December 2016

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ORIGINAL ARTICLE

Journal of Cachexia, Sarcopenia and Muscle 2016; **7**: 535–546
Published online 12 April 2016 in Wiley Online Library (wileyonlinelibrary.com) **DOI:** 10.1002/jcsm.12112

Reference ranges of handgrip strength from 125,462 healthy adults in 21 countries: a prospective urban rural epidemiologic (PURE) study

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Abstract

Background The measurement of handgrip strength (HGS) has prognostic value with respect to all-cause mortality, cardiovascular mortality and cardiovascular disease, and is an important part of the evaluation of frailty. Published reference ranges for HGS are mostly derived from Caucasian populations in high-income countries. There is a paucity of information on normative HGS values in non-Caucasian populations from low- or middle-income countries. The objective of this study was to develop reference HGS ranges for healthy adults from a broad range of ethnicities and socioeconomically diverse geographic regions.

Methods HGS was measured using a Jamar dynamometer in 125,462 healthy adults aged 35-70 years from 21 countries in the Prospective Urban Rural Epidemiology (PURE) study.

Results HGS values differed among individuals from different geographic regions. HGS values were highest among those from Europe/North America, lowest among those from South Asia, South East Asia and Africa, and intermediate among those from China, South America, and the Middle East. Reference ranges stratified by geographic region, age, and sex are presented. These ranges varied from a median (25th–75th percentile) 50 kg (43–56 kg) in men <40 years from Europe/North America to 18 kg (14–20 kg) in women >60 years from South East Asia. Reference ranges by ethnicity and body-mass index are also reported.

Conclusions Individual HGS measurements should be interpreted using region/ethnic-specific reference ranges.

Keywords handgrip strength; muscle strength; reference range; normative range; reference value

Received: 26 August 2015; Revised: 16 January 2016; Accepted: 14 February 2016
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Introduction

There is convincing evidence to indicate that handgrip strength (HGS) is of prognostic importance in the general population[1–6] and in those with existing disease.[7] HGS has prognostic value with respect to all-cause mortality,[3,5,6,8,9] cardiovascular mortality,[5,10] and cardiovascular disease (CVD).[5] independently of recognised confounding factors, including dietary habits, physical activity, and socioeconomic status. Weak HGS is also associated with high case-fatality rates in individuals who develop any of a range of major illnesses,[5] suggesting that low muscle strength may be an important indicator of vulnerability to disease and of frailty. Moreover, HGS is rapid and simple to measure, and is inexpensive. It is therefore appealing as a tool to stratify an individual's risk of developing CVD, or of susceptibility to death from an incident illness. HGS correlates closely with measures of muscle strength from other muscle groups, including the lower limbs.[11,12] Its prognostic value, the simplicity of measurement with minimal training, portability, and low cost make it an attractive clinical test to evaluate an individual's overall health in clinical or epidemiologic settings. HGS evaluation is a core part of the clinical evaluation of frailty.[13] HGS measurement is not, however, in widespread use as a risk-stratifying tool.

The lack of globally applicable reference ranges for HGS may account at least in part for its failure to be adopted clinically. Reference ranges for HGS have been reported in a number of studies, however the large majority of these studies have been undertaken in convenience samples of individuals of predominantly European ethnicity and in high-income countries.[14–21] There is a paucity of normative, population-derived data on HGS, particularly from non-Caucasian populations in low- to middle-income countries.[8,22,23] Given that HGS represents the product of age, general health, and comorbid conditions, an understanding of what constitutes "normal" HGS in different ethnic groups and geographic regions is important. Therefore, the objective of this study was to develop reference HGS ranges for healthy adults from a broad range of ethnicities and socioeconomically diverse geographic regions.

The Prospective Urban Rural Epidemiology (PURE) study is a prospective cohort study of in excess of 160,000 community-based adults from 21 low-, middle- and high-income countries.[24] The present study is an analysis of the 125,462 healthy PURE participants from these 21 countries who had HGS measured.

Methods

Study design and participants

The design of the PURE study have been described previously.[24] In brief, participating countries were selected to represent significant socioeconomic heterogeneity. For reasons of feasibility, proportionate sampling of all countries worldwide, or of

Table 1. Participant characteristics stratified by geographic region. Displayed are median (25th–75th percentile) values, mean ± standard deviation values, or column percentages

	Europe/North America		South America		Middle East		Africa
Characteristic	Women	Men	Women	Men	Women	Men	Women
N	9362	7221	12,163	7704	4241	3901	3022
Age, years	51 (44–58)	52 (44–59)	50 (43–58)	50 (43–59)	45 (39–52)	46 (40–53)	49 (41–57)
Rural location	29	30	41	49	43	39	53
Education							
Primary	22	18	58	61	59	35	71
Secondary	28	28	26	22	30	38	28
Post-secondary	50	54	16	17	11	27	1
Employed	68	74	60	70	46	83	10
Physical activity							
Low	8	10	10	15	24	28	16
Medium	39	34	35	29	54	36	38
High	53	56	55	56	22	36	46
Tobacco use							
Former	27	35	16	30	<1	12	2
Current	14	23	19	25	<1	30	22
Never	59	42	65	45	99	58	76
Alcohol use							
Former	5	7	6	12	0	2	3
Current	60	72	33	62	0	1	19
Never	35	21	61	26	100	97	78
Daily caloric intake, kcal	1941 (1513–2481)	2379 (1852–3004)	2026 (1561–2562)	2216 (1723–2824)	2099 (1622–2677)	2332 (1879–2887)	1848 (1337–2646)
Percentage of caloric intake from protein	16.5 ± 2.8	16.3 ± 2.7	16.9 ± 3.5	16.4 ± 3.4	17.1 ± 2.4	17.2 ± 2.2	13.6 ± 3.0
Height, cm	161 ± 7.2	175 ± 7.8	156 ± 7.0	169 ± 7.6	156 ± 6.2	170 ± 6.9	157 ± 6.6
Weight, kg	72 ± 15	85 ± 15	69 ± 15	78 ± 17	71 ± 15	78 ± 15	70 ± 20
Waist circumference, cm	85 ± 13	95 ± 12	89 ± 13	94 ± 12	89 ± 13	91 ± 12	85 ± 15
Body-mass index, kg/m^2	27.7 ± 6.04	27.7 ± 5.60	28.2 ± 5.85	27.5 ± 5.04	29.3 ± 5.76	27.0 ± 4.82	28.3 ± 7.69

regions within countries, was not undertaken. Countries selected included Canada, Saudi Arabia, Sweden, United Arab Emirates (high-income countries), Argentina, Brazil, Chile, China, Colombia, Iran, Malaysia, Poland, South Africa, Turkey, Philippines (middle-income countries), Bangladesh, India, Pakistan, Palestine, Tanzania, and Zimbabwe (low-income countries). Within both urban and rural communities in each country, households were selected to achieve representative sampling within the community. pecific methods used to approach households may have varied according to country context. For example, in low-income settings, a community announcement may be made through a community leader, followed by door-to-door visits. In high-income settings, initial approaches may have been made by telephone. Guidelines for the selection of countries, communities, households, and individuals to participate are presented in the Appendix, Table 5. Household members were invited to participate if aged 35-70 years.

Procedures

Trained study personnel administered a standardised set of questions to participants. These questions elicited self-reported ethnicity, demographics, cardiovascular risk factors, co-morbid conditions, education status, employment status, physical activity levels, tobacco and alcohol use, and dietary patterns. Study personnel also measured participant anthropometrics (height, weight, and waist circumference). Education was classified as up to secondary school, secondary school, and university/trade school.

HGS was measured using a Jamar dynamometer (Sammons Preston, Bolingbrook, IL, USA) according to a standardised protocol.[25] The arm was positioned at the side of the body and the dynanometer held with elbow flexed to 90^0. The participant was asked to squeeze the device as hard as possible for 3 seconds. The measurement was repeated twice more at intervals of at least 30 seconds. For the first study participants, three measurements were made from the participant's non-dominant hand. During the course of the study, the protocol was amended so that three measurements were made from both hands of each participant. For the present analysis, we used only the maximum values obtained from each hand. Overall HGS was then calculated as the mean of non-dominant and dominant hand HGS.[5] To permit estimation of overall HGS in participants where values were missing for one hand but present for the other hand, we imputed values for the missing hand using the coefficient and constant from the linear regression of non-dominant and dominant hand HGS.[5] We also present reference ranges where HGS is the maximum value obtained from both hands (Appendix).[26]

The PURE study was approved by the appropriate research ethics committees and has been performed in

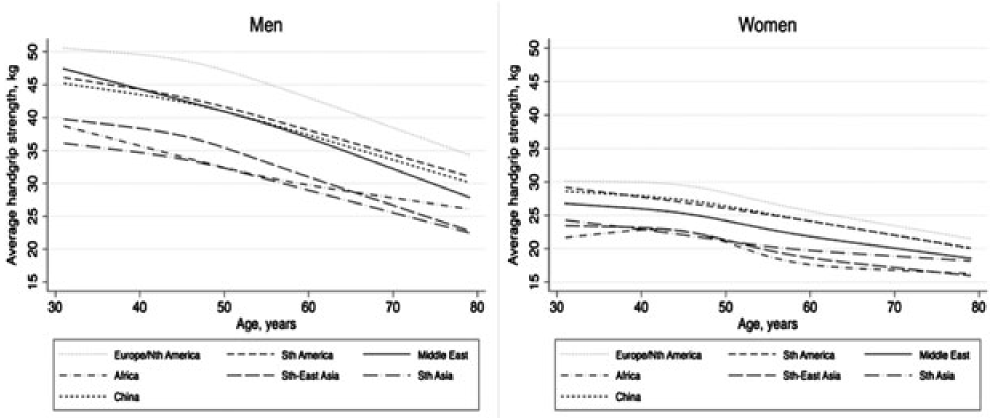
Table 1. (Continued)

Characteristic	Africa	South East Asia		South Asia		China	
	Men	Women	Men	Women	Men	Women	Men
N	1282	6002	4097	14,729	10,976	23,884	16,878
Age, years	50 (42–58)	49 (42–57)	52 (44–59)	45 (38–54)	47 (40–56)	50 (42–57)	51 (42–58)
Rural location	52	55	55	54	53	51	54
Education							
Primary	69	39	37	60	44	37	27
Secondary	29	44	43	31	39	50	56
Post-secondary	2	17	20	9	17	13	17
Employed	14	42	71	50	82	53	68
Physical activity							
Low	15	14	20	17	20	13	19
Medium	33	43	34	39	27	44	39
High	52	43	46	44	53	43	42
Tobacco use							
Former	9	2	18	<1	8	<1	9
Current	47	3	32	9	44	3	52
Never	44	95	50	91	48	97	39
Alcohol use							
Former	9	2	5	<1	5	1	6
Current	50	5	10	<1	22	5	46
Never	41	93	85	99	73	94	48
Daily caloric intake, kcal	1925 (1365–2708)	2462 (1661–3417)	2535 (1745–3674)	1869 (1468–2477)	2164 (1643–2880)	1784 (1423–2198)	2125 (1704–2621)
Percentage of caloric intake from protein	13.2 ± 3.1	16.7 ± 3.4	16.6 ± 3.4	11.5 ± 1.9	11.5 ± 2.0	15.5 ± 2.8	14.8 ± 2.9
Height, cm	167 ± 7.2	152 ± 6.4	163 ± 6.9	153 ± 6.6	165 ± 7.2	156 ± 5.8	167 ± 6.5
Weight, kg	62 ± 15	62 ± 14	69 ± 15	54 ± 13	60 ± 14	60 ± 11	69 ± 12
Waist circumference, cm	79 ± 11	83 ± 12	89 ± 12	75 ± 13	79 ± 13	79 ± 10	83 ± 10
Body-mass index, kg/m^2	22.0 ± 5.34	26.4 ± 5.42	25.8±4.77	23.2±5.33	22.1±4.44	24.6±4.07	24.4±3.83

Table 2. Median (25th–75th percentile) handgrip strength (HGS) in kg, stratified by age, sex, and region

Region	Hand	Age 35-40 years		Age 41-50 years		Age 51-60 years		Age 61-70 years	
		Women	Men	Women	Men	Women	Men	Women	Men
Europe/North America	Average	30 (26–35) n = 1332	50 (43–56) n = 897	30 (25–34) n = 3195	49 (42–56) n = 2365	27 (23–31) n = 3110	46 (39–52) n = 2512	25 (21–29) n = 1725	42 (36–47) n = 1447
	Dominant hand	31 (26–36) n = 1332	51 (44–58) n = 896	30 (26–35) n = 3190	50 (43–57) n = 2363	28 (24–32) n = 3100	47 (40–54) n = 2509	26 (22–30) n = 1721	42 (36–48) n = 1445
	Non-dominant hand	29 (24–34) n = 1329	48 (41–55) n = 896	29 (24–33) n = 3182	48 (42–54) n = 2358	26 (22–30) n = 3091	45 (38–51) n = 2504	24 (20–28) n = 1713	40 (34–46) n = 1434
South America	Average	29 (23–33) n = 2222	45 (39–52) n = 1321	27 (21–31) n = 4152	43 (37–50) n = 2662	25 (21–29) n = 3645	41 (33–46) n = 2196	23 (19–27) n = 2144	37 (31–42) n = 1525
	Dominant hand	32 (28–36) n = 353	50 (43–55) n = 283	31 (28–35) n = 816	46 (41–52) n = 661	29 (26–32) n = 809	45 (40–50) n = 619	27 (24–30) n = 398	41 (36–46) n = 387
	Non-dominant hand	27 (22–32) n = 2218	44 (38–50) n = 1318	26 (20–30) n = 4142	42 (36–49) n = 2657	24 (20–29) n = 3637	40 (32–45) n = 2190	22 (18–26) n = 2140	36 (30–40) n = 1524
Middle East	Average	26 (22–30) n = 1372	45 (40–51) n = 1042	25 (22–29) n = 1625	43 (38–48) n = 1646	23 (20–27) n = 886	40 (35–46) n = 791	21 (18–24) n = 358	35 (31–40) n = 422
	Dominant hand	27 (22–30) n = 1349	46 (40–52) n = 1032	26 (22–30) n = 1594	44 (38–49) n = 1635	24 (20–28) n = 873	41 (36–46) n = 790	22 (18–25) n = 347	36 (31–40) n = 418
	Non-dominant hand	25 (21–29) n = 1369	44 (38–50) n = 1040	25 (20–29) n = 1615	42 (36–48) n = 1632	23 (20–26) n = 881	40 (34–45) n = 789	20 (18–24) n = 353	34 (30–40) n = 419
Africa	Average	21 (13–30) n = 705	37 (26–44) n = 255	24 (14–30) n = 985	38 (26–44) n = 393	20 (11–27) n = 844	32 (22–41) n = 386	18 (10–25) n = 488	30 (21–38) n = 248
	Dominant hand	21 (13–30) n = 689	38 (28–46) n = 248	24 (14–30) n = 926	38 (24–44) n = 383	19 (11–26) n = 779	32 (21–40) n = 352	18 (10–25) n = 471	30 (21–39) n = 236
	Non-dominant hand	21 (13–30) n = 674	36 (26–44) n = 249	23 (14–30) n = 945	36 (26–44) n = 385	20 (11–26) n = 770	32 (21–40) n = 377	20 (11–24) n = 425	30 (20–38) n = 243
South East Asia	Average	23 (19–27) n = 1091	40 (34–44) n = 562	22 (19–26) n = 2234	37 (32–42) n = 1320	20 (17–23) n = 1739	33 (29–38) n = 1331	18 (14–21) n = 938	29 (24–33) n = 884
	Dominant hand	24 (20–28) n = 1091	40 (34–46) n = 561	24 (20–28) n = 2232	38 (33–44) n = 1320	21 (18–24) n = 1735	34 (30–40) n = 1330	18 (15–22) n = 937	30 (24–34) n = 883
	Non-dominant hand	22 (18–26) n = 1089	38 (32–42) n = 560	22 (18–25) n = 2226	36 (30–40) n = 1316	19 (16–22) n = 1716	32 (28–37) n = 1321	18 (14–20) n = 902	28 (22–32) n = 877
South Asia	Average	23 (19–27) n = 5662	35 (31–41) n = 3279	21 (18–25) n = 4729	33 (29–39) n = 3593	19 (16–23) n = 2833	31 (25–35) n = 2505	19 (15–23) n = 1505	27 (22–32) n = 1599
	Dominant hand	22 (18–26) n = 1502	36 (30–42) n = 910	21 (17–24) n = 1403	33 (28–40) n = 1036	20 (16–22) n = 839	32 (25–37) n = 727	19 (14–22) n = 435	28 (22–34) n = 455
	Non-dominant hand	22 (18–26) n = 5652	34 (30–40) n = 3269	20 (17–24) n = 4711	32 (28–38) n = 3587	18 (15–22) n = 2815	30 (24–34) n = 2503	18 (14–22) n = 1495	26 (21–30) n = 1594
China	Average	28 (24–32) n = 4774	45 (40–50) n = 3197	28 (23–32) n = 7773	43 (37–48) n = 5153	26 (22–29) n = 7749	40 (34–45) n = 5363	23 (20–27) n = 3588	36 (31–41) n = 3165
	Dominant hand	30 (25–33) n = 4774	46 (40–52) n = 3196	28 (24–32) n = 7771	44 (38–50) n = 5150	26 (22–30) n = 7747	41 (35–46) n = 5360	24 (20–28) n = 3585	37 (32–42) n = 3162
	Non-dominant hand	27 (23–31) n = 4757	43 (38–48) n = 3191	26 (22–30) n = 7743	41 (36–47) n = 5131	25 (20–29) n = 7691	39 (33–44) n = 5347	22 (18–26) n = 3551	35 (30–40) n = 3150

Figure 1 Average handgrip strength as a function of age. Nth = North; Sth = South.



accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments, and also in accordance with relevant national laws governing human research ethics.

Statistical analysis

For the present analysis, because we sought to describe reference ranges among healthy individuals, participants were not included if HGS was not measured in either hand, sex was not recorded, or if the participant had a history of cancer, chronic obstructive pulmonary disease, tuberculosis, Chagas disease, human immunodeficiency virus, stroke, coronary artery disease, heart failure, or diabetes. Countries were grouped to permit adequate participant numbers for stratified analyses. Canada, Sweden, Poland, and Turkey were considered Europe/North America; Argentina, Brazil, Colombia, and Chile were considered South America; United Arab Emirates, Saudi Arabia, Iran, and Palestine were considered Middle East; South Africa, Tanzania, and Zimbabwe were considered Africa; Malaysia and Philippines were considered South East Asia; Pakistan, India, and Bangladesh were considered South Asia; and China was analysed individually. Within each region, the median (25^{th}–75^{th} percentile) HGS was calculated stratified by age (35–40 years, 41–50 years, 51–60 years, and 61–70 years) and sex. The reference range is considered the 25^{th}-75^{th} percentile of HGS within each stratum. The analysis was repeated stratifying by ethnicity and by body-mass index. The expected HGS as a function of age, stratified by country and sex, was estimated by restricted cubic spline regression with four knots. We performed sensitivity analyses excluding participants who reported difficulty using their fingers to grasp or handle.

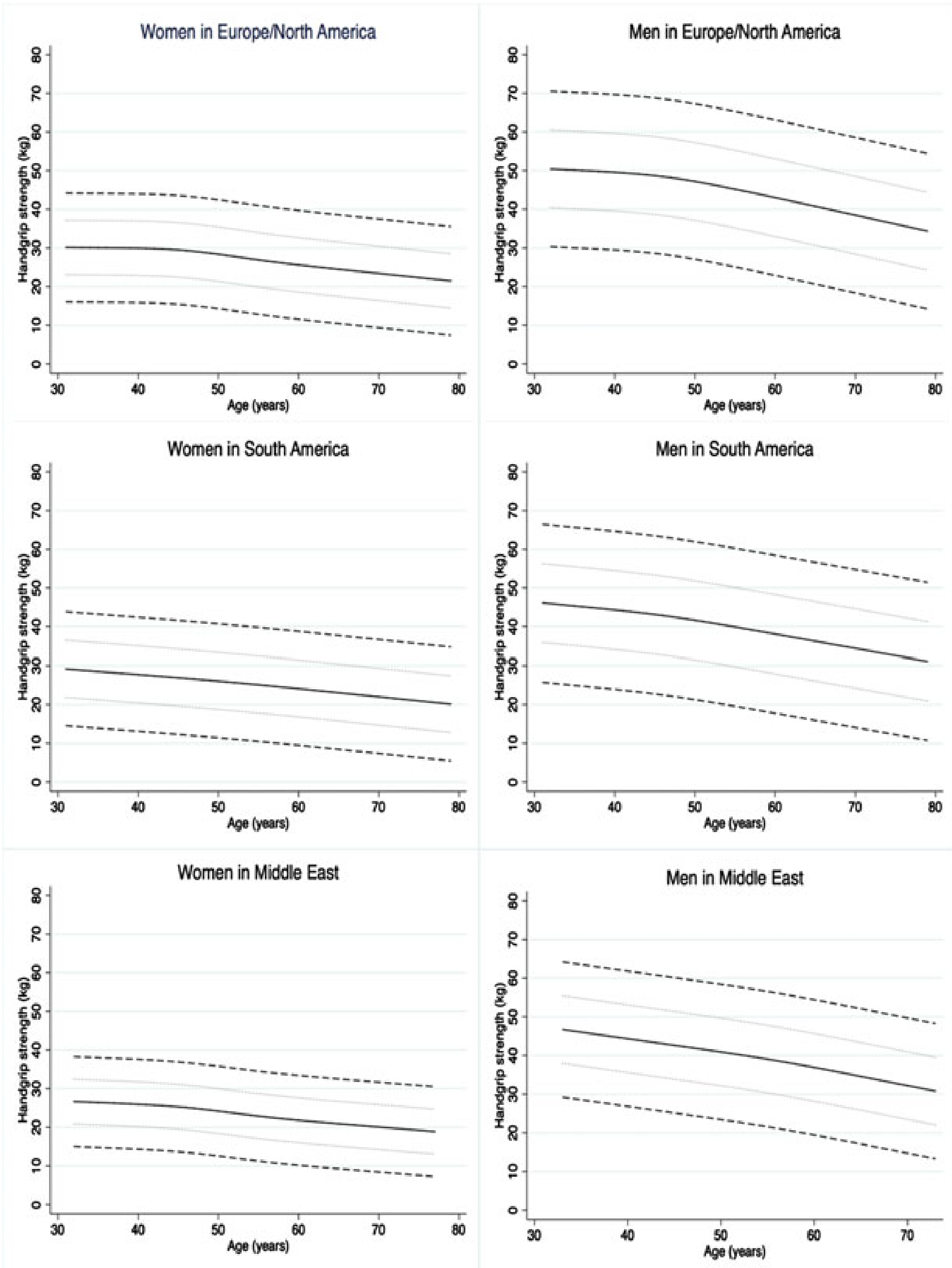
Results

The proportion of those eligible for the PURE study that provided consent was 78%. Of 189,990 individuals who did consent to participate, 31,109 had a history of an illness that necessitated exclusion from this analysis. A further 33,419 participants were not included in this analysis because HGS was not measured. Therefore the present study is based on 125,462 individuals. Participant characteristics are displayed in Table 1. Education levels were highest in Europe/North America and lowest in Africa. Men had higher employment rates than women, and employment rates were lowest in Africa. Physical activity levels were lowest in the Middle East, and were also low in South East Asia and China. Dietary caloric intake was lowest in Africa, and the percentage of caloric intake from protein was lowest in South Asia, followed by Africa. Europeans were on average tallest, heaviest, and exhibited the largest waist circumference.

HGS reference ranges by geographic region, age stratum, and sex are presented in Table 2. HGS among men exceeded HGS in women, and there was a progressive decline in HGS with increasing age. Within each age and sex stratum, up to 33% variation in median HGS values was observed among the different regions. Highest HGS values were found in Europe/North America, and lowest values in Africa, South Asia, and Southeast Asia. Average HGS stratified as a function of age, stratified by sex and geographic region is displayed in Figure 1. Expected HGS together with 95% confidence limits as a function of age, stratified by sex and country are displayed in Figure 2. HGS reference ranges by ethnicity, age stratum, and sex are presented in the Table 3. The observed values of HGS in each ethnic group reflected the geographic region where the ethnic group predominates.

DOI: 10.1002/jcsm.12112

Figure 2 Estimated handgrip strength (solid line) as a function of age. The dotted curves represent ±1 standard deviation, and the dashed curves represent ±2 standard deviations.



The median, 25th and 75th percentiles for HGS stratified by sex, age, geographic region, and body-mass index are presented in the Appendix Table 6. For this analysis, age was dichotomized to ≤50 years and >50 years, and body-mass index was categorized as underweight (body-mass index <18.5 kg/m^2), healthy weight (body-mass index 18.5 to <25 kg/m^2), overweight (body-mass index 25 to <30 kg/m^2), and obese (body-mass index ≥30 kg/m^2). This analysis suggests a positive association between HGS and body-mass index, although the relationship was less pronounced or even reversed in obese individuals.

Repeating the main analysis after excluding participants who reported difficulty using their fingers to grasp or handle did not substantially change the medians, 25th and 75th percentile values in each stratum (findings not presented).

Table 3. Median (25^{th}–75^{th} percentile) overall handgrip strength (in kg) stratified by age, sex, and ethnicity

	Age 35-40 years		Age 41-50 years		Age 51-60 years		Age 61-70 years	
Ethnicity	Women	Men	Women	Men	Women	Men	Women	Men
South Asian	23 (19–27) n = 5723	35 (31–41) n = 3326	21 (18–25) n = 4833	34 (29–39) n = 3674	19 (16–23) n = 2900	31 (25–35) n = 2569	19 (15–23) n = 1533	27 (22–32) n = 1630
Chinese	28 (24–32) n = 4716	45 (40–50) n = 3175	28 (23–32) n = 7854	43 (37–48) n = 5174	26 (22–29) n = 7832	40 (34–45) n = 5416	23 (20–27) n = 3604	36 (31–41) n = 3181
Malaysian	23 (19–27) n = 1021	40 (34–45) n = 518	23 (19–26) n = 2073	37 (32–42) n = 1214	20 (17–24) n = 1629	33 (29–38) n = 1236	18 (14–21) n = 891	29 (24–34) n = 841
Persian	27 (23–31) n = 781	47 (42–52) n = 601	26 (22–30) n = 1025	44 (38–49) n = 1068	24 (20–27) n = 611	40 (36–46) n = 551	22 (19–25) n = 256	35 (31–41) n = 290
Arab	24 (21–29) n = 597	43 (37–48) n = 450	25 (21–29) n = 621	42 (37–47) n = 621	23 (20–27) n = 290	40 (34–45) n = 263	20 (17–23) n = 106	34 (30–38) n = 138
African	22 (13–31) n = 733	38 (27–45) n = 268	24 (14–30) n = 1040	38 (26–44) n = 420	20 (11–27) n = 914	33 (23–41) n = 428	18 (10–25) n = 535	31 (22–38) n = 280
European	30 (26–35) n = 1066	50 (43–56) n = 694	30 (25–35) n = 2456	49 (42–56) n = 1761	28 (23–32) n = 2364	46 (40–52) n = 1849	25 (21–29) n = 1344	41 (35–47) n = 1112
Latin American	29 (23–33) n = 2143	45 (39–52) n = 1287	27 (22–31) n = 3999	43 (37–50) n = 2591	25 (21–30) n = 3504	41 (34–46) n = 2111	23 (19–27) n=2025	37 (31–42) n=1447

Table 4. Representative studies reporting reference ranges for handgrip strength among healthy adults or adults from the general population

Study	Population	n	Age range (years)	Dynamometer	Hand
Frederiksen *et al*.[15]	Danes; general population	8342	45–102	Smedley (TTM; Tokyo, Japan)	Maximal value from both
Tveter *et al*.[16]	Norwegians; volunteers from work places, schools, community centres	370	18–90	–	Average from both
Vaz *et al*.[23]	Indians; university students and faculty	1024	5–67	Harpenden (CMS Weighing Equipment, London, UK); Smedley (TTM, Tokyo, Japan)	Non–dominant
Mathiowetz *et al*.[14]	Americans; volunteers from shopping centres, a rehabilitation centre, a university	628	20–75	Jamar (Jackson, MI, USA)	Both
Ribom *et al*.[17]	Swedish men; general population	999	70–80	Jamar (Jackson, MI, USA)	Maximal value from both
Massy–Westropp *et al*.[18]	Australian; general population	2678	>20	Jamar	Both
Schlüssel *et al*.[22]	Brazil; general population	3050	>20	Jamar (Sammons–Preston, Korea)	Maximal value from both
Lauretani *et al*.[19]	Italy; general population	1030	>20	–	–
Günther *et al*.[20]	Germany; volunteers from workplaces, retirement homes	769	20–95	NexGen (Ergonomics Inc, Quebec, Canada)	Average of each hand
Snih *et al*.[8]	Mexican Americans in southern states; general population	2488	≥65 years	Jamar (J.A.Preston Corp., Clifton, NJ, USA)	Dominant hand
Kenny *et al*.[21]	Irish; general population	5819	≥50 years	Baseline (Fabrication Enterprises Inc., White Plains, NY, USA)	Maximum value from both

Discussion

This study has reported reference ranges for HGS derived from healthy community-dwelling adults aged 35-70 years in 21 countries of all income strata. The key finding from this analysis is that median HGS differs among the geographic regions and ethnic groups studied. Therefore individual HGS measurements should be interpreted using region/ethnic-specific reference ranges.

Interpretation of HGS measurement

Numerous studies have reported reference ranges for HGS measurement (Table 4). These studies have each involved populations from single countries, and have employed different approaches to measuring and reporting HGS ranges. The large majority of reports are from high-income countries, and from populations of predominantly European ethnicity. There is a paucity of data from low-income countries, despite the fact that HGS measurement as an inexpensive risk-stratifying test may be best suited to these resource-challenged settings.

The values of HGS observed in Europe and North America, and South America in the present study are similar to those reported in other studies of individuals from European countries,[15] the US,[14] and Brazil[22] respectively. This finding confirms the reproducibility of HGS measurement from an epidemiologic perspective, and provides face validity to the PURE data. **Our** study extends on existing literature to report reference ranges for HGS from seven geographic regions around the world, many of which have not previously been studied. We found considerable heterogeneity in median HGS among healthy adults from these different regions. This finding is an important one because we have previously reported that HGS is predictive of mortality and CVD independently of country income.[5] The present study will allow the measurement of an individual's HGS to be placed into their regional context.

Ethnic variations in muscle strength

Our findings are consistent with previous work that demonstrates variations in skeletal muscle mass from individuals of different ethnicities.[27] Taken together, these findings raise the hypothesis that genetically mediated ethnic differences in muscle strength exist. In addition, variations in muscle strength between people from different countries may be attributed in part to differences in socio-economic status. In a Spanish study of 1785 adolescents, a modest association between socio-economic status and muscle strength was observed.[28] A more profound difference in socio-economic status (in absolute terms) among participants from countries of contrasting income may therefore be expected to be associated with a larger differences in HGS. It is also likely that differences in muscle strength among diferent countries reflects variation in dietary patterns. There is a well-recognized association between dietary protein intake, which varies among different countries, and muscle strength.[29]

Remaining uncertainties

While we have speculated about potential reasons for the differences in HGS among different countries and ethnicities, the nature of these differences has not been resolved. It is also uncertain which reference range is best applied to individuals who migrate from one country to another, or who are from an ethnic minority within a particular country. These uncertainties are related to a lack of understanding of what constitute the most important determinants of muscle strength, whether ethnic and genetic factors are more important than environmental factors, and what duration and extent of exposure to environmental influences is needed to cause change in an individual's physical characteristics. While it is likely that differences in dietary quality and physical activity levels, as examples of environmental determinants of HGS, account at least in part for the variation in HGS observed among different regions, we do not present reference ranges adjusted for these factors because in a given individual, it is difficult to interpret their observed HGS when compared with the expected HGS of an individual with a globally average diet and physical activity level.

Limitations

Individuals over the age of 70 years and younger than 35 years were not included, so this study is unable to report reference ranges for HGS outside this range. Eligible individuals who declined to participate in PURE, or in whom HGS was not measured, and individuals whose HGS may have been influenced by musculoskeletal diseases of the hand, may have introduced bias or errors.

Conclusion

The expected HGS measurement for an individual of a given age and sex varies according to their geographic region and/or ethnicity. HGS measurements should be interpreted with awareness of such contextual factors. Further research is needed to evaluate possible determinants of muscle strenth in order to understand the factors that underlie the differences in muscle strength among different healthy populations.

Acknowledgements

Dr. Leong is supported by the E.J. Moran Campbell Department of Medicine Internal Career Award, McMaster University. Dr. Yusuf is funded by the Marion Burke Chair of the Heart and Stroke foundation of Canada. Dr. AlHabib is supported by the Deanship of Scientific Research at King Saud University, Riyadh, Saudi Arabia (Research group number: RG -1436-013). The authors certify that they comply with the ethical guidelines for authorship and publishing of the Journal of Cachexia, Sarcopenia and Muscle.[30]

Conflict of interest statement

Darryl P. Leong; Koon K. Teo; Sumathy Rangarajan; V. Raman Kutty; Fernando Lanas; Chen Hui; Xiang Quanyong; Qian Zhenzhen; Tang Jinhua; Ismail Noorhassim; Khalid F AlHabib; Sarah J. Moss; Annika Rosengren; Ayse Arzu Akalin; Omar Rahman; Jephat Chifamba; Andrés Orlandini; Rajesh Kumar; Karen Yeates; Rajeev Gupta; Afzalhussein Yusufali; Antonio Dans; Álvaro Avezum; Patricio Lopez-Jaramillo; Paul Poirier; Hosein Heidari; Katarzyna Zatonska; Romaina Iqbal; Rasha Khatib; and Salim Yusuf declare that they have no conflict of interest.

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Appendix

Table A1. Guidelines for the selection of countries, communities, households and individuals recruited in PURE

Countries
1. HIC, MIC and LIC, with the bulk of the recruitment from low- and middle-income regions.
2. Committed local investigators with experience in recruiting for population studies.

Communities
1. Select both urban and rural communities. Use the national definition of the country to determine urban and rural communities.
2. Select rural communities that are isolated (distance of >50 km or lack easy access to commuter transportation) from urban centers. However, consider ability to process bloods samples, eg, villages in rural developing countries should be within 45-min drive of an appropriate facility.
3. Define community to a geographical area, eg, using postal codes, catchment area of health service/clinics, census tracts, areas bordered by specific streets or natural borders such as a river bank.
4. Consider feasibility for long-term follow-up, eg, for urban communities, choose sites that have a stable population such as residential colonies related to specific work sites in developing countries. In rural areas, choose villages that have a stable population. Villages at greater distance from urban centers are less susceptible to large migration to urban centers.
5. Enlist a community organization to facilitate contact with the community, eg, in urban areas, large employers (government and private), insurance companies, club, religious organizations, clinic or hospital service regions. In rural areas, local authorities such as priests or community elders, hospital or clinic, village leader, or local politician.

Individual
1. Broadly representative sampling of adults 35 to 70 years within each community unit.
2. Consider feasibility for long-term follow-up when formulating community sampling framework, eg, small percentage random samples of large communities may be more difficult to follow-up because they are dispersed by distance. In rural areas of developing countries that are not connected by telephone, it may be better to sample entire community (ie, door-to-door systematic sampling).
3. The method of approach of households/individuals may differ between sites. In MIC and HIC, followed up by phone contact may be the practical first means of contact. In LIC, direct household contact through household visits may be the most appropriate means of first contact.
4. Once recruited, all individuals are invited to a study clinic to complete standardized questionnaires and have a standardized set of measurements.

DOI: 10.1002/jcsm.12112

Table A2. Median (25th-75th percentile) overall handgrip strength stratified by sex, age, body-mass index, and geographic region

Women

SE = Southeast. Underweight = body-mass index (BMI) <18.5kg/m^2; healthy weight = BMI 18.5 to <25kg/m^2; overweight = BMI 25 to <30kg/m^2; obese = BMI≥30kg/m^2.

	≤50 years				>50 years			
Region	Underweight	Healthy weight	Overweight	Obese	Underweight	Healthy weight	Overweight	Obese
Europe/ North America	28 (24-32) n=56	31 (26-35) n=1911	30 (26-34) n=1307	29 (24-34) n=1230	25 (19-31) n=39	27 (23-31) n=1601	27 (22-30) n=1740	26 (21-30) n=1438
South America	25 (20-31) n=75	27 (23-31) n=2140	27 (21-31) n=2294	28 (22-33) n=1803	22 (19-27) n=66	23 (20-28) n=1508	23 (20-29) n=2139	24 (20-29) n=2011
Middle East	23 (20-25) n=35	25 (22-29) n=629	26 (22-30) n=1183	25 (22-30) n=1134	21 (18-24) n=14	21 (18-25) n=215	23 (20-26) n=495	23 (20-27) n=508
Africa	23 (19-27) n=96	25 (16-30) n=546	23 (13-30) n=413	20 (12-30) n=605	21 (13-27) n=93	22 (12-27) n=410	20 (10-27) n=330	15 (10-25) n=474
SE Asia	21 (18-25) n=126	22 (19-26) n=1246	23 (19-27) n=1169	24 (20-28) n=750	17 (13-20) n=120	19 (15-22) n=2046	20 (16-23) n=982	19 (16-23) n=547
South Asia	21 (18-25) n=2096	23 (19-27) n=4621	23 (19-27) n=2591	23 (19-27) n=1010	18 (14-21) n=820	19 (15-23) n=2046	20 (17-25) n=1020	21 (17-25) n=426
China	26 (21-29) n=304	28 (23-31) n=7510	29 (24-33) n=3882	29 (25-33) n=791	21 (17-25) n=350	24 (21-28) n=5792	26 (22-30) n=4199	25 (21-30) n=960

Men

	≤50 years				>50 years			
Region	Underweight	Healthy weight	Overweight	Obese	Underweight	Healthy weight	Overweight	Obese
Europe/ North America	32 (26-41) n=10	48 (41-54) n=951	49 (43-56) n=1544	50 (44-58) n=739	33 (29-47) n=9	43 (38-49) n=1007	45 (38-51) n=1938	44 (38-51) n=994
South America	37 (33-43) n= 33	41 (35-47) n=1255	45 (39-51) n=1720	46 (40-52) n=928	33 (30-39) n=48	36 (31-42) n=1081	40 (33-45) n=1584	41 (34-47) n=975
Middle East	38 (35-41) n=47	43 (38-49) n=876	44 (39-50) n=1144	44 (38-49) n=603	34 (31-39) n=24	37 (32-42) n=399	39 (34-45) n=504	39 (34-46) n=278
Africa	35 (29-42) n=146	38 (26-44) n=396	36 (22-48) n=68	29 (15-45) n=30	31 (26-36) n=121	32 (22-41) n=363	34 (20-45) n=88	27 (17-36) n=48
SE Asia	34 (28-38) n=51	36 (31-41) n=760	39 (34-44) n=747	39 (33-44) n=299	28 (21-32) n=105	31 (25-36) n=972	32 (28-38) n=789	33 (29-39) n=328
South Asia	31 (27-37) n=1481	35 (30-39) n=3600	36 (31-41) n=1474	37 (29-41) n=265	25 (21-31) n=1040	30 (25-35) n=2115	32 (27-37) n=742	31 (25-37) n=181
China	39 (34-44) n=190	42 (37-48) n=4597	45 (40-51) n=2980	46 (40-51) n=539	33 (28-39) n=298	38 (32-43) n=4790	40 (34-45) n=2980	40 (34-46) n=433