**Prevalence of sarcopenia and relationships between muscle and bone in Indian men and women**

Ayse Zengin1\*, Bharati Kulkarni2, Anuradha V Khadilkar3, Neha Kajale3, Veena Ekbote3, Nikhil Tandon4, Santosh K Bhargava5, Harshpal Singh Sachdev6, Shikha Sinha6, David Scott1,7, Sanjay Kinra8, Caroline HD Fall9, Peter R Ebeling1

1Department of Medicine, School of Clinical Sciences, Faculty of Medicine, Nursing and Health Sciences, Monash University, Monash Medical Centre, Clayton, Victoria, Australia

2Clinical Division, National Institute of Nutrition, Jamai Osmania PO, Hyderabad, India

3Hirabai Cowasji Jehangir Medical Research Institute, Pune, India.

4Department of Endocrinology and Metabolism, All India Institute of Medical Sciences, New Delhi, India

5Department of Paediatrics, Sunder Lal Jain Hospital, New Delhi, India.

6Department of Paediatrics, Sitaram Bhartia Institute of Science and Research, New Delhi, India

7Department of Medicine and Australian Institute of Musculoskeletal Science, Melbourne Medical School – Western Campus, The University of Melbourne, St Albans, Victoria, Australia

8Department of Non-Communicable Disease Epidemiology, London School of Hygiene & Tropical Medicine, London, UK,

9MRC Lifecourse Epidemiology Unit, University of Southampton, Southampton General Hospital, Southampton, UK

**Corresponding Author:**

Dr Ayse Zengin

Department of Medicine, School of Clinical Sciences

Monash University

Level 5/Block E, Monash Medical Centre

246 Clayton Road, Clayton VIC 3168, Australia

T: +61 3 8572 2918

E: [ayse.zengin@monash.edu](mailto:ayse.zengin@monash.edu)

**Declarations**

**Funding:** This work was supported by the Australian Academy of Sciences, Australia-India Early and Mid-Career Fellowships (AZ). The third survey wave of APCAPS was funded by Wellcome Trust Strategic Award (084774). IMS was funded by the Wellcome Trust project grant (GR070797MF). NDBC was funded by the Indian Council of Medical Research, British Heart Foundation, the Wellcome Trust UK, the Medical Research Council UK, the National Institute for Health Research Nutrition and Metabolism Biomedical Research Unit, University of Southampton and the National Institute for Health Research Musculoskeletal Biomedical Research Unit, University of Oxford.

**Conflicts of interest:** all authors declare no conflicts of interest

**Ethics approval:** all studies received ethics approval, please see Methods for further details.

**Author contributions:** AZ, BK, AVK, NK, VE, NT, SKB, HSS, SS, SK, CHDF and PRE designed and conducted the study; AZ, BK, NK, SS, DS and PRE analysed the data; AZ, BK, AVK, NK, VE, NT, SKB, HSS, SS, SK, DS, CHDF and PRE interpreted the data; AZ, BK, AVK, NK, VE, NT, SKB, HSS, SS, SK, DS, CHDF and PRE prepared the manuscript and are responsible for the final content. All authors read and approved the final manuscript.

**Abstract**

**Background:** Both ethnicity and age are important determinants of musculoskeletal health. We aimed to determine the prevalence of sarcopenia, assess the suitability of current diagnostic guidelines, and explore muscle-bone relationships in adults from India.

**Methods:** 1009 young (20-35years) and 1755 older (>40years) men and women from existing studies were collated and pooled for the analysis. Dual-energy x-ray absorptiometry measured areal bone mineral density (aBMD) at the hip and spine, and fat and lean mass; hand dynamometer measured hand grip strength (HGS). Indian-specific cut-points for appendicular lean mass (ALM), ALM index (ALMI) and HGS were calculated from young Indian (-2SD mean) populations. Sarcopenia was defined using cut-points from The Foundations for the National Institutes of Health (FNIH), revised European Working Group on Sarcopenia in Older People (EWGSOP2), Asian Working Group for Sarcopenia (AWGS), and Indian-specific cut-points. Low lean mass cut-points were then compared for their predictive ability in identifying low HGS. The relationship between muscle variables (ALM, ALMI, HGS) and aBMD were explored, and sex differences were tested.

**Results:** Indian-specific cut-points (men-HGS:22.93kg, ALM:15.41kg, ALMI:6.03kg/m2; women-HGS:10.76kg, ALM:9.95kg, ALMI:4.64kg/m2) were lower than existing definitions. The Indian-specific definition had the lowest, while EWGSOP2 ALMI had the highest predictive ability in detecting low HGS (men:AUC=0.686, women:AUC=0.641). There were sex differences in associations between aBMD and all muscle variables, with greater positive associations in women than in men.

**Conclusion:** The use of appropriate cut-points for diagnosing low lean mass and physical function are necessary in ethnic populations for accurate sarcopenia assessment. Muscle-bone relationships are more tightly coupled during ageing in Indian women than men.

**Keywords:** India, hand grip strength, ethnicity, sarcopenia, muscle strength, bone mineral density

**Introduction**

Musculoskeletal disease (e.g. osteoporosis and sarcopenia) is a major contributor to the global non-communicable disease (NCD) burden [1], particularly in low-middle income countries (LMICs) as they are currently undergoing a rapid demographic transition and exponential growth of older populations [2,3]. Sarcopenia is characterized by a progressive loss of muscle mass and muscle strength, and increases the risk of adverse outcomes such as frailty, falls, fractures and mortality – all of which affect activities of daily living. The most widely used definitions of sarcopenia are from the Foundation for the National Institutes of Health (FNIH) and the revised European Working Group on Sarcopenia in Older People (EWGSOP2), and include cut-points for appendicular lean mass (ALM), appendicular lean mass index (ALMI) and functional ability (hand grip strength, HGS) [4,5]. More recently, the Asian Working Group for Sarcopenia (AWGS) was formed to assess the suitability of existing sarcopenia definitions for diagnosis of populations from Southeast Asian countries, namely China, Hong Kong, Japan, South Korea, Malaysia, Taiwan and Thailand [6].

Studies have shown that the FNIH and EWGSOP2 definitions, primarily developed in Caucasians, potentially underestimate the prevalence of sarcopenia in different ethnic populations [7,8]. This is most likely due to the ethnic differences in body habitus, as fat mass, lean mass, height and weight are different between ethnic groups [9-11]. To delineate the suitability of sarcopenia definitions in Black South African women, ALM and ALMI cut-points were derived from two young Black South African reference groups aged 18-40 years [7]. Findings from this study showed that the definitions that best predicted low functional ability (low gait speed and low HGS) in older Black women were the specific South African cut-points and the FNIH ALM criterion [7]. Across ethnic populations, there are also differences in the age at which the decline in lean mass and muscle strength begins. For example, a study in Afro-Caribbean men reported that HGS declines started at 50 years of age [12], while this decline was reported at 40 years of age in Caucasian US men [13]. Together, these studies highlight the importance of considering ethnicity in determining the prevalence of sarcopenia and its impact on functional outcomes.

There are differences in body composition in ethnic populations which may influence muscle-bone relationships due to the effects of lean mass on mechanical loading. A study in Southeast Asian men showed that Malays had higher areal bone mineral density (aBMD) at the radius compared with Chinese men for the same amount of lean mass [14]. Additionally, a meta-analysis showed the contribution of lean mass on aBMD in Southeast Asians was more pronounced than in Caucasians [15]. There has been one study from India in women aged 18-76 years which reported positive correlations between lean mass and aBMD at the radius and total hip following adjustments for age and body size [16]. There are no studies investigating the associations of muscle strength, lean mass and aBMD in Indian men and women.

Data on lean mass and muscle strength from South Asian populations are limited; there are scarce data from India, a country which currently has one third of world’s population aged ≥60 years with continuing exponential growth in this population [17]. Therefore, we aimed to identify the prevalence of sarcopenia estimated by different definitions (FNIH, EWGSOP2, AWGS, 2SDs below a young Indian reference population), and whether there are differences in the predictive ability of low lean mass cut-points between definitions for discriminating poor functional capacity in Indian men and women. The age-onset of HGS and ALM decline were determined, and sex differences examined. Muscle-bone relationships were assessed using muscle variables (ALM, ALMI and HGS), and aBMD at the hip and spine.

**Study Design**

**Pooled data from cohort studies**

To capture India’s demographic, economic, health, cultural and culinary diversity, data were collated from existing cohort studies from different regions of India. Dual energy x-ray absorptiometry (DXA) variables and HGS data were analysed from each study. Appendicular lean mass (ALM) was calculated as the sum of lean mass in arms and legs (kg), and ALMI was calculated as ALM divided by height squared (kg/m2).

**New Delhi Birth Cohort (NDBC)**

The NDBC was established in 1969 to investigate pregnancy outcomes and child growth [18]. Briefly, all families living in a 12km2 area of South Delhi were identified, and 20,755 women of reproductive age were followed up bimonthly; in total there were 9,169 pregnancies, resulting in 8,181 live births. The current study used data from the second phase of measurements during 2006–2009. The All India Institute of Medical Sciences approved the ethics for the study, which was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from each participant. Participants were selected for DXA scans based on the completeness of their weight and height record in early life. In total, 565 participants underwent DXA scans at the All India Institute of Medical Sciences, New Delhi (Hologic QDR 4500A, Waltham, MA, USA). From the 565 participants, only those aged 20-35 years were included in the current analyses; additional exclusions were made due to major medical events (stroke=1, tuberculosis=12, bypass surgery=1 and taking insulin for diabetes=1) and a BMI <18.5 and >26.0 (n=110); the final group size of 90 participants were included in the “young Indian” group. The *in vivo* precision error was 0.62% for femoral neck aBMD and 0.65% for lumbar spine aBMD [19]. HGS was measured in each arm three times using a hand dynamometer (Grip D, Takei, Tokyo, Japan). Force (kg) was recorded and the maximum value was used in the analysis.

**Andhra Pradesh Children and Parents Study (APCAPS)**

APCAPS was originally established to study the long-term effects of early-life under-nutrition on risks of cardiovascular disease [20]. Children and their mothers were followed-up in 2003 – 2005; the children were followed-up again as young adults aged 18–21 years in 2009 – 2010. Ethical approval for the study was obtained from the ethics committee of the National Institute of Nutrition, Hyderabad, and the study was performed in accordance with the Declaration of Helsinki; each participant gave informed consent. A whole-body DXA scan was performed on each participant (Hologic, Discovery A, Waltham, MA, USA); the coefficient of variation (CV) was less than 1% for the whole body lean mass measurement. Total hip and lumbar spine aBMD were measured. HGS was measured in each arm four times using a hand dynamometer (78010, Lafayette Instrument Company, Lafayette, IN, USA). Force (kg) was recorded and the maximum value was used in the analysis. Participants who did not have any chronic diseases and who had a BMI of 18.5-25.9 were included in the current analysis. Those who were aged 20 – 35 years were included in the “young Indian” group (n=790), and those who were >45 years were included in the “older Indian” group (n=1293).

**Indian Migration Study (IMS)**

The IMS was established to investigate whether rural to urban migrants in India have a higher prevalence of obesity and diabetes than rural non-migrants [21,22]. Study participants comprised rural to urban migrants and their spouses recruited from four factories in India (Lucknow, Hindustan Aeronautics Ltd.; Nagpur, Indorama Synthetics Ltd.; Hyderabad, Bharat Heavy Electricals Ltd.; and Bangalore, Hindustan Machine Tools Ltd.) and their siblings who remained in a rural area. The original fieldwork for the IMS was conducted between 2005 and 2007, during which time 1995 participants were examined in Hyderabad [21,22]. All 1995 participants of the Hyderabad arm of the IMS were invited to attend a clinic visit at the National Institute of Nutrition between January 2009 and December 2010. Ethics approval was obtained from the All India Institute of Medical Sciences Ethics Committee, and the ethics committees of the National Institute of Nutrition, India and the London School of Hygiene & Tropical Medicine, UK. The study was performed in accordance with the Declaration of Helsinki; each participant gave informed consent. Participants underwent whole body DXA scans (Hologic Discovery A, Waltham, MA, USA), the CV was <1% for the whole body lean mass measurement. Total hip and lumbar spine aBMD were measured. HGS was measured separately three times in each arm using a hand dynamometer (Grip D, Takei, Tokyo, Japan), and the maximum value from the dominant arm was used in the analysis. Participants who did not have any chronic diseases and had a BMI of 18.5-25.9 were included in the current analyses; those who were aged 20–35 years were included in the “young Indian” group (n=70), and those who were aged >45 years were included in the “older Indian” group (n=462).

**The Pune Study**

This study was performed at Jehangir Hospital, a tertiary level care hospital located in central Pune during November 2015 – November 2017. Ethical approval was obtained from the institutional ethics committee; all participants gave informed consent. The primary aim of the study was to assess the bone health of women who had a pregnancy during adolescence compared with those who were pregnant post-adolescence. In total, 257 pre-menopausal women aged 29-53 years, underwent whole body DXA scans (Lunar iDXA, GE Health Care, WI, USA); CV was <1% for whole body lean mass. HGS (kg) was measured in each arm 3 times using a hand dynamometer (Jamar Plus Hand dynamometer, Warrenville, IL, USA) and the average of three readings for each arm was recorded. Participants who did not have any chronic diseases such as hypertension, diabetes mellitus, hyperthyroidism or any cardiac related health issues, aged between 20-35.9 years and a BMI of 18.5-25.9 were included in the “young Indian” group (n=59).

**Definitions of sarcopenia**

The proportion of men and women classified with sarcopenia was calculated using the following definitions:

1. The Foundation for the National Institutes of Health (FNIH) [5]:
   * Men: ALM <19.75kg and HGS <26kg
   * Women: ALM <15.02kg and HGS <16kg
2. The revised European Working Group on Sarcopenia in Older People (EWGSOP2) criteria [4]:

* Men: <20kg ALM or <7.0kg/m2 ALMI, and HGS <27kg
* Women: <15kg ALM or <5.5kg/m2 ALMI, and HGS <16kg

1. Asian Working Group for Sarcopenia (AWGS) [6]:

* Men: ALMI <7.0kg/m2 and HGS <26kg
* Women: ALMI <5.4kg/m2 and HGS <18kg

Of note, the AWGS definition also recommends a slow gait speed (<0.8m/s) in defining sarcopenia; as this was not assessed in our cohorts, only HGS and ALMI cut-points will be used for analysis.

1. Young Indian: the population sex-specific cut-points for ALM, ALMI and HGS were calculated as values two standard deviations (SD) below the sex-specific means for young adults aged 20-35 years [23], separately from the cohort studies. Two SDs below sex-specific means was used as this the method that the three aforementioned sarcopenia definitions have used to calculate cut-points (further details can be found [5,4,6]). Values in each cohort were combined and the 2SD below the mean was re-calculated and used for concurrent analyses. The cut-points calculated from this group were defined as the “young Indian” and were:

* Men: ALM <15.41 kg, ALMI <6.03 kg/m2 and HGS <22.93 kg
* Women: ALM <9.95 kg, ALMI <4.64 kg/m2 and HGS <10.76 kg

**Data Analysis**

All analyses were performed in Stata, Version 15.0 (StataCorp, College Station, TX, USA). Descriptive statistics were used to describe participant characteristics and are presented as mean ± standard deviation (SD), and categorical variables as frequency with percent. Between-group differences (young men vs. older men; young women vs. older women) in participant characteristics were tested with a one-way ANOVA and with a chi-squared test for categorical variables. In the Indian older group, we explored the relationship of lean mass and fat variables (dependent variable: HGS, ALM, ALMI and whole body fat mass) with age (independent variable) using linear regression with adjustments for weight and height to correct for body size (ALMI was only adjusted for weight). To test if these relationships were different between the sexes, we included a sex\*age term, and the p-value from the relevant pairwise comparison was reported (p-int).

Receiver operating characteristic (ROC) analyses were used to determine the area under the curve (AUC), the sensitivity and the specificity to discriminate between individuals with sarcopenic lean mass who had low versus normal HGS, as defined by each of the definitions cut-points. Univariate odds ratios with 95% confidence intervals were then calculated to describe how well the lean mass definitions predicted low HGS in older Indian men and women aged >45 years.

We used linear regression to investigate the relationship between aBMD (dependent variable) and muscle parameters (independent variable), with adjustments for age, weight and height (for ALMI, adjustments were made only for age and weight); a muscle parameter\*sex interaction term was also included and the relevant p-value (p-int) was reported. Total hip and spine aBMD were log transformed to normalise distributions [24]. Values are presented as beta coefficients, expressed as a percent change for every 1 unit change in muscle parameter, with 95% confidence intervals. To facilitate visualisation of the results, bone variables were transformed into z-scores (per SD).

**Results**

In total, there were 1009 young (men: 602, women: 407) and 1755 older (men: 1014 and women: 741) participants. Table 1 shows the participant characteristics for men and women in the “young Indian” and “older Indian” groups. There were no differences in ALM between young and older women (Table 1). In contrast, both ALM and ALMI were lower in older men than in younger men. Total percent body fat was similar in young and older men and women (Table 1). In Indians aged >45 years: for every one-year increase in age, there was a greater decrease in men compared with women in: HGS (1.2% vs 0.2%); ALM (0.3% vs 0.1%); and ALMI (0.3% vs 0.1%), following adjustments for body size (Figure 1). Total fat mass with increasing age was similar in men and women (p-int=0.923).

The predictive ability of low lean mass definitions for low HGS is presented in Table 2. The FNIH classification had the highest sensitivity in both women and men (90.5%, and 84.2%, respectively), but the lowest specificity in women and men (27.7%, and 51.1%, respectively) compared with the other definitions. The EWGSOP2 ALMI classification had the highest sensitivity and specificity in both men and in women (Table 2). The AUCs from the ROC analyses showed that EWGSOP2 using ALMI had moderate-good ability to discriminate those with low versus normal HGS in men (AUC=0.686) and women (AUC=0.641). The AWGS definition had similar discriminative power to EWGSOP2 ALMI in men only. The young Indian definition had the highest specificity, but also the lowest sensitivity (Table 2).

The prevalence of sarcopenia in Indian men and women aged >45 years varied depending on the definition (Table 3). The prevalence of sarcopenia was higher in men than in women, irrespective of definition (Table 3). In men, mean total hip aBMD was lower in those with sarcopenia compared with those without sarcopenia, independent of the definition used; while there were no differences in mean spine aBMD (Table 3). In women, total hip and spine aBMD were lower in those with sarcopenia compared with those without, irrespective of definition (Table 3).

The associations between muscle parameters and aBMD are presented in Table 4 and Figure 2. Women had greater positive associations between muscle parameters and aBMD compared with men. In women, for every 1kg/m2 increase in ALMI, there were positive differences in total hip aBMD by 5.81%, CI: 4.39, 7.24 (vs men: 2.64%, CI:1.43, 3.85) and spine aBMD by 4.23%, CI: 2.11, 6.35 (vs men: -1.74%, CI: -3.53, 0.06) following adjustments (Table 4, Figure 2), with similar findings in ALM and HGS (all p-int<0.0001).

**Discussion**

Our study showed that in older Indian men and women aged >45 years, the prevalence of sarcopenia varied according to the definition used, and was lowest using cut-points based on Indian-specific reference data. The EWGSOP2 definition of ALMI <7.0kg/m2 in men, and <5.5kg/m2 in women, was most robust in detecting EWGSOP2 defined low HGS in Indian men and women aged >45 years. The sarcopenia cut-points developed from a young Indian cohort for HGS, ALM and ALMI, were lower compared with those previously obtained from Caucasian populations. ALM, ALMI and HGS were positively associated with total hip and spine aBMD, and by a greater magnitude in women than in men.

We compiled a cohort of young Indian men and women from existing studies across India to calculate Indian-specific cut-points, given the existing definitions were mainly developed from data derived from Caucasian populations. The cut-points calculated from the young Indian cohort for HGS, ALM and ALMI were much lower than those of FNIH and EWGSOP2. The only other study from India that explored ALMI measured with DXA, reported a cut-point of <4.42kg/m2 (2SD below the mean of young Indian women aged 20-39 years), which classified 1.1% of women aged >50 years with sarcopenia (using ALMI alone – no functional assessments were performed) [16] - comparable with our own data. Studies from other Asian studies also report extremely low sarcopenia prevalence using 2SD below a young adult mean [25-27]. It is possible that there may be a generational effect, that is, current “young” Indians have a more urbanized and westernized lifestyle compared with the current “older” group who potentially had a more traditional lifestyle. There have been large changes in the past 20–40 years in India, with differences in lifestyle, environment, economy, public transportation and socio-economic status, which may mean that young Indians have lower lean mass and strength compared with older generations at the same age. Thus, although the use of region-specific young adult reference data is recommended for identifying cut-points for sarcopenia, this may have limited utility in regions where substantial generational changes have occurred.

Our findings show positive associations between muscle parameters and aBMD in Indian men and women; these were stronger in women than in men. In line with this, a study in rural Gambians reported greater positive associations between muscle and bone parameters in women compared with men [28]. Women in rural areas may be more active compared with men, and may maintain more lean mass throughout ageing. Indeed, data from our study show that with age, men had greater decreases in HGS, ALM and ALMI compared with women. A study in Korean older adults also showed that the associations between muscle and bone throughout ageing was more tightly coupled in women than in men [29]. Men may potentially be more susceptible to deterioration of lean mass and strength with ageing compared with women.

The functional assessment of HGS is a useful tool as it is a practical method of measuring muscle strength in the clinical setting and has been shown to be a predictor of poor health outcomes including longer hospital stays, greater functional limitations, decreased health-related quality of life and mortality [30,31]. Although HGS was the only functional data available in our study, gait speed and other physical performance measures have also been included in sarcopenia definitions [32]. There has been only one study from India to report gait speed in older men and women; this study was based in Delhi with a cohort of 723 men and women aged >60 years [33]. The findings from this study show that gait speed was lower in those aged >70 years compared with those aged 60-65 years [33]. Despite the variation in gait speed with age, the cut-point for low gait speed was calculated as the lowest 25th percentile by sex and was 0.6m/s [33]. Although this was calculated in an older population, it is also lower than the EWGSOP2 definition of low gait speed of ≤0.8 m/s [4]. Studies measuring gait speed in young Indian men and women are required to determine reference values for gait speed in a healthy population. Similarly, as there are ethnic differences in life expectancy, data on gait speed throughout the ageing process in Indians (>45 years) would help identify the “age window” when the decline in gait speed commences. This would inform future strategies in fall and fracture prevention and enable a healthier ageing process for Indian men and women.

The main strength of our study is that it was performed in a large cohort of participants from various regions of the country and is representative of both urban and rural Indian populations. Our study is also the first to describe the prevalence of sarcopenia in men and women from India defined by the various current definitions. There are potential limitations in this study. The sex-specific 2SD below the mean of a young reference population to calculate low HGS was chosen arbitrarily and may not apply in the same way throughout life due to possible generational lifestyle differences between older and younger Indians. Although several studies in Caucasian populations show that lean mass and muscle strength peaks between 20-35 years of age [34,13], this may be delayed in the Indian population [16]. The age for the older group of >45 years is relatively young; however, given the life expectancy in India is lower (67 years in men and 70 years in women), this may be representative of older age. HGS was the only muscle strength assessment in these studies, and so we do not know if lean mass cut-points have different associations with other measures of physical performance. Different hand dynamometers were used in the studies which may have introduced variation. Individual aBMD values for L1, L2, L3 and L4 vertebrae were not available, and so potential spinal osteoarthritis artefacts from these scans could not be determined. Different DXA scanners were used in two of the four studies, which may have introduced variation and error. However, the current International Society for Clinical Densitometry guidelines state that “no phantom has been identified to remove systematic differences in body composition when comparing *in vivo* results across manufacturers” and “no total body phantoms are available at this time that can be used as absolute reference standards for soft tissue…” [35].

Our findings show that the ALMI criterion of the EWGSOP2 definition best identifies low HGS in older Indian men and women. Muscle variables were positively associated with aBMD at the hip and spine and these associations were stronger in women than in men. As India has over one third of world’s population aged >60 years, nutritional and exercise interventions for maintaining lean mass and strength during ageing will facilitate healthy ageing and reduce its economic healthcare burden. Using appropriate cut-points to diagnose low lean mass and poor physical function will allow identification of appropriate patient cohorts and also the monitoring of intervention effects.

**Acknowledgements:** This work was supported by the Australian Academy of Sciences, Australia-India Early and Mid-Career Fellowships (AZ). The third survey wave of APCAPS was funded by Wellcome Trust Strategic Award (084774). IMS was funded by the Wellcome Trust project grant (GR070797MF). NDBC was funded by the Indian Council of Medical Research, British Heart Foundation, the Wellcome Trust UK, the Medical Research Council UK, the National Institute for Health Research Nutrition and Metabolism Biomedical Research Unit, University of Southampton and the National Institute for Health Research Musculoskeletal Biomedical Research Unit, University of Oxford.

**References**

1. Aboderin IAG, Beard JR (2015) Older people's health in sub-Saharan Africa. The Lancet 385 (9968):e9-e11. doi:10.1016/S0140-6736(14)61602-0

2. Gregson CL, Cassim B, Micklesfield LK, Lukhele M, Ferrand RA, Ward KA, Group SCW (2019) Fragility fractures in sub-Saharan Africa: time to break the myth. The Lancet Global health 7 (1):e26-e27. doi:10.1016/S2214-109X(18)30412-1

3. Tollman SM, Norris SA, Berkman LF (2016) Commentary: The value of life course epidemiology in low- and middle-income countries: an ageing perspective. International Journal of Epidemiology 45 (4):997-999. doi:10.1093/ije/dyw109

4. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyere O, Cederholm T, Cooper C, Landi F, Rolland Y, Sayer AA, Schneider SM, Sieber CC, Topinkova E, Vandewoude M, Visser M, Zamboni M, Writing Group for the European Working Group on Sarcopenia in Older P, the Extended Group for E (2019) Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 48 (1):16-31. doi:10.1093/ageing/afy169

5. Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, Ferrucci L, Guralnik JM, Fragala MS, Kenny AM, Kiel DP, Kritchevsky SB, Shardell MD, Dam TT, Vassileva MT (2014) The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates. J Gerontol A Biol Sci Med Sci 69 (5):547-558. doi:10.1093/gerona/glu010

6. Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS, Chou MY, Chen LY, Hsu PS, Krairit O, Lee JS, Lee WJ, Lee Y, Liang CK, Limpawattana P, Lin CS, Peng LN, Satake S, Suzuki T, Won CW, Wu CH, Wu SN, Zhang T, Zeng P, Akishita M, Arai H (2014) Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 15 (2):95-101. doi:10.1016/j.jamda.2013.11.025

7. Kruger HS, Micklesfield LK, Wright HH, Havemann-Nel L, Goedecke JH (2015) Ethnic-specific cut-points for sarcopenia: evidence from black South African women. Eur J Clin Nutr 69 (7):843-849. doi:10.1038/ejcn.2014.279

8. Zengin A, Maple-Brown LJ, Brennan-Olsen S, Center JR, Eades S, Ebeling PR (2018) Musculoskeletal health of Indigenous Australians. Archives of osteoporosis 13 (1):77. doi:10.1007/s11657-018-0493-x

9. Zengin A, Prentice A, Ward KA (2015) Ethnic Differences in Bone Health. Frontiers in Endocrinology 6. doi:10.3389/fendo.2015.00024

10. Shah AD, Kandula NR, Lin F, Allison MA, Carr J, Herrington D, Liu K, Kanaya AM (2015) Less favorable body composition and adipokines in South Asians compared with other US ethnic groups: results from the MASALA and MESA studies. International journal of obesity 40:639. doi:10.1038/ijo.2015.219

<https://www.nature.com/articles/ijo2015219#supplementary-information>

11. Zengin A, Pye SR, Cook MJ, Adams JE, Wu FC, O'Neill TW, Ward KA (2016) Ethnic differences in bone geometry between White, Black and South Asian men in the UK. Bone 91:180-185. doi:10.1016/j.bone.2016.07.018

12. Forrest KY, Bunker CH, Sheu Y, Wheeler VW, Patrick AL, Zmuda JM (2012) Patterns and correlates of grip strength change with age in Afro-Caribbean men. Age Ageing 41 (3):326-332. doi:10.1093/ageing/afs030

13. Metter EJ, Conwit R, Tobin J, Fozard JL (1997) Age-associated loss of power and strength in the upper extremities in women and men. J Gerontol A Biol Sci Med Sci 52 (5):B267-276

14. Yang PL, Lu Y, Khoo CM, Leow MK, Khoo EY, Teo A, Lee YS, Das De S, Chong YS, Gluckman PD, Tai ES, Venkataraman K, Ng CM (2013) Associations between ethnicity, body composition, and bone mineral density in a Southeast Asian population. J Clin Endocrinol Metab 98 (11):4516-4523. doi:10.1210/jc.2013-2454

15. Ho-Pham LT, Nguyen UD, Nguyen TV (2014) Association between lean mass, fat mass, and bone mineral density: a meta-analysis. J Clin Endocrinol Metab 99 (1):30-38. doi:10.1210/jc.2013-3190

16. Marwaha RK, Garg MK, Bhadra K, Mithal A, Tandon N (2014) Assessment of lean (muscle) mass and its distribution by dual energy X-ray absorptiometry in healthy Indian females. Archives of osteoporosis 9:186. doi:10.1007/s11657-014-0186-z

17. Smith J, Majmundar M (2012) Aging in Asia: Findings From New and Emerging Data Initiatives. In: Smith JP, Majmundar M (eds) National Research Council (US) Panel on Policy Research and Data Needs to Meet the Challenge of Aging in Asia. . The National Academies Collection: Reports funded by National Institutes of Health. National Academies Press (US), Washington (DC). doi:10.17226/13361

18. Bhargava SK, Sachdev HS, Fall CH, Osmond C, Lakshmy R, Barker DJ, Biswas SK, Ramji S, Prabhakaran D, Reddy KS (2004) Relation of serial changes in childhood body-mass index to impaired glucose tolerance in young adulthood. The New England journal of medicine 350 (9):865-875. doi:10.1056/NEJMoa035698

19. Tandon N, Fall CH, Osmond C, Sachdev HP, Prabhakaran D, Ramakrishnan L, Dey Biswas SK, Ramji S, Khalil A, Gera T, Reddy KS, Barker DJ, Cooper C, Bhargava SK (2012) Growth from birth to adulthood and peak bone mass and density data from the New Delhi Birth Cohort. Osteoporos Int 23 (10):2447-2459. doi:10.1007/s00198-011-1857-x

20. Kinra S, Radha Krishna KV, Kuper H, Rameshwar Sarma KV, Prabhakaran P, Gupta V, Walia GK, Bhogadi S, Kulkarni B, Kumar A, Aggarwal A, Gupta R, Prabhakaran D, Reddy KS, Smith GD, Ben-Shlomo Y, Ebrahim S (2014) Cohort profile: Andhra Pradesh Children and Parents Study (APCAPS). Int J Epidemiol 43 (5):1417-1424. doi:10.1093/ije/dyt128

21. Ebrahim S, Kinra S, Bowen L, Andersen E, Ben-Shlomo Y, Lyngdoh T, Ramakrishnan L, Ahuja RC, Joshi P, Das SM, Mohan M, Davey Smith G, Prabhakaran D, Reddy KS, Indian Migration Study g (2010) The effect of rural-to-urban migration on obesity and diabetes in India: a cross-sectional study. PLoS Med 7 (4):e1000268. doi:10.1371/journal.pmed.1000268

22. Lyngdoh T, Kinra S, Shlomo YB, Reddy S, Prabhakaran D, Smith GD, Ebrahim S, Indian migration study g (2006) Sib-recruitment for studying migration and its impact on obesity and diabetes. Emerg Themes Epidemiol 3:2. doi:10.1186/1742-7622-3-2

23. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD (1998) Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol 147 (8):755-763

24. Cole TJ (2000) Sympercents: symmetric percentage differences on the 100 log(e) scale simplify the presentation of log transformed data. Stat Med 19 (22):3109-3125. doi:10.1002/1097-0258(20001130)19:22<3109::AID-SIM558>3.0.CO;2-F [pii]

25. Kim YS, Lee Y, Chung YS, Lee DJ, Joo NS, Hong D, Song G, Kim HJ, Choi YJ, Kim KM (2012) Prevalence of sarcopenia and sarcopenic obesity in the Korean population based on the Fourth Korean National Health and Nutritional Examination Surveys. J Gerontol A Biol Sci Med Sci 67 (10):1107-1113. doi:10.1093/gerona/gls071

26. Lau EM, Lynn HS, Woo JW, Kwok TC, Melton LJ, 3rd (2005) Prevalence of and risk factors for sarcopenia in elderly Chinese men and women. J Gerontol A Biol Sci Med Sci 60 (2):213-216

27. Lee WJ, Liu LK, Peng LN, Lin MH, Chen LK, Group IR (2013) Comparisons of sarcopenia defined by IWGS and EWGSOP criteria among older people: results from the I-Lan longitudinal aging study. J Am Med Dir Assoc 14 (7):528 e521-527. doi:10.1016/j.jamda.2013.03.019

28. Zengin A, Jarjou LM, Prentice A, Cooper C, Ebeling PR, Ward KA (2018) The prevalence of sarcopenia and relationships between muscle and bone in ageing West-African Gambian men and women. J Cachexia Sarcopenia Muscle 9 (5):920-928. doi:10.1002/jcsm.12341

29. Kim KM, Lim S, Oh TJ, Moon JH, Choi SH, Lim JY, Kim KW, Park KS, Jang HC (2017) Longitudinal Changes in Muscle Mass and Strength, and Bone Mass in Older Adults: Gender-Specific Associations Between Muscle and Bone Losses. The Journals of Gerontology: Series A 73 (8):1062-1069. doi:10.1093/gerona/glx188

30. Ibrahim K, May C, Patel HP, Baxter M, Sayer AA, Roberts H (2016) A feasibility study of implementing grip strength measurement into routine hospital practice (GRImP): study protocol. Pilot Feasibility Stud 2:27. doi:10.1186/s40814-016-0067-x

31. Leong DP, Teo KK, Rangarajan S, Lopez-Jaramillo P, Avezum A, Jr., Orlandini A, Seron P, Ahmed SH, Rosengren A, Kelishadi R, Rahman O, Swaminathan S, Iqbal R, Gupta R, Lear SA, Oguz A, Yusoff K, Zatonska K, Chifamba J, Igumbor E, Mohan V, Anjana RM, Gu H, Li W, Yusuf S, Prospective Urban Rural Epidemiology Study i (2015) Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet 386 (9990):266-273. doi:10.1016/S0140-6736(14)62000-6

32. Perez-Sousa MA, Venegas-Sanabria LC, Chavarro-Carvajal DA, Cano-Gutierrez CA, Izquierdo M, Correa-Bautista JE, Ramirez-Velez R (2019) Gait speed as a mediator of the effect of sarcopenia on dependency in activities of daily living. J Cachexia Sarcopenia Muscle. doi:10.1002/jcsm.12444

33. Gunasekaran V, Banerjee J, Dwivedi SN, Upadhyay AD, Chatterjee P, Dey AB (2016) Normal gait speed, grip strength and thirty seconds chair stand test among older Indians. Arch Gerontol Geriatr 67:171-178. doi:10.1016/j.archger.2016.08.003

34. Kallman DA, Plato CC, Tobin JD (1990) The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitudinal perspectives. J Gerontol 45 (3):M82-88

35. Shepherd JA, Schousboe JT, Broy SB, Engelke K, Leslie WD (2015) Executive Summary of the 2015 ISCD Position Development Conference on Advanced Measures From DXA and QCT: Fracture Prediction Beyond BMD. J Clin Densitom 18 (3):274-286. doi:10.1016/j.jocd.2015.06.013

**Figures**

**Figure 1:** Sex differences in muscle parameters (hand grip strength, ALM and ALMI) with age in Indian men and women aged >45 years. Blue triangles indicate men, red circles indicate women. Data are expressed as percent difference in muscle parameter per 1 year increase in age; values are beta-coefficients with 95% confidence intervals. P values are reported from sex\*age interactions and denoted as p-int. ALM, appendicular lean mass; ALMI, appendicular lean mass index.

**Figure 2:** The relationship between muscle parameters (ALM, ALMI and hand grip strength) and aBMD at the total hip and spine (expressed as per SD) in Indian men (blue triangles) and women (red circles) aged >45 years. Adjustments were made for age, weight and height (only age and weight for ALMI), and a sex\*muscle parameter interaction was included and denoted as p-int. ALM, appendicular lean mass; ALMI, appendicular lean mass index.

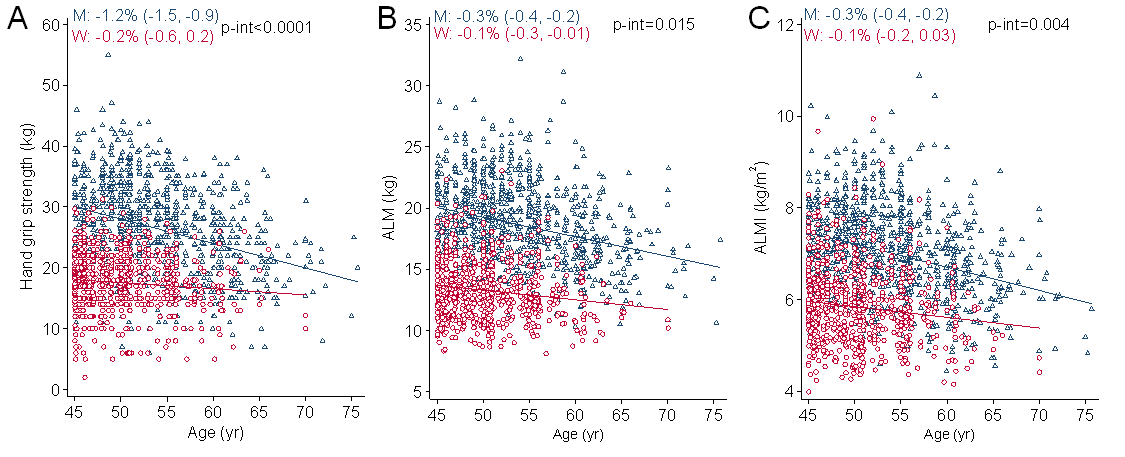
Figure 1



Figure 2

