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Criterion-Referenced Cut-Points For Handgrip Strength To Detect Metabolic Syndrome In U.S. Adults

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CRITERION REFERENCED CUT-POINTS FOR HANDGRIP STRENGTH TO DETECT METABOLIC SYNDROME IN U.S. ADULTS

by

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This document, submitted in partial fulfillment of the requirements for the degree from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Abstract

Purpose: To establish gender- and age-group specific criterion-referenced cut-points for handgrip strength (HGS) associated with metabolic syndrome (MetS) in United States (U.S.) adults.

Methods: A secondary analysis of data from the 2011–12 and 2013–14 cycles of the National Health and Nutrition Examination Survey was performed on U.S. adults aged 20 years and older. HGS was measured using handheld dynamometry. MetS was measured as the presence of three or more cardiometabolic risk factors according to the American Heart Association criteria. Crude and fully adjusted receiver operating characteristic (ROC) curves were used to identify gender- and age group-specific cut-points for HGS associated with increased MetS. Effect sizes for the area under the curve of 0.56, 0.64, and 0.71 were used as thresholds for low, moderate, and high discriminatory ability, respectively.

Results: Crude ROC models demonstrated negligible discriminatory ability of HGS to detect MetS (AUC range: 0.49 to 0.55), with negligible to low discriminatory ability for the detection of the component risk factors (AUC range: 0.49 to 0.61). Adjusted ROC models demonstrated low to moderate discriminatory ability of HGS to detect MetS (range AUC: 0.55 to 0.70), with negligible to moderate discriminatory ability for the detection of the component risk factors (AUC range: 0.49 to 0.69).

Conclusion: This study is the first to establish criterion-referenced cut-points for HGS to detect MetS in U.S. adults. HGS shows negligible to low discriminatory ability to detect MetS and its risk components, with the discriminatory ability of HGS improving with the addition of covariates. Although these findings do not support the use of HGS as a diagnostic tool for the detection of MetS among U.S. adults, future studies should consider other muscular fitness measures to identify health-related cut-points for MetS.

Introduction

The United States (U.S.) has the highest healthcare expenditure and chronic disease burden of any country in the world (1), with annual costs of cardiovascular disease and type 2 diabetes at ~US$450 billion (1). Considering both diseases are preventable and, in some cases, reversable, a significant cost saving could be made if a cluster of risk factors (including obesity, dyslipidemia, hyperglycemia, and hypertension) known as metabolic syndrome (MetS) is identified and treated early. Using nationally-representative data between 2011 and 2016, Hirode et al. (2) estimated that nearly 35% of U.S. adults had MetS, with prevalence estimates stable over time (except for temporal increases among young adults and certain ethnic groups) and highest among older adults (2). Adults with MetS have a higher risk of developing cardiovascular disease, type 2 diabetes, and/or stroke in later life (3). Unfortunately, traditional testing of MetS requires a physical examination and blood sampling, which is expensive and invasive, and may help explain why only one in five U.S. adults visit a physician annually for preventative healthcare examinations (4). Research indicates that handgrip strength (HGS), a robust and reliable measure of overall strength capacity (5,6,7), is a powerful health marker (8). Low adult HGS is significantly associated with early all-cause and cardiovascular mortality, and disability (8). HGS measured by handheld dynamometry is a feasible, non-invasive, and safe test (9,10,11,12) that has screening utility, and may help to reduce the physical and financial burden associated with traditional MetS screening.

HGS has historically been interpreted using normative-referenced standards, where an individual's HGS is compared to a reference population (normally nationally-representative data) to determine how well they compare to their peers. Because these normative-referenced standards are time dependent, such norms may not reflect the current population. Moreover, the degree to which existing norms relate to health indicators of interest (such as MetS) is often unknown or poorly established. For example, HGS quartiles (normalized for body mass index [BMI]) have been generated to identify risk for MetS in a nationally-representative sample of U.S. adults aged 20 years and older. Churilla et al. (13) found those who fell into the lowest quartiles were more likely to have MetS and contributing risk factors. More recently, there has been a shift towards health-related criterion-referenced cut-points, where adult HGS levels are compared against an absolute, often health-related, criterion (14,15). Such studies (16,17) used the nationally-representative National Health and Nutrition Examination Survey (NHANES) dataset to establish criterion-referenced cut-points for body mass normalized HGS associated with type 2 diabetes mellitus for U.S. adults. Brown et al. (16), using logistic regressions with the best Akaike information criterion (AIC), reported combined NHGS (grip kg/weight kg) cut-points of 0.78 and 0.57 for younger men and women (aged 20–50 years), and 0.68 and 0.49 for older men and women (aged 50+ years). Peterson et al. (17), also using logistic regressions and AIC, found lower thresholds for combined NHGS (grip kg/weight kg) 0.56, 0.50, and 0.45 for men (20-39, 40-59, 60-80yrs) and 0.42, 0.38, and 0.33 for women, respectively. A possible explanation for the discrepancy in cut-points could be due to the different distribution of population between studies. While health-related criterion-referenced cut-points for HGS have been established for chronic diseases, such cut-points have yet to be established for MetS among U.S. adults. The aim of this study, therefore, is to establish criterion-referenced cut-points for HGS to help detect MetS in a nationally-representative sample of U.S. adults aged 20 to 80+ years.

Methods

Participants

Secondary analyses of data from the 2011–12 and 2013–14 cycles of the National Health and Nutrition Examination Survey were used for this study. These cycles of the NHANES were selected because they included HGS measurements. NHANES used a cross-sectional, complex multistage probability design to examine the health and nutritional survey of the U.S. non-institutionalized civilian population (18). To summarize, U.S. counties, known as primary sampling units, were broken down into smaller subgroups represented by clusters of homes. Specific households were then selected from within these clusters and after an initial screening, with individuals selected from those households to participate. Trained interviewers completed health interviews in respondents' homes, and study participants were also invited to visit a mobile examination centers for direct health measures. Interviewers and mobile examination centers traveled to various locations across the United States to help obtain a diversified sample. Oversampling for persons aged 60 years and older, Hispanics, non-Hispanic Asians, and non-Hispanic Blacks occurred to generate reliable data that represented all ages and ethnicities in the U.S. (18). Written informed consent was provided by participants and the National Center for Health Statistics Research Ethics Review Board approved NHANES protocols (Protocol #2011-17).

While NHANES recruited participants aged 6–80 years, we only used data on adults aged 20 years and older (20–80+ years, with adults aged 80 years and over top-coded in the NHANES at 80 years of age) in this study (19). Of the initial 19,931 participants, 15,855 were excluded for the following reasons: (a) were younger than 20 years (*n*=8602), (b) were pregnant (*n*=301), (c) due to physical limitations performed the assessment seated (*n*=347), (d) did not perform the test on both hands (*n*=1451), and (e) had incomplete data (*n*=5154). The analytical sample, therefore, comprised 4076 participants.

Measures

Handgrip strength

The HGS protocol is described in detail elsewhere (20). HGS was measured using Takei digital handgrip dynamometer (Model T.K.K.5401, Takei Scientific Instruments, Niigata City, Japan). The protocol was first explained and demonstrated by trained staff, the dynamometer was then sized to the participant's hand, and a submaximal practice trial was administered to make sure the participant understood the protocol. Participants were randomly assigned to start with either their right or left hand, and were instructed to stand upright with their feet hip width apart (unless they were physically limited), their arm fully extended at their side and away from their body, and to maximally squeeze the dynamometer while continuously exhaling. Each hand was tested three times, alternating hands between trials, with 60 seconds of rest between measurements on the same hand. Participants who did not perform the HGS test on both hands either due to surgery, injury, or missing limb(s), were excluded from this analysis. For this study, a raw HGS (kg) score was used since normalizing HGS by body mass, as seen in other studies (16,17), fails to remove the association between HGS and weight. This not only increases practicality but also accuracy of the cut-points. HGS was taken as the combined maximum raw score attained for each hand.

Criterion health measures (Metabolic syndrome)

Several criterion health measures were used in this study, including waist circumference, blood pressure, HDL-cholesterol (HDL-c), glucose, triglycerides, and a composite measure of MetS. Waist circumference (cm) was measured at end-tidal expiration using a steel measuring tape placed directly on the skin at the level of the superior lateral border of the iliac crests. Systolic and diastolic blood pressure were taken in a seated position after 5 minutes of rest with a calibrated mercury true gravity wall model sphygmomanometer. The average of three consecutive readings was recorded, with participants excluded if there was an obstruction on the arm (e.g., rash, lesion, cast). Glucose and triglycerides were obtained from fasted blood samples. Blood was collected using the venipuncture technique via the Nipro and BD Safety-Lok Collection Set, with 5 oz of blood collected per participant. Samples were handled by trained phlebotomists, divided into subsamples, labeled, refrigerated or frozen, and shipped to contracted labs across the U.S. for analysis. Blood taking and handling procedures are described in detail elsewhere (19).

The AHA cut-points for MetS were used in this study (20). MetS was defined as the presence of three or more of the following five risk factors: waist circumference (>102 cm [men], >88 cm [women]), triglycerides (≥1.7 mmol/L), HDL-c (<1.04 mmol/L [men], <1.3 mmol/L [women]), systolic blood pressure (>130 mmHg) and/or diastolic blood pressure (>85 mmHg), or glucose (>5.6 mmol/L). Adults who self-reported as currently taking prescription medication for blood pressure or blood glucose levels (i.e., antiarrhythmic agents, beta-adrenergic blocking agents, calcium channel blocking agents) were coded as at-risk for elevated blood pressure and glucose, respectively. Since prescription medication to control cholesterol can affect both HDL-c and triglyceride levels, adults who self-reported taking such medication were also coded as at-risk for these respective categories.

Statistical analyses

Statistical analyses were performed using the Statistical Analysis System Enterprise Guide (v9.4, SAS Institute, Cary, NC). All analyses were stratified by gender (male and female) and age group (20–49 and 50–80+ years). Gender- and age-specific cut-points for HGS associated with increased MetS (plus the component risk factors) were identified using crude and adjusted Receiver Operating Characteristic (ROC) curve analysis (22). The fully adjusted model included marital status, highest level of education, self-reported general health, and the use of a walking aid as covariates. ROC curve values were plotted as sensitivity and specificity for each potential cut-point value. We selected the cut-point that maximized both sensitivity and specificity (Youden's index), with greater accuracy reflected by a higher score. The area under the curve (AUC) summarized the discriminatory ability of HGS. To interpret the magnitude of AUC values, effect sizes of 0.56, 0.64, and 0.71 were used as thresholds for low, moderate, and high, respectively, with effect sizes <0.56 considered to be negligible (23). To obtain nationally-representative estimates, analyses were conducted using NHANES sample weights (survey, strata, and cluster weights), which account for the complex survey design (including oversampling), survey non-response, and post-stratification (24).

Results

Table 1 presents the descriptive characteristics of the participants. Collectively, HGS was 1.6-fold higher for men compared to women. MetS was slightly more prevalent among males (40.7%) than among women (40.1%), with the prevalence of MetS increasing with age. Among men and women, approximately 54.7% and 72.1% had a high waist circumference, 44.7% and 41.0% had high blood pressure, 24.1% and 33.8% had low HDL-c, 49.9% and 36.7% had high blood glucose, and 50.6% and 42.1% had high triglycerides, respectively.

Table 1. Descriptive statistics for U.S. adults aged 20 years and older who completed HGS testing as part of the NHANES.

Characteristics	**Young Men**	**Young Women**	**Older Men**	**Older Women**
	(n=2541)	**(n=2394)**	**(n=2135)**	**(n=2160)**
	Mean (95%Cl)			
Age, %	34.2 (33.4, 34.9)	34.7 (33.9, 35.6)	62.4 (61.9, 62.8)	62.9 (62.3, 63.4)
Race, %				
Non-Hispanic white	59.8 (54.2, 65.3)	59.9 (53.7, 66.2)	76.5 (71.8, 81.1)	76.5 (72.0, 81.0)
Non-Hispanic black	11.5 (8.7, 14.2)	13.1 (9.9, 16.3)	9.3 (6.6, 12.0)	9.9 (7.1, 12.6)
Non-Hispanic Asian	5.8 (4.4, 7.2)	6.3 (5.0, 7.6)	3.7 (2.7, 4.8)	3.9 (2.9, 4.9)
Hispanic	19.3 (15.0, 23.6)	17.6 (13.0, 22.2)	8.5 (5.9, 11.1)	8.3 (5.8, 10.8)
Other	3.7 (2.5, 4.8)	3.1 (2.2, 3.9)	1.9 (1.1, 2.8)	1.5 (0.5, 2.4)
Education				
Less than high school	15.4 (12.7, 18.1)	12.7 (10.3, 15.1)	16.7 (13.7, 19.7)	14.9 (11.3, 18.5)
High school	23.6 (20.5, 26.7)	17.3 (14.7, 20.0)	20.5 (17.6, 23.3)	22.4 (19.4, 25.4)
University degree or more	61.0 (56.6, 65.4)	70.0 (65.7, 74.2)	62.8 (58.7, 66.9)	62.7 (58.0, 67.4)
Marital status				
Married or common law	58.5 (55.3, 61.7)	59.9 (56.1, 63.8)	74.4 (71.2, 77.7)	57.7 (54.9, 60.5)
Self-reported general health				
Excellent, very good, or good	86.4 (84.9, 88.0)	84.9 (82.6, 87.2)	81.6 (79.5, 83.7)	80.8 (77.4, 84.1)
Use of walking aid				
Yes	2.1 (1.2, 2.9)	2.9 (2.2, 3.6)	6.8 (5.7, 7.9)	9.2 (7.5, 10.8)
Handgrip Strength (kg)				
Combined HGS	95.9 (95.0, 96.9)	60.8 (60.4, 61.2)	82.7 (81.1, 84.3)	51.7 (51.0, 52.4)
Waist circumference, cm				
Waist circumference	98.5 (97.4, 99.7)	94.6 (93.6, 95.5)	105.1 (104.1, 106.2)	98.8 (97.7, 100.0)
Elevated waste circumference %	47.1 (43.4, 50.8)	66.3 (62.9, 69.6)	63.7 (61.1, 66.4)	78.5 (75.4, 81.6)
HDL, mmol/L				
HDL	1.21 (1.19, 1.23)	1.46 (1.44, 1.48)	1.27 (1.24, 1.31)	1.56 (1.53, 1.60)
Reduced HDL %	25.6 (22.5, 28.6)	37.4 (34.4, 40.5)	22.4 (19.4, 25.4)	29.8 (26.9, 32.8)
Systolic Blood Pressure, mmHg				
Systolic Blood Pressure	119.4 (118.7, 120.2)	112.9 (112.0, 113.7)	128.5 (127.0, 129.9)	128.2 (126.9, 129.5)
Diastolic Blood Pressure	71.9 (71.0, 72.8)	69.7 (68.9, 70.5)	71.9 (71.0, 72.8)	69.9 (69.0, 70.8)
Elevated blood pressure %	26.5 (23.9, 29.2)	19.5 (17.2, 21.8)	66.4 (63.1, 69.8)	64.8 (61.7, 68.0)
Triglycerides, mmol/L				
Triglycerides	1.59 (1.49, 1.69)	1.16 (1.08, 1.24)	1.54 (1.37, 1.72)	1.39 (1.30, 1.48)
Elevated triglyceride %	34.9 (30.8, 39.0)	21.7 (17.5, 26.0)	68.7 (64.7, 72.7)	64.0 (60.2, 67.8)
Fasting glucose, mmol/L				
Fasting glucose	5.69 (5.58, 5.81)	5.43 (5.35, 5.52)	6.33 (6.21, 6.46)	6.04 (5.85, 6.24)
Elevated fasting glucose %	39.4 (34.5, 44.3)	22.8 (18.9, 26.8)	61.9 (57.5, 66.4)	51.6 (47.1, 56.0)
Metabolic Syndrome				
Metabolic Syndrome %	28.3 (24.6, 32.1) [1109]	24.1 (19.9, 28.3) [1037]	54.9 (49.9, 59.8 [964]	57.2 (52.4, 61.9) [966]

Note: HDL, high-density lipoprotein.

The crude and adjusted ROC curve generated cut-points for HGS (and corresponding AUCs) associated with MetS (plus the component risk factors) for each gender and age group are presented in Tables 2 and Table 3. Crude ROC models demonstrated negligible discriminatory ability of HGS to detect MetS (AUC range: 0.49 [older women] to 0.55 [young women]) and negligible to low discriminatory ability for the detection of the component risk factors (AUC range: 0.49 [triglycerides for older men and young women] to 0.61 [waist circumference for young women]). Adjusted ROC models demonstrated low to moderate discriminatory ability of HGS to detect MetS (AUC range: 0.55 [older men] to 0.70 [young women]) and negligible to moderate discriminatory ability for the detection of the component risk factors (AUC range: 0.49 [triglycerides for older males] to 0.69 [waist circumference for young women]).

Table 2. Crude ROC curve determined cut-points (and corresponding AUCs) in HGS associated with MetS and its component risk factors.

	Young males				**Older males**			
Risk factor	**Cut-point**	**AUC**	**Sens**	**Spec**	**Cut-point**	**AUC**	**Sens**	**Spec**
MetS	83.6	0.54 (0.51, 0.58)	0.79	0.30	102.5	0.50 (0.46, 0.53)	0.08	0.94
Waist circumference	92.6	0.56 (0.54, 0.58)	0.59	0.50	67.4	0.54 (0.51, 0.57)	0.70	0.37
Blood pressure	92.7	0.55 (0.52, 0.57)	0.60	0.48	76.9	0.53 (0.50, 0.56)	0.46	0.62
HDL	91.4	0.51 (0.48, 0.53)	0.60	0.44	78.8	0.54 (0.51, 0.57)	0.46	0.62
Glucose	83.0	0.50 (0.47, 0.54)	0.77	0.28	85.2	0.53 (0.49, 0.57)	0.57	0.50
Triglycerides	108.3	0.50 (0.47, 0.54)	0.22	0.82	84.8	0.49 (0.46, 0.52)	0.66	0.36
	Young women				**Older women**			
Risk factor	**Cut-point**	**AUC**	**Sens**	**Spec**	**Cut-point**	**AUC**	**Sens**	**Spec**
MetS	68.4	0.55 (0.51, 0.59)	0.30	0.83	44.3	0.49 (0.45, 0.53)	0.75	0.28
Waist circumference	60.3	0.61 (0.59, 0.64)	0.29	0.82	66.0	0.59 (0.56, 0.63)	0.39	0.75
Blood pressure	69.2	0.58 (0.55, 0.61)	0.30	0.85	48.7	0.56 (0.53, 0.59)	0.45	0.66
HDL	62.9	0.54 (0.51, 0.56)	0.43	0.65	59.3	0.50 (0.47, 0.53)	0.24	0.80
Glucose	68.2	0.53 (0.49, 0.57)	0.29	0.82	66.0	0.50 (0.47, 0.54)	0.93	0.09
Triglycerides	68.3	0.49 (0.45, 0.53)	0.24	0.80	53.3	0.56 (0.53, 0.59)	0.45	0.66

Note: Cut-points in HGS are in kilograms (kg); AUC=Area under the curve with AUC values of 0.56, 0.64, and 0.71 as thresholds for low, moderate, and high effect sizes; Sens=sensitivity; Spec=specificity.

Table 3. Fully adjusted ROC curve determined cut-points (and corresponding AUCs) for HGS associated with MetS and its component risk factors.

	Young males				**Older males**			
Risk factor	**Cut-point**	**AUC**	**Sens**	**Spec**	**Cut-point**	**AUC**	**Sens**	**Spec**
MetS	81.6	0.63 (0.60, 0.67)	0.59	0.54	80.6	0.55 (0.51, 0.59)	0.67	0.43
Waist circumference	114.4	0.64 (0.62, 0.66)	0.55	0.66	86.5	0.58 (0.55, 0.61)	0.42	0.72
Blood pressure	61.5	0.60 (0.54, 0.63)	0.34	0.82	89.5	0.57 (0.54, 0.60)	0.54	0.58
HDL	63.5	0.59 (0.57, 0.62)	0.72	0.43	70.7	0.58 (0.55, 0.61)	0.56	0.60
Glucose	149.5	0.57 (0.54, 0.61)	0.72	0.42	92.4	0.54 (0.51, 0.58)	0.73	0.36
Triglycerides	125.5	0.60 (0.57, 0.64)	0.65	0.52	79.7	0.49 (0.46, 0.52)	0.71	0.38
	Young women				**Older women**			
Risk factor	**Cut-point**	**AUC**	**Sens**	**Spec**	**Cut-point**	**AUC**	**Sens**	**Spec**
MetS	56.0	0.70 (0.66, 0.74)	0.55	0.78	28.6	0.66 (0.63, 0.69)	0.58	0.68
Waist circumference	64.7	0.69 (0.66, 0.71)	0.48	0.81	45.5	0.67 (0.64, 0.70)	0.69	0.58
Blood pressure	70.3	0.66 (0.64, 0.69)	0.59	0.68	65.8	0.61 (0.58, 0.63)	0.62	0.57
HDL	72.1	0.64 (0.61, 0.66)	0.55	0.67	43.5	0.61 (0.58, 0.64)	0.68	0.52
Glucose	81.2	0.67 (0.63, 0.71)	0.51	0.77	62.6	0.61 (0.57, 0.64)	0.60	0.59
Triglycerides	43.2	0.64 (0.60, 0.68)	0.48	0.76	36.0	0.61 (0.58, 0.64)	0.60	0.58

Note: Cut-points in HGS are in kilograms (kg); AUC=Area under the curve with AUC values of 0.56, 0.64, and 0.71 as thresholds for low, moderate, and high effect sizes; Sens=sensitivity; Spec=specificity.

Discussion

This is the first study to establish gender- and age group-specific criterion-referenced cut-points in HGS associated with MetS in a nationally-representative sample of U.S. adults. Crude ROC models for HGS demonstrated negligible discriminatory ability to detect MetS, and negligible to moderate discriminatory ability to detect its component risk factors. Fully adjusted ROC models showed slightly better discriminatory ability, with low to moderate discriminatory ability for MetS and negligible to moderate discriminatory ability for the component risk factors. The improved discriminatory ability of the adjusted ROC models are rewarded by the increase of the model complexity. Although this improves the magnitude of corresponding AUCs, the addition of multiple health measures reduces the clinical utility of HGS. HGS should still be utilized as a predicter for other health measures (i.e., physical function, muscular strength) however, these results do not support the use of HGS as a diagnostic tool for the detection of MetS among U.S. adults.

The results of this study differed to previous studies that have established criterion-referenced health-related cut-points for HGS. The Brown et al. and Peterson et al. (16,17) studies established cut-points in NHGS associated with Type 2 diabetes among U.S. adults. Despite all three of these studies (16,17) using adults aged 20 years and older from the NHANES dataset, differences in main findings may be due to methodological and analytical differences. For example, between-study differences included: (a) the way in which HGS was expressed (e.g., absolute HGS [this study] vs. HGS normalized for body mass); (b) the health-related outcome (MetS [this study] vs. Type 2 diabetes); (c) the use of AUCs in this study vs. AIC as a metric to evaluate logistic regressions. Although Brown et al. did not report a magnitude of fit, Peterson et al. did report a high AUC (0.85) for their corresponding model with the best AIC. Which is expected given the number of covariates in their model. Finally, (d) covariates among studies differed in fully adjusted models (16,17). Brown included sedentary behavior, alcohol use, and cigarette use while Peterson included sedentary behavior as a potential covariate.

Some studies have established criterion-referenced health-related cut-points for other fitness measures (i.e., cardiorespiratory fitness). A recent study by Wolfe Phillips et al. (23) developed and validated criterion-referenced cut-points for the modified Canadian Aerobic Fitness Test (mCAFT) — a submaximal bench stepping task — associated with MetS in a national-representative dataset of Canadian adults aged 18–69 years (25). Using ROC analysis, they found that the mCAFT demonstrated moderate discriminatory ability for the detection of MetS. Despite potential differences among the Canadian and U.S. adult populations, these results indicate that cardiorespiratory fitness has better predictive utility for MetS compared to HGS among North American adults.

Strengths of this study include the use of a nationally-representative dataset for U.S. adults, objectively measured HGS and MetS components, and the AHA criteria for determination of MetS. This study is not without its limitations. The use of fasted blood samples considerably reduced the sample size, which reduced statistical power and limited our analysis to two broad age categories. The inclusion of additional age groups, given that results supported the use of HGS, would have strengthened the argument for HGS in clinical use.

Conclusion

This study was the first to establish criterion-referenced cut-points for HGS associated with MetS using a nationally-representative sample of U.S. adults. While HGS is an important marker of current health and a predictor of future health, this study found that HGS demonstrates negligible to low ability to detect MetS and its component risk factors. There was a small improvement in discriminatory ability with the inclusion of covariates in the ROC models. These findings do not support the practical use of HGS in clinical and professional settings for the detection of MetS among U.S. adults. Future research should examine the predictive ability of other muscular fitness and cardiorespiratory fitness measures to identify health-related cut-points for MetS.

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