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

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### Introduction

There is convincing evidence to indicate that handgrip strength (HGS) is of prognostic importance in the general population and in those with existing disease. HGS has prognostic value with respect to all-cause mortality, cardiovascular mortality, and cardiovascular disease (CVD) 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, 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. 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. 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. There is a paucity of normative, population-derived data on HGS, particularly from non-Caucasian populations in low- to middle-income countries. 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. 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. In brief, participating countries were selected to represent significant socioeconomic heterogeneity. For reasons of feasibility, proportionate sampling of all countries worldwide, or of

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

| Characteristic | Europe/North America | South America | Middle East | Africa |
|----------------|----------------------|---------------|-------------|--------|
|                | Women | Men | Women | Men | Women | Men | Women | Men | Women | Men |
| N              | 9362  | 7221 | 12,163 | 7704 | 4241  | 3901 | 3022  | 49  |
| Age, years     | (44–58) | (44–59) | (43–58) | (43–59) | (39–52) | (40–53) | (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 | 8 | 10 | 10 | 15 | 24 | 28 | 16 |
| Low            | 39 | 34 | 35 | 29 | 54 | 36 | 38 |
| Medium         | 53 | 56 | 55 | 56 | 22 | 36 | 46 |
| High           | 8 | 10 | 10 | 15 | 24 | 28 | 16 |
| Tobacco use    | 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    | 5 | 7 | 6 | 12 | 0 | 2 | 3 |
| Former         | 60 | 72 | 33 | 62 | 0 | 1 | 19 |
| Current        | 35 | 21 | 61 | 26 | 100 | 97 | 78 |
| Never          | 1941 | 2379 | 2026 | 2216 | 2099 | 2332 | 1848 |
| Daily caloric intake, kcal | (1513–2481) | (1852–3004) | (1561–2562) | (1723–2824) | (1622–2677) | (1879–2887) | (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     | 156 ± 7.2 | 156 ± 7.0 | 156 ± 7.0 | 160 ± 7.6 | 156 ± 6.2 | 170 ± 6.9 | 157 ± 6.6 |
| Weight, kg     | 82 ± 15 | 85 ± 15 | 85 ± 15 | 89 ± 15 | 78 ± 17 | 71 ± 15 | 81 ± 15 |
| Waist circumference, cm | 85 ± 13 | 95 ± 12 | 89 ± 13 | 94 ± 12 | 89 ± 13 | 91 ± 12 | 85 ± 15 |
| Body-mass index, kg/m² | 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. Specific 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. The arm was positioned at the side of the body and the dynamometer held with elbow flexed to 90°. 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. 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.

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

| Characteristic          | Africa | South East Asia | South Asia | China |
|-------------------------|--------|-----------------|------------|-------|
|                         | 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) | (42-57) | (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   | 9     | 46    |
| Never                   | 41     | 93              | 85         | 99    | 73   | 94    | 48    |
| Daily caloric intake, kcal | 1925 (1365–2078) | 2462 (1661–3417) | 2535 (1745–3674) | 1869 (1468–2487) | 2164 (1643–2880) | 2178 (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/m²  | 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 1. (Continued)
| Region                        | Age 35-40 years | Age 41-50 years | Age 51-60 years | Age 61-70 years |
|------------------------------|-----------------|-----------------|-----------------|-----------------|
|                              | Women | Men   | Women | Men   | Women | Men   | Women | Men   | Women | Men   | Women | Men   |
| Europe/North America         |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 30 (26–35) | 50 (43–56) | 30 (25–34) | 49 (42–56) | 27 (23–31) | 46 (39–52) | 25 (21–29) | 42 (36–47) |       |       |       |       |
| Dominant hand                | n = 1332 | n = 897 | n = 3195 | n = 2365 | n = 3110 | n = 2512 | n = 1725 | n = 1447 |       |       |       |       |
| Non-dominant hand            | n = 1332 | n = 896 | n = 3190 | n = 2363 | n = 3100 | n = 2509 | n = 1721 | n = 1445 |       |       |       |       |
| South America                |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 29 (24–34) | 48 (41–55) | 29 (24–33) | 48 (42–54) | 26 (22–30) | 45 (38–51) | 24 (20–28) | 40 (34–46) |       |       |       |       |
| Dominant hand                | n = 1329 | n = 896 | n = 3182 | n = 2358 | n = 3091 | n = 2504 | n = 1713 | n = 1434 |       |       |       |       |
| Non-dominant hand            | n = 2222 | n = 1321 | n = 4152 | n = 2662 | n = 3645 | n = 2196 | n = 2144 | n = 1525 |       |       |       |       |
| Middle East                  |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 26 (22–30) | 45 (40–51) | 25 (22–29) | 43 (38–48) | 23 (20–27) | 40 (35–46) | 21 (18–24) | 35 (31–40) |       |       |       |       |
| Dominant hand                | n = 1372 | n = 1042 | n = 1625 | n = 1646 | n = 886 | n = 791 | n = 358 | n = 422 |       |       |       |       |
| Non-dominant hand            | n = 705 | n = 255 | n = 985 | n = 393 | n = 844 | n = 386 | n = 488 | n = 248 |       |       |       |       |
| Africa                       |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 21 (13–30) | 37 (26–44) | 24 (14–30) | 38 (26–44) | 20 (11–27) | 32 (22–41) | 18 (10–25) | 30 (21–38) |       |       |       |       |
| Dominant hand                | n = 970 | n = 255 | n = 985 | n = 393 | n = 844 | n = 386 | n = 488 | n = 248 |       |       |       |       |
| Non-dominant hand            | n = 689 | n = 248 | n = 926 | n = 383 | n = 779 | n = 352 | n = 471 | n = 236 |       |       |       |       |
| South East Asia              |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 23 (19–27) | 40 (34–44) | 22 (19–26) | 37 (32–42) | 20 (17–23) | 33 (29–38) | 18 (14–21) | 29 (24–33) |       |       |       |       |
| Dominant hand                | n = 1091 | n = 562 | n = 2234 | n = 1320 | n = 1739 | n = 1331 | n = 938 | n = 884 |       |       |       |       |
| Non-dominant hand            | n = 1091 | n = 561 | n = 2232 | n = 1320 | n = 1735 | n = 1330 | n = 937 | n = 883 |       |       |       |       |
| South Asia                   |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 23 (19–27) | 35 (31–41) | 21 (18–25) | 33 (29–39) | 19 (16–23) | 31 (25–35) | 19 (15–23) | 27 (22–32) |       |       |       |       |
| Dominant hand                | n = 5662 | n = 3279 | n = 4729 | n = 3593 | n = 2833 | n = 2505 | n = 1505 | n = 1599 |       |       |       |       |
| Non-dominant hand            | n = 1502 | n = 910 | n = 1403 | n = 1036 | n = 839 | n = 727 | n = 435 | n = 455 |       |       |       |       |
| China                        |       |       |       |       |       |       |       |       |       |       |       |       |
| Average                      | 28 (24–32) | 45 (40–50) | 28 (23–32) | 43 (37–48) | 26 (22–29) | 40 (34–45) | 23 (20–27) | 36 (31–41) |       |       |       |       |
| Dominant hand                | n = 4774 | n = 3197 | n = 7773 | n = 5153 | n = 7749 | n = 5363 | n = 3588 | n = 3165 |       |       |       |       |
| Non-dominant hand            | n = 4774 | n = 3196 | n = 7771 | n = 5150 | n = 7747 | n = 5360 | n = 3585 | n = 3162 |       |       |       |       |

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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 (25th–75th 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 25th–75th 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.
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/m²), healthy weight (body-mass index 18.5 to <25 kg/m²), overweight (body-mass index 25 to <30 kg/m²), and obese (body-mass index ≥30 kg/m²). 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 (25th–75th percentile) overall handgrip strength (in kg) stratified by age, sex, and ethnicity

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

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

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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 strength in order to understand the factors that underlie the differences in muscle strength among different healthy populations.

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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; Rajjeev Gupta; Afzalhussein Yusufali; Antonio Dans; Álvaro Avezum; Patricio Lopez-Jaramillo; Paul Poirier; Hosein Heidari; Katarzyna Zatonska; Romaina Iqbal; Rashan 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 blood 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. |
Table A2. Median (25th-75th percentile) overall handgrip strength stratified by sex, age, body-mass index, and geographic region

| Region          | ≤50 years |       |       |       |       | ≥50 years |       |       |       |       |
|-----------------|-----------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|
|                 | Underweight | Healthy weight | Overweight | Obese |       | Underweight | Healthy weight | Overweight | Obese |       |
| European/North  | 28 (24-32) | 31 (26-35) | 30 (26-34) | 29 (24-34) |       | 25 (19-31) | 27 (23-31) | 27 (22-30) | 26 (21-30) |       |
| Americas        | n=56      | n=1911 | n=1307 | n=1230 |       | n=39      | n=1601 | n=1740 | n=1438 |       |
| South America   | 25 (20-31) | 27 (23-31) | 27 (21-31) | 28 (22-33) |       | 22 (19-27) | 23 (20-28) | 23 (20-29) | 24 (20-29) |       |
| n=75            | n=2140    | n=2294 | n=1803 |       | n=66      | n=1508 | n=2139 | n=2011 |       |
| Middle East     | 23 (20-25) | 25 (22-29) | 26 (22-30) | 25 (22-30) |       | 21 (18-24) | 21 (18-25) | 23 (20-26) | 23 (20-27) |       |
| n=35            | n=629     | n=1183 | n=1134 |       | n=14      | n=215  | n=495  | n=508  |       |
| Africa          | 23 (19-27) | 25 (16-30) | 23 (13-30) | 20 (12-30) |       | 21 (13-27) | 22 (12-27) | 20 (10-27) | 15 (10-25) |       |
| n=96            | n=546     | n=413  | n=605  |       | n=93      | n=410  | n=330  | n=474  |       |
| SE Asia         | 21 (18-25) | 22 (19-26) | 23 (19-27) | 24 (20-28) |       | 17 (13-20) | 19 (15-22) | 20 (16-23) | 19 (16-23) |       |
| n=126           | n=1246    | n=1149 | n=750  |       | n=120     | n=2046 | n=982  | n=547  |       |
| South Asia      | 21 (18-25) | 23 (19-27) | 23 (19-27) | 23 (19-27) |       | 18 (14-21) | 19 (15-23) | 20 (17-25) | 21 (17-25) |       |
| n=2096          | n=4621    | n=2591 | n=1010 |       | n=820     | n=2046 | n=1020 | n=426  |       |
| China           | 26 (21-29) | 28 (23-31) | 29 (24-33) | 29 (25-33) |       | 21 (17-25) | 24 (21-28) | 26 (22-30) | 25 (21-30) |       |
| n=304           | n=7510    | n=3882 | n=791  |       | n=350     | n=5792 | n=4199 | n=960  |       |

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