Hand Grip Muscle Strength, Endurance, and Anthropometric Parameters in Healthy Young Adults: Assessing the Predictive Value of Height, Weight, and BMI in a Cross-Sectional Analysis

Dr. Arijit Mazumdar,[1*] Mr. Mriganka Das [2]

1 – Assistant professor, Department of Physiology, P A Sangma International Medical College & Hospital, USTM Complex, Meghalaya, India

2- Lab Assistant, P A Sangma International Medical College and Hospital, USTM Complex, Meghalaya, India

Corresponding Author:
Dr. Arijit Mazumdar
Flat No: 101/C, Nihar apartment
PO: Pandu, Dt, Kamrup (Metropolitan)
Assam, PIN: 781012

Abstract:

Introduction: Hand grip muscle strength (HGS) and endurance are widely recognized as non-invasive, simple diagnostic tools for both the assessment and prognosis of health and disease. It is an isometric form of exercise. However, its reliability can be compromised by multiple influencing factors, including age, sex, and ethnicity. Without accounting for these determinants, the diagnostic and prognostic value of HGS and endurance measurements may be less. **Methods:** This cross-sectional study was conducted in the Department of Physiology at P A Sangma International Medical College and Hospital, Meghalaya, India, during March and April 2025, and as done following Institutional Ethical Committee approval. One hundred fifty five (155) healthy young adults provided informed written consent to participate. Anthropometric measurements (height and weight) were obtained using standardized protocols and BMI was calculated as weight (kg) divided by height squared (m^2). Hand grip muscle strength and endurance were assessed using a hand grip dynamometer. Data analysis included calculation of means, Pearson correlation coefficients, and analysis of variance (ANOVA), with significance set at $p \leq 0.05$. **Result:** Among the 155 participants, 62 (40%) were male and 93 (60%) were female. Males demonstrated higher mean values for height, weight, and muscle strength, while BMI was higher in females. Height ($r = 0.873$, $p < 0.05$) and weight ($r = 0.894$, $p < 0.05$) showed significant moderate positive correlations with HGS, and height ($r = 0.564$, $p < 0.05$) showed slight positive correlation with muscle endurance. **Conclusion:** The findings indicate that height and weight are significant anthropometric determinants of hand grip muscle strength, and height also influences endurance. These factors should be considered when interpreting HGS and endurance as diagnostic or prognostic tools in clinical and research settings.

Keywords: Endurance, Hand grip dynamometer, strength, isometric exercise, BMI

Introduction:

The isometric exercise done with the hand grip dynamometer in which hand grip strength (HGS) is a critical component in the execution of precise and refined fine motor tasks. It serves as a fundamental parameter in the physical assessment of a wide spectrum of diseases affecting the musculoskeletal, neuromuscular, and cardiorespiratory systems, particularly in paediatric, geriatric, and obese populations.[1,3] HGS is recognized for its predictive value regarding nutritional status, as well as its association with both short-term and long-term morbidity and mortality across various clinical conditions. Clinically, HGS[2,3] is frequently employed as a specific diagnostic and evaluative tool, facilitating disease diagnosis, monitoring therapeutic interventions, assessing treatment progression, and providing objective feedback during rehabilitation.[4]

A reduction in HGS can result in significant functional impairments, manifesting as diminished capacity to perform both basic and instrumental activities of daily living, ultimately compromising an individual's quality of life. However, HGS is not a static measure; it is modulated by a multitude of intrinsic and extrinsic factors. These include, but are not limited to, fatigue, diurnal variation, age, sex, nutritional status, restricted joint mobility, anthropometric characteristics, and pain perception. Numerous investigations have underscored the influence of age, sex, body size, stature, and body mass on HGS, particularly during the early stages of puberty in children.[5] Additional research has identified other anthropometric determinants, such as forearm circumference, as significant contributors to hand grip muscle strength in prepubertal cohorts. Furthermore, alternative methodologies, such as the use of modified sphygmomanometers, have been utilized to elucidate the impact of age, height, and weight on HGS in healthy young adults.[6]

Obesity has emerged as a pervasive public health concern globally, largely attributable to sedentary lifestyles, insufficient physical activity[7] and suboptimal dietary habits.[8] The prevalence of obesity in young adults is particularly alarming, given its established association with an elevated risk of chronic diseases, including type 2 diabetes mellitus, hypertension, dyslipidemia, asthma, and certain malignancies.[9,10,11] Despite the recognized importance of anthropometric parameters—such as height, weight, and body mass index (BMI)—in influencing HGS and muscular endurance,[11,12,13] the relationship between these variables in healthy young adults remains inadequately characterized. While some studies have explored the impact of anthropometric measures on HGS, the majority have focused on elderly populations or athletes, with limited research targeting young adults.[14,15] Moreover, there is a paucity of data from specific geographic regions, further highlighting the need for localized investigations.

The existing literature suggests that anthropometric factors may exert a significant influence on hand grip muscle strength and endurance, yet comprehensive studies in young adult populations are scarce.[16] This gap in knowledge underscores the necessity for targeted research to elucidate the extent to which height, weight, and BMI affect HGS and endurance in this demographic.[17] Addressing this gap, the present study was conceptualized with the hypothesis that anthropometric parameters—specifically height, weight, and BMI—are significant determinants of hand grip muscle strength and endurance in healthy young adults.[18,19]

The primary objective of this investigation was to systematically evaluate the impact of these anthropometric variables on hand grip muscle strength and endurance. Additionally, the study

aimed to quantify the correlation between these parameters and HGS, thereby providing a more nuanced understanding of the interplay between body composition and muscular function in young adults.[20] By focusing on a population that has been underrepresented in previous research, this study seeks to contribute valuable data to the existing body of knowledge and inform future clinical assessments and interventions targeting hand grip strength and endurance in young adults.[21]

Materials and Methods

This investigation was designed as a cross-sectional study to evaluate the influence of anthropometric parameters—specifically height, weight, and body mass index (BMI)—on hand grip muscle strength and endurance among healthy young adults. The study was conducted in the Department of Physiology at P A Sangma International Medical College and Hospital, USTM Complex, Meghalaya, India, during March-April 2025, following approval from the Institutional Ethics Committee.

Study Population and Sampling

A total of 155 healthy students, comprising both males and females aged 19 to 22 years, were recruited from medical course at P A Sangma International Medical College and Hospital. All participants provided written informed consent prior to inclusion in the study. The sample size was determined based on the 2021 Indian census,[22] which is yet to be reported and based on the interim reports that people in the age group of 19-22 years constitute approximately 29% of the national population. Using a confidence level of 95% (Z = 1.96) and a precision of 8, the sample size was calculated using the formula:

$N=Z^2*p*q/d^2$

, where, p=population=29, q=100-p=100-29=71

d=precision=8

in this study, N=1·96X1·96X29X71/8X8=123

where p=29 (population percentage), q=100−p=71, and d=8. Substituting these values yielded a sample size of 123; however, we got 155 volunteers.

Inclusion and Exclusion Criterias

Inclusion criterias: Right-hand dominant individuals were considered as it would lend a uniformity to the test. All participants in the study were right-handed, as previous research has indicated that right-hand dominant individuals may exhibit variance in muscle strength between hands, whereas left-handed individuals do not demonstrate significant inter-limb differences. Those volunteers were considered who were not having any muscular atrophy or hypertrophy nor there were any evidences of any neurological involvement in the right arm, forearm as well as hand. .

Exclusion criterias: The volunteers who were having any history of cardiovascular diseases or metabolic disorders. Those who attended gym attendance exceeding three weeks as there would be muscle hypertrophy after doing resistance exercises and lifting of weights. Those volunteers who regularly participated in sports involving upper limbs (e.g., basketball, volleyball), which could confound hand grip measurements.

Data Collection Procedures: On the day of assessment, participants were briefed regarding the study protocol. A brief medical history was obtained to ensure compliance with inclusion and exclusion criteria. Anthropometric measurements and hand grip assessments were then performed as follows:

Anthropometric Measurements

- **Body Weight:** Measured using a digital weighing machine. Participants wore light clothing, were barefoot, and stood upright on the scale, looking straight with the weight taken for all volunteers premeal. The weight was taken in kilograms.
- **Height:** Measured in centimeters using a stadiometer. with the occipital region, the sacral region, the calf muscle and the heels touching the stadiometer rod. The height was measured at the same time of the day in bare feet.
- **BMI Calculation:** BMI was computed using the standard formula: BMI=Weight (kg) / [(Height (m)]^2

Guidelines for obesity and overweight based on body mass indices (BMI) for Asian Indians were revised based on consensus developed through discussions by a Prevention and Management of Obesity and Metabolic Syndrome group [23]

Body Mass Index (BMI) was derived from booking weight (kilograms) and height (metres). Using this, the patients were categorized as underweight (<18.5 kg/m^2), normal or lean BMI (18.5–22.9 kg/m^2), overweight (23.0 –24.9 kg/m^2) and obese (≥25 kg/m^2) based on the revised consensus guidelines for India.

Hand Grip Strength and Endurance Assessment

Hand grip muscle strength of the right hand was measured using a standard hand grip dynamometer (manufactured by Rymet, Micro lab supplied by B.D Instrumentation India, ISO 9001:2008, WHO-GMP Certified). The assessment was conducted with participants seated, feet flat on the floor, and the dominant arm placed on a table. The elbow was flexed at 90°, the forearm in a mid-prone position, and the wrist in a neutral position. Participants were instructed to squeeze the dynamometer handles maximally and sustain the contraction for at least three seconds. Two measurements were taken within a 30-second interval, and the higher value was recorded as the maximal hand grip strength.

Hand grip endurance (HGE) was assessed by instructing participants to maintain one-third of their maximal voluntary contraction for as long as possible, with the duration recorded in seconds.[24]

Fig: 1 Hand grip Dynamometer

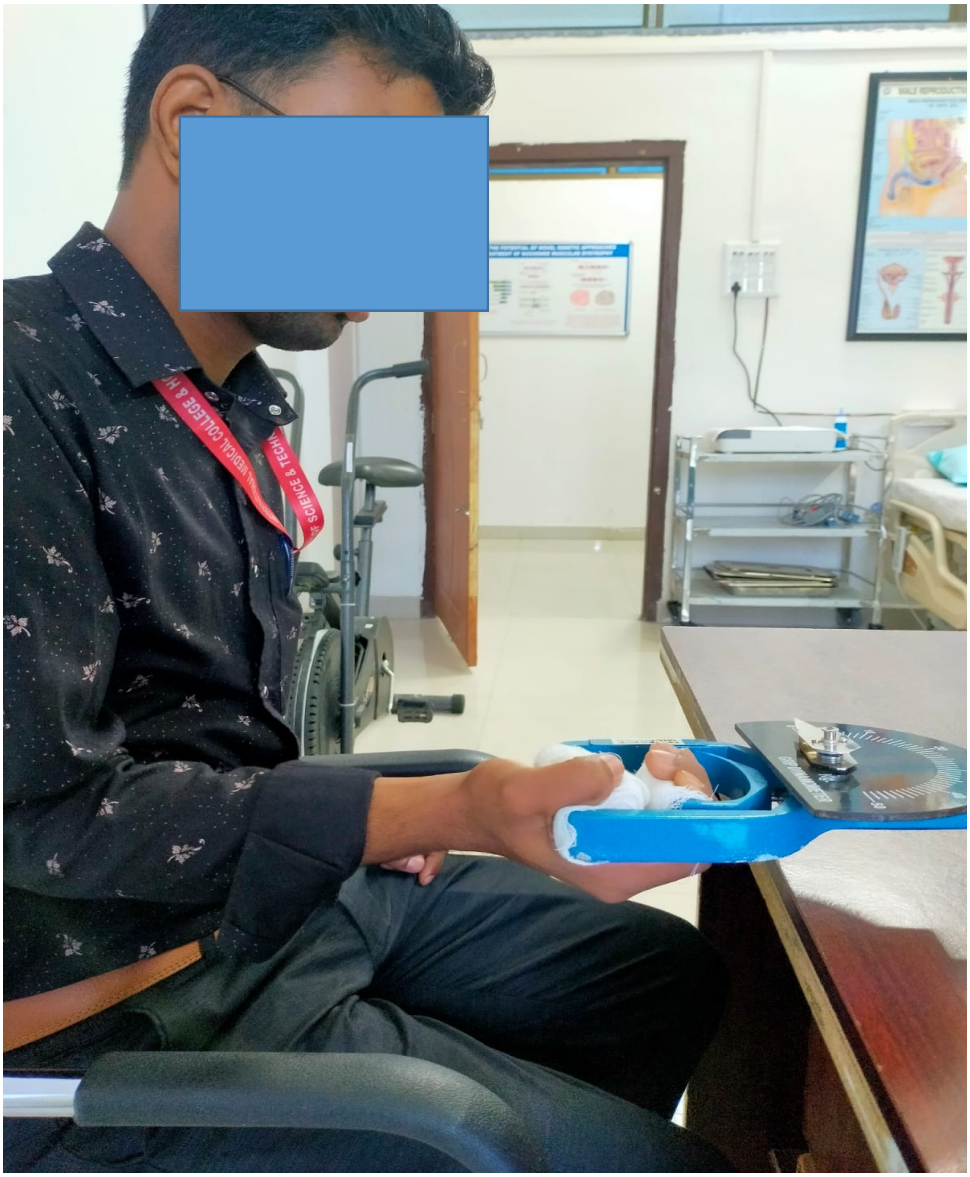

Fig: 2 Handgrip dynamometer held in hand for the HGS & HGE test.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 21. Descriptive statistics, including means and standard deviations, were calculated for all variables. The Pearson correlation coefficient was employed to assess the relationship between anthropometric parameters (height, weight, BMI) and hand grip muscle strength and endurance. Analysis of Variance (ANOVA) was used to determine the statistical significance of observed differences. A p-value of ≤ 0.05 was considered indicative of statistical significance.

Results:

Of the 155 participants, 62 were males (40%) and 93 (60%) were females. Males demonstrated higher mean values for height, weight, and muscle strength compared to females, although BMI was higher in females. The average height of males and females were 165.50±5.25 cms and 153.87±5.90 cms respectively. Average weight of males and females were 61.14±10.03kgs and 53.33±9.04kgs respectively. The average BMI of male and female subjects were 20.48±3.50 kg/m^2 and 20.68±4.5 kg/m^2 respectively.

The average handgrip muscle strength among males was 24.5±7.56 kgs and in females it was 12.50±6.27 kgs. When evaluated with the hand grip endurance it was found to be 24.52±6.3 seconds in males as against and 12.22±4.50 seconds in females.

Statistical analysis revealed a significant moderate positive correlation between height ($r = 0.621$, $p < 0.001$) and weight ($r = 0.519$, $p < 0.001$) with hand grip muscle strength. Additionally, height ($r = 0.438$, $p < 0.001$) was significantly correlated with hand grip endurance. These findings suggest that height and weight are important anthropometric determinants of hand grip muscle strength, while height also influences hand grip endurance.

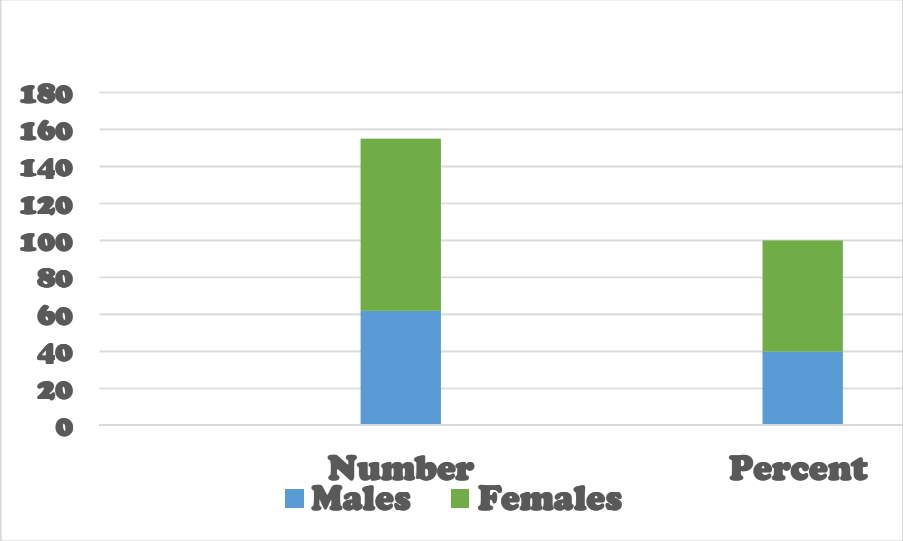

Fig:3 Number and percentage of participants in respect of Gender.

Variables	Male (62)	Female(93)	Total (155)
	Mean±SD	Mean±SD	Mean±SD
Height(cms)	165.50±5.25 cms	153.87±5.90 cms	160.79±5.58cms
Weight(Kgs)	61.14±10.03kgs	53.33.±9.04kgs	61.27±9.83kgs
BMI (Kg/m^2)	20.48±3.50	20.68±4.50	20.74±3.15
HGS (in Kg)	24.5±7.56	12.5±6.27	19.35±5.04
HE(in sec)	24.52±6.3	12.22±4.50	19.98±5.56

Table 1: Descriptive statistics for general samples.

SD: standard deviation, n: total number, cm: centimetre, kg: kilogram, m: meter, sec: second, HGS: Hand grip muscle strength, HGE: Hand grip muscle endurance

Parameters		Underweight (M=08, F=22) TOTAL=30	Normal weight (M=38, F=63) TOTAL=101	Overweight (M=11, F=6) TOTAL=17	Obese (M=5, F=2) TOTAL=7	Significance
Handgrip Strength Mean±SD	Male	23.5±5.67	26.65±7.03	27.18±9.36	25.12±7.78	>0.05,non Significant
	Female	10.52±6.3	12.12±8.97	14.45±5.46	10.32±1.34	>0.05,non Significant
	Total	19.98±4.5	20.42±10.33	22.07±9.76	18.64±4.78	>0.05,non Significant
Handgrip Endurance Mean±SD	Male	30.5±10.43	33.12±12.43	27.45±8.54	26.21±4.5	>0.05,non Significant
	Female	20.47±4.56	15.45±11.25	13.02±6.34	10.50±2.5	>0.05,non Significant
	Total	29.36±5.32	23.36±13.3	20.43±6.54	20.34±2.54	>0.05,non Significant

Table :2 Gender specific distribution of HGS and HGE as per BMI (Indian Standards)

The differences in hand grip muscle strength and endurance in different categories of BMI was investigated. The study revealed nuanced relationships between body composition and hand grip performance. While maximal hand grip strength (HGS) was observed in obese individuals (BMI ≥25 kg/m²), this finding lacked statistical significance ($p > 0.05$), suggesting no robust association between BMI and HGS. Further analysis using Pearson correlation coefficients demonstrated a moderate positive correlation between HGS and both height ($r = 0.893$, $p < 0.05$) and weight ($r = 0.874$, $p < 0.05$), indicating that increased stature and body mass predict greater grip strength in cases of isometric exercises like handgrip dynamometer. Similarly, a low but statistically significant positive correlation emerged between height and hand grip endurance (HGE) ($r = 0.564$, $p < 0.05$), implying that taller individuals exhibit enhanced muscular endurance.

Correlation of the different variables	Correlation coefficient(r)	P value	Significant / Not significant
Weight vs Handgrip strength	0.874	<0.05	Significant
Height vs Handgrip strength	0.893	<0.05	Significant
BMI vs handgrip strength	0.196	1.03	Not significant
Weight vs Muscle endurance	0.235	0.064	Not significant
Height vs Muscle endurance	0.564	<0.05	Significant
BMI vs Muscle endurance	-0.032	0.752	Not significant

Table;3 Anthropometric traits of 155 subjects compared with handgrip strengths and endurance. Pearson's coefficient of correlation was done to determine correlation amongst two variables.

In contrast, BMI showed no significant correlation with either HGS or HGE ($p > 0.05$), reinforcing the limited predictive utility of BMI alone in this context. These findings align with biomechanics principles, as height and weight reflect skeletal leverage and muscle mass—key determinants of force production. The dissociation between BMI and grip metrics may stem from BMI's inability to distinguish fat mass from lean mass. Clinically, these results underscore the importance of prioritizing height and weight over BMI when interpreting grip strength and endurance in young adults, particularly for diagnostic or prognostic applications requiring precision.

Discussion:

This cross-sectional study systematically explored the associations between key anthropometric parameters—height, weight, and BMI—and hand grip muscle strength (HGS) and endurance (HGE) in a class of healthy young adults.[25] The findings provide important insights into how these physical characteristics influence muscle function, with significant implications for clinical assessment and research.

Influence of Anthropometric Parameters on HGS and HGE

The results demonstrated that height exerts a positive influence on both hand grip muscle strength and endurance, while weight is positively associated with muscle strength alone. These findings underscore the necessity for clinicians to account for individual anthropometric differences when interpreting HGS and HGE measurements,[26,27] particularly if these assessments are to be used as diagnostic or prognostic tools. Failure to consider these factors could compromise the reliability and validity of grip strength as a marker of health or disease progression.[28]

Sex Differences in HGS and HGE

Consistent with previous literature, male participants exhibited higher values for height, weight, HGS, and endurance compared to females, although BMI was higher in females.[29] This pattern aligns with studies conducted among diverse populations, such as Nigerian secondary school students, where similar sex-based differences in grip strength and anthropometric measures were observed.[30] The higher muscle mass and strength observed in males can be attributed, at least in part, to the influence of testosterone, which not only promotes muscle hypertrophy but also increases bone density.[31] Studies have shown a significant relationship between male stature and circulating testosterone levels, further supporting the biological basis for these differences.[32]

Correlation of Height and Weight with HGS

The positive correlations identified between height, weight, and HGS in this study are consistent with findings from other research. For example, Chatterjee and Chowdhury reported that HGS measured by a dynamometer was positively correlated with weight, height, and body surface area.[33] The relationship between height and grip strength may be explained by biomechanical principles: greater height typically corresponds to longer upper limbs, which provide a mechanical advantage (longer lever arms) for force generation, thereby facilitating higher grip strength.[34,35] Similarly, body weight reflects not only adiposity but also lean body mass, the latter being a primary determinant of muscle strength. Individuals with greater lean mass are capable of generating more force.[36] Chandrasekaran et al. also reported strong correlations between age, height, weight, and grip strength using standardized measurement protocols.[37]

BMI and Its Limited Predictive Value

Interestingly, while some studies in athletic populations have found significant positive correlations between HGS and BMI, the present study did not observe a significant association between BMI and either HGS or HGE.[38,39,43] This discrepancy may be partially explained by the relatively small sample size or the specific characteristics of the study. [44,45] More fundamentally, BMI is a composite measure that does not distinguish between fat mass and lean muscle mass, nor does it provide information on the distribution of adipose tissue. [40,41]Waist circumference, a more direct measure of central adiposity, has been shown to correlate inversely with muscle strength, suggesting that fat distribution rather than total body mass may be more relevant for functional outcomes.[46] These findings reinforce the limitations of BMI as a solitary predictor of muscle function in young adults.[47]

Height and Endurance

A notable finding of this study was the significant positive correlation between height and muscle endurance, a relationship not observed with weight or BMI. This observation is consistent with other research, such as the study by Lad et al., which found that individuals with BMI values outside the normal range (either underweight or overweight) tended to have lower endurance, although the correlation was weak.[53] Another investigation conducted in Jammu similarly reported significant associations between height, weight, and endurance, but no correlation between BMI and endurance. The biomechanical explanation for the association between height and endurance may relate to the mechanical advantage conferred by longer limbs, which can generate greater force and sustain contraction over longer periods.[54,55]

Hand Anthropometry and Functional Implications

Recent studies have expanded the analysis of grip strength to include detailed hand anthropometric measurements, such as hand width, thickness, grip diameter, and circumference. These dimensions have been shown to significantly predict grip strength in both dominant and non-dominant hands, accounting for up to 52% of the variance in strength among adults.[58] Additionally, hand and forearm dimensions, as well as their ratios, have been linked to both grip strength and hand functionality, further emphasizing the multifactorial nature of muscle performance.[56,57] These findings highlight the importance of comprehensive anthropometric assessment when evaluating hand function in both clinical and occupational settings.[55]

Practical and Clinical Implications

The practical significance of these findings lies in the standardization of grip strength and endurance measurements. Given that height and weight are influential determinants of muscle strength, and height also impacts endurance,[56] it is essential to account for these variables when establishing normative values for specific populations. This is particularly relevant in clinical practice, where grip strength is used as a surrogate marker for overall health, nutritional status, or rehabilitation progress. Adjusting for anthropometric differences ensures more accurate assessment and enhances the utility of grip strength as a diagnostic and prognostic tool.[59] While the present study provides valuable insights, certain limitations must be acknowledged. The sample size, though adequate for preliminary analysis, may limit the generalizability of the findings. Additionally, the exclusive focus on right-handed individuals and a narrow age range may restrict applicability to broader populations. Future research should aim to include larger, more diverse cohorts and incorporate additional measures of body composition, such as bioelectrical impedance analysis or dual-energy X-ray absorptiometry, to better differentiate between fat and lean mass. Longitudinal studies would also help clarify the causal relationships

between anthropometric variables and muscle function over time. To summarise, this study confirms that height and weight are significant predictors of hand grip muscle strength, while height also correlates with muscular endurance in young adults. BMI, in contrast, is not a reliable indicator of grip strength or endurance in this population. These findings underscore the necessity of considering individual anthropometric characteristics when utilizing grip strength and endurance as clinical or research metrics. Standardization of measurement protocols and reference values, adjusted for height and weight, will enhance the precision and interpretability of hand grip assessments, ultimately improving their value in both clinical and epidemiological contexts.[60,61]

Conclusion:

This study demonstrates that anthropometric parameters exert distinct influences on hand grip muscle strength (HGS) and endurance (HGE) in healthy young adults. Height and weight exhibited significant positive correlations with HGS ($r = 0.874$ and $r = 0.893$, respectively; $p < 0.05$), while height alone showed a moderate yet statistically significant association with HGE ($r = 0.564$, $p < 0.05$). These findings suggest that taller individuals benefit from enhanced biomechanical leverage, as longer limbs optimize force generation through increased lever arm efficiency. Similarly, greater body weight, often indicative of higher lean muscle mass, contributes to improved grip strength. In contrast, body mass index (BMI) showed no significant correlation with either HGS or HGE, likely due to its inability to differentiate between adiposity and muscle mass, thereby limiting its utility in predicting functional outcomes.

The dissociation between BMI and grip performance underscores the importance of prioritizing direct anthropometric measures—height and weight—over composite indices like BMI in clinical and research settings. These parameters should be integral to protocols standardizing HGS and HGE assessments, particularly when establishing population-specific reference values or evaluating interventions. For instance, taller individuals may inherently exhibit greater endurance due to physiological adaptations in muscle fibre composition or metabolic efficiency, warranting tailored interpretations of endurance metrics.

These results advocate for the integration of height and weight adjustments in diagnostic and prognostic frameworks utilizing grip strength, such as assessing nutritional status, monitoring rehabilitation progress, or predicting morbidity risks. Future studies should explore these relationships in diverse demographics, including older adults and individuals with chronic conditions, while incorporating advanced body composition analyses (e.g., dual-energy X-ray absorptiometry) to delineate the contributions of fat-free mass versus adipose tissue. Such refinements will enhance the precision of HGS and HGE as biomarkers, ensuring their reliability in both clinical practice and public health initiatives.

Limitations of the study:

The present study is subject to certain limitations that may affect the generalizability and precision of the findings. Primarily, the relatively small sample size restricts the statistical power and may limit the detection of subtler associations between anthropometric variables and hand grip muscle function. Additionally, the study employed a conventional hand grip dynamometer rather than an advanced digital dynamometer, which could have provided more accurate and sensitive measurements of muscle strength and endurance. Furthermore, the assessment was confined exclusively to the dominant right hand of right-handed participants, thereby excluding potential bilateral differences and the influence of handedness on grip performance. Future research should aim to include larger, more diverse cohorts encompassing

various age groups, utilize high-precision digital dynamometers, and evaluate grip strength and endurance bilaterally in both right- and left-handed individuals. Such methodological enhancements would improve the robustness and applicability of results, facilitating a more comprehensive understanding of the interplay between anthropometric factors and hand grip muscle function.

Conflict of interest: The authors declare no conflict of interest with any person or organization.

Author Contribution: Dr. Arijit Mazumdar with the conceiving of the article, writing the abstract, introduction and methodology as well as framing the discussion and conclusion as well as data entry and evaluation.

Mr Mriganka Das – Data Entry, calculation and tabulation, critical analysis, inputs in each of the segments.

Financial assistance and sponsorship: Self-Funding

Ethical Clearance: Approved

References:

- 1. Toselli S., Badicu G., Bragonzoni L., Spiga F., Mazzuca P., Campa F. Comparison of the effect of different resistance training frequencies on phase angle and handgrip strength in obese women: A randomized controlled trial. IJERPH. 2020;17:1163. doi: 10.3390/ijerph17041163. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 2. Campa F., Silva A., Toselli S. Changes in phase angle and handgrip strength induced by suspension training in older women. Int. J. Sports Med. 2018;39:442–449. doi: 10.1055/a-0574-3166. [DOI] [PubMed] [Google Scholar]
- 3.Trivic T., Eliseev S., Tabakov S., Raonic V., Casals C., Jahic D., Jaksic D., Drid P. Somatotypes and hand-grip strength analysis of elite cadet sambo athletes. Medicine. 2020;99 doi: 10.1097/MD.0000000000018819. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 4.Lee K.-S., Jung M. Ergonomic evaluation of biomechanical hand function. Saf. Health Work. 2014;6:9–17. doi: 10.1016/j.shaw.2014.09.002. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 5.AlAhmari K., Silvian S.P., Reddy R.S., Kakaraparthi V.N., Ahmad I., Alam M.M. Hand grip strength determination for healthy males in Saudi Arabia: A study of the relationship with age, body mass index, hand length and forearm circumference using a hand-held dynamometer. J. Int. Med. Res. 2017;45:540–548. doi: 10.1177/0300060516688976. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 6.Leong D.P., Teo K.K., Rangarajan S., López-Jaramillo P., Avezum A., Orlandini A., Serón P., Ahmed S.H., Rosengren A., Kelishadi R., et al. Prospective Urban Rural Epidemiology (PURE) study investigators. Prognostic value of grip strength: Findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet. 2015;386:266–273. doi: 10.1016/S0140-6736(14)62000-6. [DOI] [PubMed] [Google Scholar]
- 7.Oliveira V.H.F., Wiechmann S.L., Narciso A.M., Deminice R. Knee extension and flexion strength asymmetry in Human Immunodeficiency Virus positive subjects: A cross-sectional study. Braz. J. Phys. Ther. 2017;21:434–439. doi: 10.1016/j.bjpt.2017.06.010. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 8.Oksuzyan A., Demakakos P., Shkolnikova M., Thinggaard M., Vaupel J.W., Christensen K., Shkolnikov V.M. Handgrip strength and its prognostic value for mortality in Moscow, Denmark, and England. PLoS ONE. 2017;12:e0182684. doi: 10.1371/journal.pone.0182684. [DOI] [PMC free article] [PubMed] [Google Scholar]

- 9.Rabelo N.D.D.A., Lucareli P.R.G. Do hip muscle weakness and dynamic knee valgus matter for the clinical evaluation and decision-making process in patients with patellofemoral pain? Braz. J. Phys. Ther. 2017;22:105–109. doi: 10.1016/j.bjpt.2017.10.002. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 10.Santos C., Matos S., Pitanga F., Maia H. Handgrip strength as discriminator of sarcopenia and sarcopenia obesity in adults of the ELSA-Brasil. Eur. J. Public Health. 2018;28(Suppl. 4) doi: 10.1093/eurpub/cky214.158. [DOI] [Google Scholar]
- 11.Ekşioğlu M. Normative static grip strength of population of Turkey, effects of various factors and a comparison with international norms. Appl. Ergon. 2016;52:8–17. doi: 10.1016/j.apergo.2015.06.023. [DOI] [PubMed] [Google Scholar]
- 12.Meldrum D., Cahalane E., Conroy R., Fitzgerald D., Hardiman O. Maximum voluntary isometric contraction: Reference values and clinical application. Amyotroph. Lateral Scler. 2007;8:47–55. doi: 10.1080/17482960601012491. [DOI] [PubMed] [Google Scholar]
- 13.Mathiowetz V., Kashman N., Volland G., Weber K., Dowe M., Rogers S. Grip and pinch strength: Normative data for adults. Arch. Phys. Med. Rehabil. 1985;66:69–74. [PubMed] [Google Scholar]
- 14.Portney L.G., Watkins M.P. Foundations of Clinical Research: Applications to Practice. 3rd ed. Prentice-Hall; Upper Saddle River, NJ, USA: 2008. [Google Scholar]
- 15.Sağiroğlu I., Kurt C., Kurt Ömürlü I., Çatikkaş F. Does hand grip strength change with gender? The traditional method vs. the allometric normalisation method. EJPESS. 2016;2:84–93. [Google Scholar]
- 16.Chelliah K., Rizam R. Association of dominant hand grip strength with anthropometric measurements and Body Mass Index. Int. J. Pharm. Sci. Res. 2018;10:525–531. [Google Scholar]
- 17.Andersen-Ranberg K., Petersen I., Frederiksen H., MacKenbach J.P., Christensen K. Cross-national differences in grip strength among 50+ year-old Europeans: Results from the SHARE study. Eur. J. Ageing. 2009;6:227–236. doi: 10.1007/s10433-009-0128-6. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 18.Bohannon R. Hand-grip dynamometry predicts future outcomes in aging adults. J. Geriatr. Phys. Ther. 2008;31:3–10. doi: 10.1519/00139143-200831010-00002. [DOI] [PubMed] [Google Scholar]
- 19.Amo-Setién F.J., Leal-Costa C., Abajas-Bustillo R., González-Lamuño D., Redondo-Figuero C. Factors associated with grip strength among adolescents: An observational study. J. Hand Ther. 2020;33:96–102. doi: 10.1016/j.jht.2018.10.005. [DOI] [PubMed] [Google Scholar]
- 20. Rantanen T, Guralnik JM, Foley D, Masaki K, Leveille S, Curb JD, et al. Midlife hand grip strength as a predictor of old age disability. JAMA. 1999;281:558-60. Doi: 10.1001/jama.281.6.558. PMID: 10022113.
- 21.Petrofsky JS, Lind AR. Aging, isometric strength and endurance, and cardiovascular responses to static effort. J Appl Physiol. 1975;38:91-95. Doi: https://doi.org/10.1152/jappl.1975.38.1.91. PMID: 1110248.
- 22. Wang AY, Sea MM, Ho ZS, Lui SF, Li PK, Woo J. Evaluation of handgrip strength as a nutritional marker and prognostic indicator in peritoneal dialysis patients. Am J Clin Nutr. 2005;81:79-86. Doi: 10.1093/ajcn/81.1.79. PMID: 15640464.

- 23.Norman K, Stobäus N, Gonzalez MC, Schulzke JD, Pirlich M. Hand grip strength: Outcome predictor and marker of nutritional status. Clin Nutr. 2011;30:135-42. Doi: 10.1016/j.clnu.2010.09.010. Epub 2010 Oct 30. PMID: 21035927.
- 24. Jürimäe T, Hurbo T, Jürimäe J. Relationship of handgrip strength with anthropometric and body composition variables in prepubertal children. Homo.2009;60(3):225-38. Doi: 10.1016/j.jchb.2008.05.004. Epub 2008 Nov 8. PMID: 18996520.
- 25. Hogrel JY, Decostre V, Alberti C, Canal A, Ollivier G, Josserand E, et al. Stature is an essential predictor of muscle strength in children. BMC Musculoskelet Disord. 2012;13:176. Doi: 10.1186/1471-2474-13-176. PMID: 22989265.
- 26. Incel NA, Ceceli E, Durukan PB, Erdem HR, Yorgancioglu ZR. Grip strength: Effect of hand dominance. Singapore Med J. 2002;43(5):234-37. PMID: 12188074.
- 27. Koley S, Singh AP. An association of dominant hand grip strength with some anthropometric variables in Indian collegiate population. Anthropol Anz. 2009;67(1):21-28. Doi: 10.1127/0003-5548/2009/0003. PMID: 19462672.
- 28. Jürimäe T, Hurbo T, Jürimäe J. Relationship of handgrip strength with anthropometric and body composition variables in prepubertal children. Homo. 2009;60:225-38. Doi: 10.1016/j.jchb.2008.05.004. PMID: 18996520.
- 29. Budziareck MB, Pureza Duarte RR, Barbosa-Silva MC. Reference values and determinants for handgrip strength in healthy subjects. Clin Nutr. 2008;27:357-62. Doi: 10.1016/j.clnu.2008.03.008. PMID: 18455840.
- 30. Alaska Department of Health and Social Services, Division of Public Health, Section of Chronic Disease Prevention and Health Promotion. Prevalence of overweight and obesity among anchorage school district students, 1998-2008. Chronicles. 2009;2(1).
- 31. Koley S, Singh AP. An association of hand grip strength with some anthropometric variables in Indian cricket players. Phys Educ Sport. 2009;7:113-23. PMID: 19462672.
- 32. Smrithi Shetty C, Parakandy SG, Nagaraja S. Influence of various anthropometric parameters on handgrip strength and endurance in young males and females. IntJ Biol Med Res. 2012;3(3):2153-57.
- 33. Body mass index-BMI; https://www.euro.who.int/en/health-topics/diseaseprevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi;last accessed on 21/04/2022.
- 34. Andersen-Ranberg K, Petersen I, Frederiksen H, Mackenbach JP, Christensen K. Cross-national differences in grip strength among 50+year-old Europeans: Results from the SHARE study. Eur J Ageing. 2009;6:227-36. Doi: 10.1007/s10433-009-0128-6. PMID: 28798606.
- 35. Oseloka IA, Bello BM, Oliver HW, Emmanuel UU, Abraham MS. Association of handgrip strength with body mass index among nigerian students. J Pharm Biol Sci. 2014;9(1):01-07. Doi: https://doi.org/10.9790/3008-09160107.
- 36. The Effects of Testosterone on the Body, https://www.healthline.com/health/lowtestosterone/ effects-on-body. Last accessed on 21/04/2022.
- 37. Kowal M, Sorokowski P, Żelaźniewicz A, Nowak J, Orzechowski S, Żurek A, et al. A positive relationship between body height and the testosterone response to

physical exercise. Evolution and Human Behavior. 2021;42(3):179-85. Doi: https://doi.org/10.1016/j.evolhumbehav.2020.08.012.

- 38. Chatterjee S, Chowdhuri BJ. Comparison of grip strength and isometric endurance between the right and left hands of men and their relationship with age and other physical parameters. J Human Ergology. 1991;20:41-50.
- 39.Harris T. Muscle mass and strength: Relation to function in population studies. J Nutr. 1997;127(5):10045-65. Doi: https://doi.org/10.1093/jn/127.5.1004S. PMID: 9164284.

40. Chandrasekaran B, Ghosh A, Prasad C, Krishnan K, Chandrasharma B. Age and anthropometric traits predict handgrip strength in healthy normals. J Hand Microsurg. 2010;2(2):58-61. Doi: 10.1007/s12593-010-0015-6. PMid: 22282669.

- 41..Dolcos F., Rice H.J., Cabeza R. Hemispheric asymmetry and aging: Right hemisphere decline or asymmetry reduction. Neurosci. Biobehav. Rev. 2002;26:819–825. doi: 10.1016/S0149-7634(02)00068-4. [DOI] [PubMed] [Google Scholar]
- 42.Bohannon R.W. Grip strength: A summary of studies comparing dominant and nondominant limb measurements. Percept. Mot. Ski. 2003;96:728–730. doi: 10.2466/pms.2003.96.3.728. [DOI] [PubMed] [Google Scholar]
- 43.Roy E.A., Bryden P., Cavill S. Hand differences in pegboard performance through development. Brain Cogn. 2003;53:315–317. doi: 10.1016/S0278-2626(03)00133-7. [DOI] [PubMed] [Google Scholar]
- 44.Noguchi T., Demura S., Aoki H. Superiority of the dominant and nondominant hands in static strength and controlled force exertion. Percept. Mot. Ski. 2009;109:339–346. doi: 10.2466/pms.109.2.339-346. [DOI] [PubMed] [Google Scholar]
- 45.Aoki H., Demura S. Laterality and accuracy of force exertion in elbow flexion. Adv. Phys. Educ. 2017;7:101–106. doi: 10.4236/ape.2017.71009. [DOI] [Google Scholar]
- 46.Corballis M.C. Handedness and cerebral asymmetry: An evolutionary perspective. In: Hugdahl K., Westerhausen R., editors. The Two Halves of the Brain: Information Processing in the Cerebral Hemispheres. MIT Press; Cambridge, MA, USA: 2010. [DOI] [Google Scholar]
- 47.Annett M. Handedness as a continuous variable with dextral shift: Sex, generation, and family handedness in subgroups of left- and right-handers. Behav. Genet. 1994;24:51–63. doi: 10.1007/BF01067928. [DOI] [PubMed] [Google Scholar]
- 48.Raymond M., Pontier M., Dufour A.-B., Møller A.P. Frequency-dependent maintenance of left handedness in humans. Proc. R. Soc. B Boil. Sci. 1996;263:1627–1633. doi: 10.1098/rspb.1996.0238. [DOI] [PubMed] [Google Scholar]
- 49.Bryden M., Roy E., Manus I., Mc Bulman-Fleming M. On the Genetics and Measurement of Human Handedness. Laterality. 1997;2:317–336. doi: 10.1080/713754269. [DOI] [PubMed] [Google Scholar]
- 50.McManus C. Right Hand Left Hand: The Origins of Asymmetry in Brains, Bodies, Atoms and Culture. Harvard University Press; Cambridge, MA, USA: 2002. [Google Scholar]
- 51.Porac C., Coren S., Duncan P. Life-span Age Trends in Laterality. J. Gerontol. 1980;35:715–721. doi: 10.1093/geronj/35.5.715. [DOI] [PubMed] [Google Scholar]
- 52.Geschwind N., Galaburda A.M. Cerebral Lateralization: Biological Mechanisms, Associations, and Pathology. MIT Press; Cambridge, MA, USA: 1987. [Google Scholar]

- 53.Halpern D.F., Coren S. Handedness and life span. N. Engl. J. Med. 1991;324:998. doi: 10.1056/nejm199104043241418. [DOI] [PubMed] [Google Scholar]
- 54.Annett M. Handedness and Brain Asymmetry: The Right Shift Theory. Psychology Press; Hove, UK: 2002. [Google Scholar]
- 55.Musalek M. Skilled performance tests and their use in diagnosing handedness and footedness at children of lower school age 8–10. Front. Psychol. 2015;5:5. doi: 10.3389/fpsyg.2014.01513. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 56.Brown S., Roy E., Rohr L., Bryden P. Using hand performance measures to predict handedness. Laterality. 2006;11:1–14. doi: 10.1080/1357650054200000440. [DOI] [PubMed] [Google Scholar]
- 57.Whittington J.E., Richards P.N. The stability of children's laterality prevalences and their relationship to measures of performance. Br. J. Educ. Psychol. 1987;57:45–55. doi: 10.1111/j.2044-8279.1987.tb03060.x. [DOI] [Google Scholar]
- 58.Sommer I.E.C., Aleman A., Somers M., Boks M.P.M., Kahn R.S. Sex differences in handedness, asymmetry of the Planum Temporale and functional language lateralization. Brain Res. 2008;1206:76–88. doi: 10.1016/j.brainres.2008.01.003. [DOI] [PubMed] [Google Scholar]
- 59.Johnston D.W., Nicholls M.E.R., Shah M., Shields M.A. Nature's experiment? Handedness and early childhood development. Demography. 2009;46:281–301. doi: 10.1353/dem.0.0053. [DOI] [PMC free article] [PubMed] [Google Scholar]
- 60.Shahida M.N., Zawiah M.S., Case K., Shalahim N.S.M. The relationship between anthropometry and hand grip strength among elderly Malaysians. Int. J. Ind. Ergon. 2015;50:17–25. doi: 10.1016/j.ergon.2015.09.006. [DOI] [Google Scholar]
- 61.Rønn P.F., Andersen G.S., Lauritzen T., Christensen D.L., Aadahl M., Carstensen B., Jørgensen M.E. Ethnic differences in anthropometric measures and abdominal fat distribution: A cross-sectional pooled study in Inuit, Africans and Europeans. J. Epidemiol. Community Health. 2017;71:536–543. doi: 10.1136/jech-2016-207813. [DOI] [PubMed] [Google Scholar]