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Growth Charts for Muscular Strength Capacity With Quantile Regression

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Abstract

Introduction—Muscle strength preservation may play an important role in protecting against cardiometabolic diseases, functional decline, musculoskeletal deterioration, and early all-cause mortality. However, sex-specific strength growth charts and curves using data from a U.S.-representative sample and clinically feasible measurement remain to be established.

Methods—A sample of 7,119 individuals, aged 6–80 years, was included from the 2011–2012 National Health and Nutrition Examination Survey. Analyses were performed in 2015. Grip strength was assessed using a hydraulic handheld dynamometer; peak force values were normalized per body mass. Parametric quantile regression was used to determine unique normalized and absolute strength percentiles for men and women. Responses were fitted with a parametric model, involving six powers of age.

Results—Growth charts and curves were created using output from the quantile regression from reference values of normalized and absolute grip strength corresponding to the fifth, tenth, 25th, 50th, 75th, 90th, and 95th percentiles across all ages. For men, there was a small drop in normalized strength at age 6 years followed by quick growth until about age 25 years. Among women, normalized strength grew gradually until about age 15 years. For both men and women, normalized strength declined throughout middle age and later adulthood; however, these rates were greater among men. More-pronounced patterns of growth and decline were observed for absolute strength in men and women.

Conclusions—The established strength quantiles can easily be incorporated into a clinical setting for screening individuals that would benefit from lifestyle interventions to improve muscular fitness and reduce health risks.

Introduction

A growing body of literature demonstrates an independent association between muscle weakness and early cardiovascular and all-cause mortality.[1–7] The contribution of muscle

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weakness to progression of secondary complications with aging and disease (e.g., fragility, mobility–disability) is equally unequivocal. Although there has been a recent upsurge of efforts to identify weakness thresholds among aging adults,[7,8] there is yet to be adequate attention on early screening among younger populations. Nevertheless, in a study of more than 1 million adolescent boys, low muscular strength was a primary risk factor for major causes of death, such as cardiovascular diseases, and effect sizes were equivalent to those of established risk factors such as elevated BMI.[9] Moreover, we and others have shown a robust, independent association between low strength and cardiometabolic risk clustering among adolescents[10–13]—reiterating the need for improved clinical screening strategies across all ages. This is only feasible if population-based growth charts of strength are readily available to clinicians. Therefore, the purpose of this study was to create growth charts and curves of strength from a population-representative sample of individuals aged 6–80 years from the U.S.

Methods

Study Population

The National Health and Nutrition Examination Survey (NHANES) is a program of studies designed to assess the health and nutritional status of U.S. adults and children. NHANES 2011–2012 was specifically chosen based on the inclusion of direct measures of muscle strength capacity among children, adolescents, and adults. Of the 9,756 NHANES 2011–2012 participants aged ≥6 years, 7,119 (49.3% female) had complete demographic and anthropometric data, and valid strength data from a handgrip dynamometer. Analyses were performed in 2015.

Measures

Sociodemographic characteristics were characterized by self-report during an in-home interview. Age was used as a continuous variable. Weight was measured using a digital Toledo scale (Mettler-Toledo International, Inc.), and participants wore only underwear gown and foam slippers when measured.

Strength was assessed using a hydraulic handgrip dynamometer (Takei Digital Grip Strength Dynamometer, Model T.K.K.5401). Detailed descriptions of the protocol are provided in the NHANES Muscle Strength/Grip Test Procedure Manual (http://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/Muscle_Strength_Proc_Manual.pdf). A trained examiner explained and demonstrated the protocol, then adjusted the grip size of the dynamometer to the participant's hand size, and asked the participant to squeeze the dynamometer for a practice trial. Thereafter, the participant was randomly assigned to start the test with their dominant or non-dominant hand, and was asked to squeeze the dynamometer as hard as possible in the standing position, exhaling while squeezing. The test was then repeated for the opposite hand. Each hand was tested three times, alternating hands between trials with a 60-second rest between measurements, and the largest grip strength reading from either hand was used for the analyses. Participants were excluded if they were unable to hold the dynamometer and perform strength testing with both hands. Because there is substantial covariance between strength capacity and body mass, and normalized strength is associated with various risk factors of chronic health,[10,14] grip strength growth curves were determined for both absolute strength, and normalized as strength per body mass as follows:

$$\left(\frac{Grip\ Strength[kg]}{Body\ Mass[kg]}\right).$$

Statistical Analysis

All statistical analyses were conducted using SAS, version 9.3. To obtain population-representative findings, analyses were conducted using sample weights for the 2011–2012 NHANES cycle, which accounts for the complex survey design (including oversampling), survey nonresponse, and post-stratification. To create growth charts for normalized and absolute grip strength, parametric quantile regression was used to determine the fifth, tenth, 25th, 50th, 75th, 90th, and 95th percentiles for ages 6–80 years. This has the advantages of allowing examination at multiple points in the distribution of strength capacity rather than only at the mean, it does not require assumptions about the distribution of the regression residuals, and is not influenced by outliers or skewness in the distribution of the outcome. To explore the sex-specific growth patterns of normalized and absolute strength, parametric polynomial quantile regression models were used to predict strength with six powers of age (age^{-1}, √age, age, √age X age, age^2, age^3) using the QUANTREG procedure.[15] The estimated parameters and their 95% CIs were constructed using a Markov chain marginal bootstrap of He and Hu,[16] which promotes the bootstrap method for quantile regression. Quantile regression was used for seven centiles in order to construct the strength growth charts for both male and female participants, using the SAS macro as described by Chen.[15] For each centile, the fitted values of normalized and absolute strength were computed at each observed age and saved in an output data set. These fitted values were then plotted against age to create the percentile curves.

Results

The seven percentile curves with polynomials together with a scatterplot of normalized and absolute strength for men and women are shown in Figures 1 and 2. For men, starting from age 6 years, there was a small drop in normalized strength followed by quick growth until about age 25 years. Among women, there was gradual growth until about age 15 years . For both men and women, there was a decline in normalized strength throughout middle age and later adulthood; however, the rates of decline were greater among men (Figure 1). Similar but more-pronounced patterns of growth and decline were observed for absolute strength curves in men and women (Figure 2).

Appendix Tables 1 and 2 provide growth charts of normalized and absolute strength values for men and women separately.

Discussion

Increasingly compelling evidence has highlighted the potential role of muscular strength capacity as a protective factor for health across populations. Using a population-representative sample, we have, for the first time, constructed growth charts of both normalized and absolute grip strength using parametric quantile regression. As an important point of distinction about these percentiles, and as compared to other recent efforts to identify normative values or *t*-scores in non-U.S. cohorts and samples,[17–20] our growth charts were constructed to include both age- and sex-specific normalized and absolute strength curves/charts in a large U.S. population-representative sample. As there is substantial covariance between strength capacity and body mass, and, moreover, that the link between muscle strength and both physical function and chronic health is directly mediated by the proportion of strength relative to body mass, these new reference criteria represent an important addition to the body of literature. However, with regard to absolute strength growth curves, these U.S.-representative data are very similar to previously published growth curves developed from a large collection of different British studies.[19]

Despite the known links between weakness, functional decline in mobility, and early all-cause mortality, less is known about the temporal sequence underlying these associations. An obvious limitation to the inference of exposure thresholds or percentiles ascertained from cross-sectional data is the inability to understand longitudinal changes or direction of causation between the exposure and outcomes of interest. Herein, we provide centiles of strength from a large, U.S. population-representative sample that could be used for the purpose of normative reference testing in clinical, academic, and community settings. However, future research is certainly needed to create unique risk-categorization algorithms specific to particular clinical and global health outcomes. Such efforts will dramatically improve the personalization of screening, stratification, and clinical decision making at the individual patient level.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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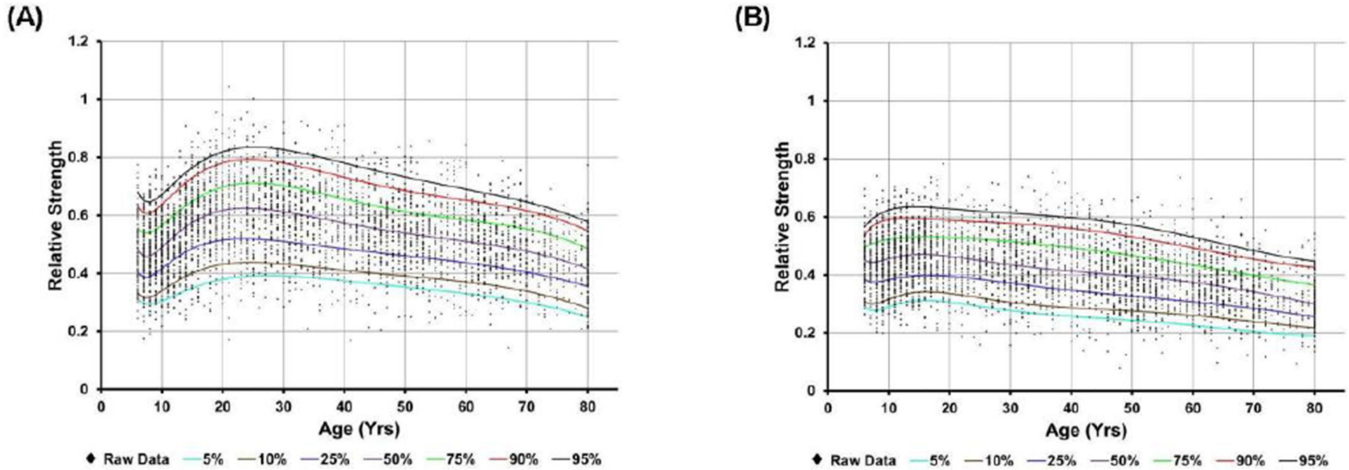

Figure 1.

Normalized strength growth percentile curves with polynomials for men (A) and women (B).

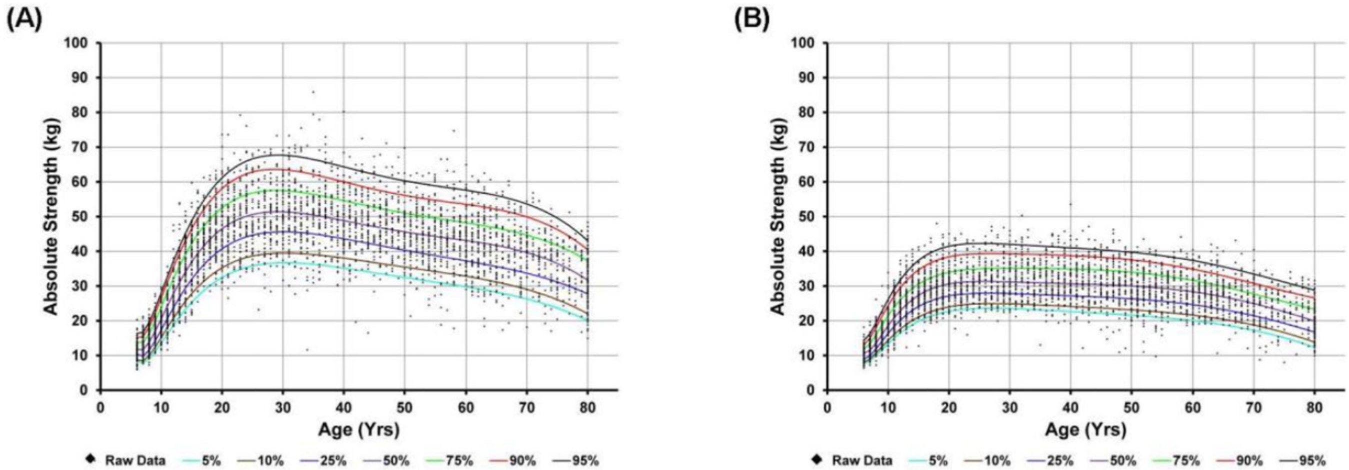

Figure 2.

Absolute raw strength growth percentile curves with polynomials for men (A) and women (B).