)	24.6 (3.7)	23.9 (3.1)	24.2 (2.5)	23.9 (3.4)	0.272
Forearm length (cm)	24.3 (1.2) ^{fg}	23.9 (1.2)	24.1 (1.2) ^{fg}	23.6 (1.3)	23.7 (1.0)	23.1 (1.2) ^{ac}	23.2 (1.1) ^{ac}	<0.001
Forearm girth (cm)	25.8 (2.2)	26.0 (1.7)	26.4 (1.9) ^g	26.3 (1.6) ^g	26.1 (1.4) ^g	25.4 (1.2)	25.0 (1.5) ^{cde}	0.001
HGS (kg)	47.4 (7.3) ^{efg}	48.2 (7.1) ^{efg}	46.7 (6.6) ^{efg}	43.8 (6.7) ^{fg}	40.6 (6.7) ^{abcg}	36.7 (5.1) ^{abcedg}	33.2 (4.3) ^{abcdef}	<0.001
MT-ulna (cm)	3.94 (.30) ^{fg}	3.84 (.33) ^g	3.87 (.32) ^{fg}	3.82 (.33) ^g	3.81 (.29) ^g	3.65 (.26) ^{ac}	3.60 (.31) ^{abcde}	<0.001
HGS/MT-ulna (kg/cm)	12.1 (1.6) ^{efg}	12.5 (1.3) ^{defg}	12.1 (1.6) ^{efg}	11.5 (1.7) ^{bfg}	10.7 (1.9) ^{abcg}	10.1 (1.3) ^{abcd}	9.2 (1.0) ^{abcde}	<0.001

^aSignificant difference from age 20–29^bSignificant difference from age 30–39^cSignificant difference from age 40–49^dSignificant difference from age 50–59^eSignificant difference from age 60–69^fSignificant difference from age 70–79^gSignificant difference from age 80–89

$r = 0.378$ [$n = 133$], both $p < 0.001$) and women ($r = 0.421$ [$n = 90$] and $r = 0.369$ [$n = 137$], both $p < 0.001$).

Prevalence of low forearm muscle quality detected by fMQ

Low fMQ was not observed in men and women who were aged 50 years and younger. The numbers of participants classified with low fMQ were 2, 6, 9, and 15 in men (ages 50–59, 60–69, 70–79, and 80–89, respectively) and 5, 5, 7, and 14 in women (ages 50–59, 60–69, 70–79, and 80–89, respectively). The prevalence rate of functional impairment in ages 80–89 was 38 % for men and 33 % for women.

Discussion

The main findings of the present study were that (1) HGS was progressively lower with age after the fifth decade in both men and women, (2) lower muscle quality (fMQ) was a major contributing factor to the age-related decline in HGS in both sexes prior to the

seventh decade, and (3) HGS declines were accelerated after the seventh decade due to forearm muscle loss.

Previously, numerous cross-sectional and longitudinal studies have reported that HGS decreased gradually with increasing age in both men and women (Kallman et al. 1990; Rantanen et al. 1998; Lauretani et al. 2003; Vianna et al. 2007), although the beginning age when HGS declines differs among those studies. For instance, a study (Kallman et al. 1990) from a cross-sectional analysis of 847 subjects (age 20 to 100 years) observed a decline in HGS beginning in the sixth decade and become progressively lower at an accelerated rate, such that the ages 80–89 had 37 % less HGS than ages 30–39. In the present study, our results are consistent with the previous studies (Kallman et al. 1990; Vianna et al. 2007) that HGS declined progressively with age after the fifth decade in both sexes and that the age 80–89 group had approximately 30 % less HGS than the younger aged group in men and women.

It is well known that the age-related decline in handgrip strength (HGS) is a strong predictor of future disability (Rantanen et al. 1999; Giampaoli et al. 1999) and mortality (Rantanen et al. 2000; Metter et al. 2002; Al Snib et al. 2002; Newman et al. 2006; Sasaki et al. 2007; Ruiz et al. 2008; Koopman et al. 2015). However, the

Table 2 Handgrip strength (HGS) and muscle thickness (MT) in the forearm of women ($n = 307$) in each age group

	Age group (years)							<i>p</i> value
	20–29	30–39	40–49	50–59	60–69	70–79	80–89	
<i>N</i>	40	40	43	47	47	48	42	
Age (years)	23 (3) ^{bdefg}	35 (3) ^{acdefg}	44 (3) ^{abdefg}	54 (3) ^{abcefg}	65 (3) ^{abdefg}	74 (2) ^{abcedg}	83 (2) ^{abcdef}	<0.001
Height (m)	160 (5) ^{defg}	158 (6) ^{efg}	159 (6) ^{efg}	156 (5) ^{afg}	153 (5) ^{abcg}	150 (6) ^{abcedg}	147 (5) ^{abcdef}	<0.001
Body mass (kg)	54.6 (7.3)	51.4 (5.7) ^c	56.3 (8.7)	54.9 (10.2)	56.0 (8.0) ^b	52.5 (8.0)	52.2 (7.3)	0.023
BMI (kg/m ²)	21.4 (2.6) ^{ef}	20.6 (2.2) ^{efg}	22.3 (3.1)	22.7 (4.2)	23.9 (3.6) ^{ab}	23.1 (3.1) ^b	24.3 (3.1) ^{ab}	<0.001
Forearm length (cm)	21.9 (1.0) ^{dff}	21.9 (1.2) ^{fg}	21.7 (1.2) ^g	21.2 (1.0) ^a	21.3 (1.0)	21.1 (1.2) ^{ab}	20.9 (0.9) ^{abc}	<0.001
Forearm girth (cm)	22.8 (1.6)	21.9 (1.2) ^{cde}	23.3 (1.8) ^b	23.0 (2.0) ^b	23.2 (1.7) ^b	22.8 (2.0)	22.3 (1.6)	0.004
HGS (kg)	31.9 (5.0) ^{defg}	30.2 (3.6) ^{defg}	30.9 (4.2) ^{defg}	28.3 (5.2) ^{abcefg}	26.6 (3.6) ^{abcg}	25.8 (3.6) ^{abcedg}	22.2 (3.8) ^{abcdef}	<0.001
MT-ulna (cm)	3.28 (.27) ^g	3.10 (.20)	3.24 (.30) ^g	3.16 (.30)	3.15 (.27)	3.16 (.33)	3.03 (.25) ^{ac}	0.002
HGS/MT-ulna (kg/cm)	9.7 (1.3) ^{efg}	9.8 (1.1) ^{defg}	9.6 (1.1) ^{efg}	9.0 (1.6) ^{bfg}	8.5 (1.3) ^{abcg}	8.2 (1.1) ^{abcedg}	7.3 (1.2) ^{abcdef}	<0.001

^a Significant difference from age 20–29^b Significant difference from age 30–39^c Significant difference from age 40–49^d Significant difference from age 50–59^e Significant difference from age 60–69^f Significant difference from age 70–79^g Significant difference from age 80–89

mechanism explaining the inverse association between HGS and morbidity and mortality is not well known (Leong et al. 2015; Leong and Teo 2015). To understand the mechanism of those relationships, the contribution of muscle mass and muscle quality to the age-related decline in HGS may be useful to find solutions. Our finding showed that lower muscle quality was a major contributing factor to the age-related decline in HGS in middle-aged and older adults, and the accelerating decline of HGS after the seventh decade was associated with forearm muscle mass loss. Therefore, considering the prevalence of disability/mortality during middle-aged reported previously (Rantanen et al. 1999; Sasaki et al. 2007), low HGS caused by low fMQ might be an independent risk factor for developing those events.

In the present study, our results indicated that muscle quality detected by fMQ was similar between the third and fifth decades and after that fMQ decreased progressively with increasing age until the ninth decade. Muscle quality related to HGS has been reported by previous studies (Newman et al. 2003; Cawthon et al. 2009; Hairi et al. 2010), although the parameter of muscle size differs between the previous (arm lean mass measured by dual-energy X-ray absorptiometry (DXA)) and present (MT-ulna measured by ultrasound) studies.

For example, Cawthon et al. (2009) investigated the relationships between loss of upper (HGS) and lower (knee extension) extremity muscle strength, lean mass, and muscle quality and the risk of hospitalization in men aged 70 to 80. The muscle quality in the upper extremity was defined as the ratio of HGS to arm lean mass (arm-LM) measured by DXA. The authors reported that low muscle quality (HGS to arm-LM ratio) was associated with greater risk of hospitalization over nearly 5 years of follow-up. Other previous studies (Newman et al. 2003; Hairi et al. 2010) reported a decreasing muscle quality (HGS/arm-LM ratio) with increasing age in men aged 70 and older. These results suggest that the HGS/arm-LM ratio decreased with age during the eighth and ninth decades. Our findings are consistent with the previous studies, even if the results of the previous studies are in part the results of the present study. In addition, our resent study revealed that ultrasound-measured MT-ulna is strongly associated with DXA-measured appendicular lean mass in middle-aged and older men and women (Abe et al. 2015b). Therefore, the MT-ulna would be a similar variable to evaluate limb muscle size. From a clinical standpoint, the ultrasound is a portable alternative technique to estimate muscle quality detected by fMQ.

We found that the prevalence of low fMQ was approximately 10 % of men and women between 50 and 69 years and 20–30 % of those between 70 and 89 years. In half of the men with low fMQ, HGS was less than 30 kg, which is a cutoff point for the diagnosis of sarcopenia (Cruz-Jentoft et al. 2010). However, the other half of them had HGS >30 kg, which may be due to sufficient muscle mass in the forearm even if fMQ is low. A similar phenomenon was observed in women aged >50. Interestingly, a few old men ($n = 4$) aged >80 had low HGS, less than 30 kg, but the fMQ was similar to the mean value of younger men (>9.0 kg/cm of fMQ). This result suggests that low muscle mass is a major reason for decreasing HGS in the old men described above and they were well-conditioned (Short Physical Performance Battery, >10 points). Several studies (Rantanen et al. 1998; Luna-Heredia et al. 2005) have shown that anthropometric variables (e.g., height) are directly correlated to HGS because those variables are closely related to muscle mass. On an individual basis, measuring not only HGS but also fMQ may be useful for evaluating the age-related change in physical function and performance.

Our results support the previous studies (Abe et al. 2014b, 2015a) that a relationship between HGS and MT-ulna was stronger in young men and women ($r = 0.606$ and $r = 0.536$, respectively) than in middle-aged and older men and women ($r = 0.369$ to $r = 0.421$). Varied fMQ in the middle-aged and older men and women may help to explain the weaker correlation coefficients found between HGS and MT-ulna. On the other hand, it is unknown whether ultrasound-measured MT-ulna is a surrogate for physiological muscle CSA of the forearm flexor muscles, especially with differences in age and sex. Additional research is needed to address these issues.

In conclusion, our results demonstrated that HGS was progressively lower with age after the fifth decade in both men and women. In both sexes, MT-ulna and muscle quality detected by fMQ were similar between the third and fifth decades and after that fMQ decreased progressively with increasing age until the ninth decade. Decline in HGS was accelerated after the seventh decade due to forearm muscle loss. Thus, decreasing muscle quality is a major contributing factor to the age-related decline in HGS in middle-aged and older adults.

Acknowledgments Our appreciation is extended to the men and women who participated in this study. We also thank Akemi Abe for her assistance in the testing of this study.

Compliance with ethical standards This study was partly supported by the Japanese Society of Wellness & Preventive Medicine funded research (TA). Takashi Abe, Robert Thiebaud and Jeremy Loenneke declare that they have no conflicts of interest relevant to the content of this manuscript.

References

- Abe T, Loenneke JP, Thiebaud RS, Loftin M (2014a) Morphological and functional relationships with ultrasound measured muscle thickness of the upper extremity and trunk. *Ultrasound* 22:229–235
- Abe T, Thiebaud RS, Loenneke JP, Ogawa M, Mitsukawa N (2014b) Association between forearm muscle thickness and age-related loss of skeletal muscle mass, handgrip and knee extension strength and walking performance in old men and women: a pilot study. *Ultrasound Med Biol* 40:2069–2075
- Abe T, Counts BR, Barnett BE, Dankel SJ, Lee K, Loenneke JP (2015a) Associations between handgrip strength and ultrasound-measured muscle thickness of the hand and forearm in young men and women. *Ultrasound Med Biol* 41: 2125–2130
- Abe T, Thiebaud RS, Loenneke JP, Young KC (2015b) Prediction and validation of DXA-derived appendicular lean soft tissue mass by ultrasound in older adults. *Age (Dordr)* 37:114
- Al Snib S, Markides KS, Ray L, Ostir GV, Goodwin JS (2002) Handgrip strength and mortality in older Mexican Americans. *J Am Geriatr Soc* 50:1250–1256
- Cawthon PM, Fox KM, Gandra SR, Delmonica MJ, Chiu CF, Anthony MS, Sewall A, Goodpaster B, Satterfield S, Cummings SR, Harris TB (2009) Do muscle mass, muscle density, strength, and physical function similar influence risk of hospitalization in older adults? *J Am Geriatr Soc* 57:1411–1419
- Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinkova E, Vandewoude M, Zamboni M, European Working Group on Sarcopenia in Older People (2010) Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing* 39:412–423
- Doherty TJ (2003) Invited review: aging and sarcopenia. *J Appl Physiol* 95:1717–1727
- Leong DP, Teo KK, Rangarajan S, Lopez-Jaramillo P, Avezumi Jr A, Orlandini A, Seron P, Ahmed SH, Rosengren A, Kelishadi R, Rahman O, Swaninathan S, Iqbal R, Gupta R, SA L, Oguz A, Yusoff K, Zatonska K, Chifamba J, Igumbor E, Mohan V, Anjana RM, Gu H, Li W, Yusuf S, Prospective Urban Rural Epidemiology (PURE) Study Investigators (2015) Prognostic value of grip strength: findings from the prospective urban rural epidemiology (PURE) study. *Lancet* 386: 266–273
- Giampaoli S, Ferrucci L, Cecchi F, Lo Noce C, Poce A, Dima F, Santaquilani A, Vescio MF, Menotti A (1999) Hand-grip

- strength predicts incident disability in non-disabled older men. *Age Ageing* 28:283–288
- Hairi NN, Cumming RG, Naganathan V, Handelsman DJ, Le Couteur DG, Creasey H, Waite LM, Seibel MJ, Sambrook PN (2010) Loss of muscle strength, mass (sarcopenia) and quality (specific force) and its relationship with functional limitation and physical disability: the Concord health and ageing in Men Project. *J Am Geriatr Soc* 58:2055–2062
- Kallman DA, Plato CC, Tobin JD (1990) The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitude perspectives. *J Gerontol* 45:M82–M88
- Koopman JJ, van Bodegom D, van Heemst D, Westendorp RG (2015) Handgrip strength, ageing and mortality in rural Africa. *Age Ageing* 44:465–470
- Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, Corsi AM, Rantanen T, Guralnik JM, Ferrucci L (2003) Age-associated changes in skeletal muscle and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol* 95:1851–1860
- Leong DP, Teo KK (2015) Predicting cardiovascular disease from handgrip strength: the potential clinical implications. *Expert Rev Cardiovasc Ther* 13:1277–1279
- Luna-Heredia E, Martin-Pena G, Ruiz-Galiana J (2005) Handgrip dynamometry in healthy adults. *Clin Nutr* 24:250–258
- Manini TM, Clark BC (2012) Dynapenia and aging: an update. *J Gerontol A Biol Sci Med Sci* 67:28–40
- Metter EJ, Talbot LA, Schrager M, Conwit R (2002) Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *J Gerontol A Biol Sci Med Sci* 57:B359–B365
- Newman AB, Haggerty CL, Goodpaster B, Harris T, Kritchevsky S, Nevitt M, Miles TP, Visser M (2003) Strength and muscle quality in well-functioning cohort of older adults: the health, aging and body composition study. *J Am Geriatr Soc* 51:323–330
- Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB, Tyllavsky FA, Rubin SM, Harris TB (2006) Strength, but not muscle mass, is associated with mortality in health, aging and body composition study cohort. *J Gerontol A Biol Sci Med Sci* 61:72–77
- Rantanen T, Masaki K, Foley D, Izmirlian G, White L, Guralnik JM (1998) Grip strength changes over 27 yr in Japanese-American men. *J Appl Physiol* 85:2047–2053
- Rantanen T, Guralnik JM, Foley D, Masaki K, Leveille S, Gurb JD, White L (1999) Midlife hand grip strength as a predictor of old age disability. *JAMA* 281:558–560
- Rantanen T, Harris T, Leveille SG, Visser M, Foley D, Masaki K, Guralnik JM (2000) Muscle strength and body mass index as long-term predictors of mortality in initially healthy men. *J Gerontol A Biol Sci Med Sci* 55:M168–M173
- Ruiz JR, Sui X, Lobelo F, Morrow JR Jr, Jackson AW, Sjostrom M, Blair SN (2008) Association between muscular strength and mortality in men: prospective cohort study. *BMJ* 337:a439
- Sasaki H, Kasagi F, Yamada M, Fujita S (2007) Grip strength predicts cause-specific mortality in middle-aged and elderly persons. *Am J Med* 120:337–342
- Vianna LC, Oliveira RB, Araujo CG (2007) Age-related decline in handgrip strength differs according to gender. *J Strength Cond Res* 21:1310–1314
- Weir JP (2005) Quantifying test-retest reliability using the intraclass correlation coefficient and SEM. *J Strength Cond Res* 19:231–240