Research Report

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
2017, Vol. 45(2) 540–548

DOI: 10.1177/0300060516688976
journals.sagepub.com/home/imr
SAGE

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

Khalid A Alahmari, S. Paul Silvian, Ravi Shankar Reddy, Venkata Nagaraj Kakaraparthi, Irshad Ahmad and Mohammad Mahtab Alam

Abstract

Objectives: To determine whether age, body mass index (BMI), hand length and forearm circumference were predictive of hand grip strength in healthy Saudi Arabian adult males.

Methods: This cross-sectional descriptive study recruited healthy adult male volunteers. Their anthropometric characteristics including age, BMI, hand length and forearm circumference were measured using routine techniques. Hand grip strength was assessed using a Jamar® Hydraulic Hand Dynamometer. The data were analysed using Pearson correlation coefficient (*r*) as well as by a stepwise multiple linear regression analysis.

Results: The study included 116 healthy males who satisfied the inclusion criteria. A Pearson correlation coefficient matrix demonstrated that all the four measures, age, BMI, hand length and forearm circumference, were significantly correlated with hand grip strength. Age had an inverse correlation with hand grip strength. The anthropometric measures of hand length, age and forearm circumference accounted for 44.2% (R^2 0.442) of the variation of the hand grip strength.

Conclusion: Hand length, age and forearm circumference significantly impacted on hand grip strength in Saudi Arabian healthy adult males.

Department of Medical Rehabilitation Sciences, College of Applied Medical Sciences, King Khalid University, Abha, Kingdom of Saudi Arabia

Corresponding author:
S. Paul Silvian, Department of Medical Rehabilitation Sciences, College of Applied Medical Sciences, King Khalid University, PO box no. 3665, Guraiger, Abha, Kingdom of Saudi Arabia.
Email: pslvin@kku.edu.sa

Keywords
Hand grip strength, hand length, age, forearm circumference, healthy adult males, hand-held dynamometer, Saudi Arabia

Date received: 9 July 2016; accepted: 20 December 2016

Introduction

Hand grip strength estimation is imperative in determining the efficacy of treatment strategies and hand rehabilitation. This strength is the result of a maximum voluntary forceful flexion of the fingers by an individual under normal conditions.[1] Grip strength is crucial for the human body while performing prehensile and precision hand functions. The human hand is a complex structure tailored to the functions of manipulation, and the hand conveys sensory information to brain about temperature, form and texture of the objects it controls.[2] Grip strength has been studied as a predictor of general health, heart disease,[3] cerebrovascular disease,[4,5] disability,[4,5] cognitive decline,[4,5] future fracture risks,[6,7] and mortality.[8,9] Many studies have correlated grip strength with various physical variables like nutritional status, bone mineral content, and muscle strength.[4,10] Research suggests that there are strong correlations between grip strength and various anthropometric traits, such as age,[11] hand length,[12] body mass index (BMI),[13] and upper arm circumference.[14] Such correlations have been found to exist in studies among children, adults and aging people.[15]

Previously published studies have used regression models to understand the role of anthropometric measures in determining hand grip strength. For example, hand length and hand width were positively associated with grip strength.[16,17] It has also been shown that the dominant hand has approximately 10% stronger grip strength than the non-dominant hand.[18] Research suggests that forearm circumference is predictive of grip strength in men but not in women.[19] A previous study proposed that the hand circumference could be used for predicting hand grip strength among undergraduate students.[20] In a study of the relationship between hand grip strength and stature, weight, arm circumferences and subcutaneous skin folds, males attained greater values for anthropometric variables and greater hand grip strength values than their female counterparts.[21] Research has been undertaken to determine the relationship between forearm circumference and grip strength among athletes and basketball players.[22,23] To date, there are mixed opinions on whether anthropometric measures can predict maximum hand grip strength.[24]

Hand grip strength measurement becomes reliable only when standardized methods and calibrated equipment are used, even when there are different assessors or different brands of dynamometers.[25] Hand-held dynamometers have been used to measure muscle strength, especially muscles that are strong enough to exert force against gravity and tolerate resistance. The Jamar® Hydraulic Hand Dynamometer (Patterson Medical [formerly Sammons Preston], Warrenville, IL, USA) was found to give the most accurate and acceptable measures of grip strength.[26,27]

From a literature review, many studies mention various measurements such as hand breadth, hand length, or circumferences of the wrist and forearm as predictors of hand grip strength, but the evidence remains scarce and varied. For example, some research has investigated hand grip strength in children and adolescents,[28] while other studies have considered differences between the dominant and non-dominant hand.[18,22] Data on healthy adults and hand grip

strength are scarce in the Middle East. A study that assessed the hand grip strength in healthy adults from 21 countries found that men in the Middle East exhibited intermediate hand grip strength compared with the highest levels of hand grip strength noted among European and North American populations.[29] Other than this recent study, there is still a dearth of available literature on hand grip strength in the Saudi Arabian male population. Recent studies have suggested that hand length and forearm circumference should be studied as additional factors when measuring hand grip strength.[28,30] Previous research using predictive analyses have confirmed hand circumference to be the most significant predictor of grip strength.[28] There are very few studies that have compared a wide range of age in terms of understanding the relationship between age and hand grip strength.[4,31] There have been varied results in the understanding of the relationship between BMI and hand grip strength;[1,10] with BMI being shown to be insignificant in some studies of hand grip strength.[12,32]

This present study aimed to determine whether age, BMI, hand length and forearm circumference were predictive of hand grip strength in healthy adult Saudi Arabian males.

Patients and methods

Study population

This cross-sectional descriptive study enrolled healthy male subjects who were randomly recruited during the time of student admission to King Khalid University, Abha, Kingdom of Saudi Arabia. The study was conducted by the Department of Medical Rehabilitation Sciences, College of Applied Medical Sciences, King Khalid University, Abha, Kingdom of Saudi Arabia between December2015 and April 2016. Data were collected by the Department of Physical Therapy, King Khalid University. Inclusion criteria were as follows: (i) aged 20–74 years; (ii) in good health; (iii) willing to participate in the study. Exclusion criteria were as follows: (i) recent hand injury or surgery; (ii) hand deformity: (iii) any oedematous, vascular, or inflammatory condition of the hand; (iv) neck problems.

The study received ethical approval from the King Khalid University Ethical Committee (registration no. Ha-06-B-001). Healthy subjects gave written informed consent after being provided with a brief description of the study.

Anthropometric measurements

Age was recorded for each study subject. BMI was measured using a standard digital weighing scale and a standard height scale and was calculated using the formula: $BMI = \text{weight (kg)}/\text{height (m)}^2$. The forearm girth circumference of each study subject was measured using a flexible measuring tape (cm) at a point 3 cm below the cubital fossa. The point to be measured was marked with a marker pen. The hand length was measured from the distal crease of the wrist to the tip of the middle finger using a flexible measuring tape (cm).

Hand grip strength recording

Prior to the commencement of data collection, a practice trial was undertaken in order to familiarize the subjects with the Jamar® Hydraulic Hand Dynamometer (Patterson Medical [formerly Sammons Preston], Warrenville, IL, USA). Before testing, the examiner (V.N.K.) demonstrated how to hold the handle of the dynamometer. Subjects were asked to maximally squeeze the handle of the dynamometer with their dominant hand for 3 s and this process was repeated for all of the handle positions. For standardization, the third handle position was selected on the basis of comfort and

maximum voluntary contraction. The subjects were asked to sit with their shoulders in a neutral position and the dominant arm was positioned at the side of the body with the elbow flexed to 90° and the wrist in a mild ulnar deviated position. The same instructions were given for each trial. After the subject was positioned with the dynamometer, the examiner (V.N.K.) instructed the subject to 'squeeze as hard as possible – hard, harder and relax'. The subjects were provided with a rest period of 2 min to control for the effects of fatigue. Three trials were performed and recorded for each subject and the maximum voluntary hand grip strength was calculated as the mean of the three trials of grip strength for the dominant hand.

Statistical analyses

The sample size (SS) of 115.67 was calculated using the following formula, where, $Z = 1.96$ at 95% confidence level, $p =$ proportion of population picking a choice ($p = 0.082$, derived from a pilot study; $1 - p = 0.918$), and $e^2 =$ margin of error (0.05):

$$SS = \frac{Z^2 \times (p) \times (1 - p)}{e^2}$$

All statistical analyses were performed using the SPSS® statistical package, version 22.0 (SPSS Inc., Chicago, IL, USA) for Windows®. The mean of three consecutive trials of hand grip strength for each subject was used for the analyses. After establishing normality of the data using the Shapiro–Wilk parametric test, a stepwise multiple linear regression analysis was used to determine the influence of anthropometric data on hand grip strength. Pearson correlation coefficient was used to provide a better understanding of the relationship between four anthropometric measures and hand grip strength. The mean hand grip strength value of the dominant hand was used as the dependent variable hand grip strength for the stepwise regression analyses. A P-value ≤ 0.05 was considered statistically significant.

Results

A total of 125 healthy volunteers were screened for inclusion in the study. Of these, seven were excluded based on the inclusion and exclusion criteria and two refused to participate. The remaining 116 subjects had a mean ± SD age of 42.55 ± 15.45 years (range, 20 – 74 years). The majority of the study subjects were right hand dominant (113; 97.4%) and three subjects were left hand dominant (2.6%). The anthropometric measurements are presented in Table 1.

A Pearson correlation coefficient matrix for age, BMI, hand length, forearm circumference and hand grip strength is presented in Table 2. Hand grip strength demonstrated significant correlations with all four anthropometric measurements ($P \leq 0.05$).

Table 1. Anthropometric characteristics for healthy male subjects who participated in a study to determine the relationship between anthropometric measurements and hand grip strength ($n = 116$).

Anthropometric characteristic	
Age, years	42.55 ± 15.45
20–30	25
31–40	32
41–50	19
51–60	20
61–74	20
Body mass index, kg/m^2	27.52 ± 5.08
<18.5	0
18.5–24.9	46
25.0–29.9	32
30.0–39.9	38
Forearm circumference, cm	28.07 ± 1.78
Hand length, cm	19.08 ± 0.85

Data presented as mean ± SD or *n* of patients.

Table 2. Pearson correlation coefficient matrix for anthropometric characteristics and hand grip strength in healthy male subjects ($n = 116$).

	Age	BMI	Forearm circumference	Hand length	Hand grip strength
Age	1				
BMI	−0.143	1			
Forearm circumference	0.029	0.680[a]	1		
Hand length	−0.222[b]	0.222[b]	0.447[a]	1	
Hand grip strength	−0.453[a]	0.288[a]	0.409[a]	0.500[a]	1
n	116	116	116	116	116

[a]Correlation was significant at the 0.01 level (2-tailed).
[b]Correlation was significant at the 0.05 level (2-tailed).
BMI, body mass index.

Table 3. Stepwise regression analysis for anthropometric characteristics and hand grip strength in healthy male subjects ($n = 116$).

Variables in the equation	R	R^2	Adjusted R^2	R^2 change	Standardized β coefficients	*t*-value	*P*-value
HL	0.500	0.250	0.244	0.250	0.279	3.416	$P = 0.01$
HL + age	0.611	0.373	0.362	0.123	−0.399	−5.451	$P < 0.01$
HL + age + FC	0.665	0.442	0.427	0.069	0.312	3.708	$P < 0.01$

HL, hand length; FC, forearm circumference.

A stepwise multiple linear regression analysis was used to understand the predictive linear trend among the independent and dependent variables. The variables age, BMI, forearm circumference and hand length were entered into the equation. This regression analysis was used to evaluate the order of importance of the four variables and to select the useful subset of variables in explaining the dependent variable.[33] The regression model selected only three variables, hand length, age and forearm circumference to be the significant predictors of hand grip strength (Table 3). Hand length was found to have a correlation with hand grip strength indicated by $R = 0.500$ and accounted for 25.0% (R^2 value $= 0.250$) of the variation in hand grip strength. Age was the second variable selected into the regression equation, with an inverse correlation (indicated by $R = 0.611$ and a negative *t*-value). Age accounted for an additional 12.3% (R^2 change) and together with hand length accounted for 37.3% of the variation in hand grip strength among healthy males. Forearm circumference accounted for an additional 6.9% (R^2 change) and together with age and hand length accounted for 44.2% of the variation in hand grip strength. The three variables together predicted 44.2% ($R^2 = 0.442$) of what constitutes hand grip strength of healthy adult males in Saudi Arabia.

Discussion

The results of the present study show that a stronger hand grip strength is determined by a longer hand length, a larger forearm circumference and a younger age in Saudi

Arabian men. To the best of our knowledge, this present study is the only one to report the predictive relationships between hand grip strength and the anthropometric measures under study in a Saudi Arabian population of adult males. This present study provides evidence that body dimensions can influence hand grip strength, which might have an impact on rehabilitation. The hand length of a patient can be measured easily and conveniently, and this can be a practical measure for predicting hand grip strength. The wide variation in the age of the healthy participants in the present study provided a better understanding of the effect of age on hand grip strength.

The present study was designed to determine the relationship between hand grip strength and hand dimensions using a standardized protocol so that the predictors of hand grip strength could be identified. The study used the third handle position of the Jamar® Hydraulic Hand Dynamometer. Grip testing is usually undertaken using the second and third handle positions of the Jamar® Hydraulic Hand Dynamometer,[34] but the participants in the present study exhibited comfort and maximum hand grip strength when using the third handle position. Because of the difference in hand size, women tend to exhibit their greatest grip strengths with the handle in the second position, whereas the third handle position is usually the most advantageous for men.[35]

A Pearson correlation coefficient matrix for age, BMI, hand length, forearm circumference and hand grip strength demonstrated that the five anthropometric measures had correlations with each other, except for age, which was not correlated with BMI and forearm circumference. All four anthropometric measures had significant correlations with hand grip strength. An earlier study found that only hand circumference had a significant impact on hand grip strength.[20] Another study conducted in Malaysia found that forearm circumference and hand length were systematically selected in a regression model predicting hand grip.[24] Hand length was found to be the most significant contributor to hand grip strength in the present study, accounting for 25% of the variation in the hand grip strength. Previous research demonstrated that hand length had a significant impact on the grip strength.[29] Men are found to have longer hands when compared with women.[7] Dominant right hand grip strength was found to be strongly associated with hand length, hand width, and forearm girth, but was not associated with height, weight and BMI in healthy Indian collegiate females aged 18–25 years.[22] Since the hand length measured in the present study also measured the middle finger length (distal crease), the variable hand length could encompass a more predictive power when measuring hand grip strength.

In the present study, hand grip strength was inversely associated with age and the relationship was likely caused by a decline in musculoskeletal strength and muscle mass with increasing age. There might also have been reduced steadiness of the hand among the older participants compared with younger participants, which could have led to reduced hand grip strength in this present study. The mean age of the participants in this present study was 42.55 years and the majority were older than 31 years ($n = 91$), which might explain the inverse correlation with age. Prior research has demonstrated that hand grip strength showed a significant correlation with age when measured using a Jamar® Smart Hand Dynamometer.[36]

Forearm circumference provides the most practical index of hand grip strength related to muscle mass, and was the most significant predictor of hand grip strength in several studies.[20,25] In the stepwise multiple linear regression equation in the present study, forearm circumference was found to contribute only 6.9% to hand grip strength, making it the third and last predictor.

The muscles used to produce grip force are predominantly located in the forearm and would be heavily influenced by the amount of fat.[37] In this present study, there is a high correlation between BMI and forearm circumference ($r = 0.680$), indicating that the hand size of the participants was higher. Since the majority of the population lies in the overweight and obese categories,[15] this could be the reason why the forearm circumference was found to have a lower regression value of 6.9% on hand grip strength in this Saudi Arabian population. Fat-free cross-sectional area is found to be highly correlated with hand grip strength.[20] In a recent study comparing the global hand grip strength, the BMI of Middle Eastern men was $27.0 \pm 4.82\,kg/m^2$, indicating that there was a higher number of overweight individuals in the Middle East when compared with Asian, Chinese and African male populations.[29]

In the present study, BMI demonstrated a positive correlation with hand grip strength, but it was excluded from the stepwise regression model. The reason for the exclusion would be the lack of participants in the lowest BMI category ($n = 0$; $<18.5\,kg/m^2$). BMI and hand grip strength research has provided conflicting findings. For example, elderly individuals with normal BMI show positive correlations, whereas in adults aged 25–70 years in the overweight and obese ranges, BMI was correlated with a lower hand grip strength.[10,32] This could also be the reason why in the Pearson correlation coefficient matrix in the present study, age was not significantly correlated with BMI.

In the present study, hand length was found to be the most significant variable in predicting hand grip strength among Saudi Arabian men. Hand length, age and forearm girth circumference predicted 44.2% of hand grip strength in the Saudi Arabian men in this present study. This result concurs with earlier studies, which demonstrated that hand length and forearm circumference contributed to 23% of hand grip strength.[24,38] The present study demonstrated a higher R^2 value (0.44) when compared with previous research,[24] but it was still <50%, which reduced the predictive capacity of the overall model.

The study had several limitations. First, the small sample size, lack of female participants and the wide age range makes it difficult to make generalizations based on the findings. Secondly, a better prediction model could have been obtained if the study had taken account of the dominant hand, physical activity of the participant, hand problems and muscle mass. Thirdly, the cross-sectional nature of this study cannot determine the longitudinal course of individual grip strengths. Future research could also determine if palm width, middle finger length, shoulder position, joint position, thumb position and body posture impact on the hand grip strength.

In conclusion, the present study provides a sample of healthy adult male data on hand grip strength for clinical use and hand rehabilitation. It explored the relationship between grip strength and hand length, age and forearm circumference. Hand length and forearm circumference should be considered for hand grip strength measurements in the older age group since these anthropometric measures could impact on the results of therapy and influence hand function training.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Oseloka IA, Bello BM, Oliver HW, et al. Association of handgrip strength with body mass index among Nigerian students. *IOSR-JPBS* 2014; 9: 1–7.
2. Wilk KE and Arrigo C. Current concepts in the rehabilitation of the athletic shoulder. *J Orthop Sports Phys Ther* 1993; 18: 365–378.
3. Silventoinen K, Magnusson PK, Tynelius P, et al. Association of body size and muscle strength with incidence of coronary heart disease and cerebrovascular diseases: a population-based cohort study of one million Swedish men. *Int J Epidemiol* 2009; 38: 110–118.
4. Cooper R, Kuh D, Cooper C, et al. Objective measures of physical capability and subsequent health: a systematic review. *Age Ageing* 2011; 40: 14–23.
5. Hebert LE, Scherr PA, McCann JJ, et al. Change in direct measures of physical performance among persons with Alzheimer's disease. *Aging Ment Health* 2008; 12: 729–734.
6. Cawthon PM, Fullman RL, Marshall L, et al. Physical performance and risk of hip fractures in older men. *J Bone Miner Res* 2008; 23: 1037–1044.
7. Sirola J, Rikkonen T, Tuppurainen M, et al. Grip strength may facilitate fracture prediction in perimenopausal women with normal BMD: a 15-year population-based study. *Calcif Tissue Int* 2008; 83: 93–100.
8. Cooper R, Kuh D and Hardy R. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. *BMJ* 2010; 341: c4467.
9. Sasaki H, Kasagi F, Yamada M, et al. Grip strength predicts cause-specific mortality in middle-aged and elderly persons. *Am J Med* 2007; 120: 337–342.
10. Liao K-H. Hand grip strength in low, medium, and high body mass index males and females. *Middle East J Rehabil Health* 2016; 3: e53229.
11. Martin JA, Ramsay J, Hughes C, et al. Age and grip strength predict hand dexterity in adults. *PLoS One* 2015; 10: e0117598.
12. Koley S and Pal Kaur S. Correlations of hand grip strength in selected hand-arm-anthropometric variables in Indian inter-university female volleyball players. *Asian J Sports Med* 2011; 2: 220–226.
13. Hager-Ross C and Rosblad B. Norms for grip strength in children aged 4–16 years. *Acta Paediatr* 2002; 91: 617–625.
14. Ibegbu AO, Baita MB, Hamman WO, et al. Evaluation of the relationship between handgrip strength with some anthropometries among Nigerian secondary school students. *IOSR Journal* 2014; 17: 921–927.
15. Memish ZA, El Bcheraoui C, Tuffaha M, et al. Obesity and associated factors—Kingdom of Saudi Arabia, 2013. *Prev Chronic Dis* 2014; 11: E174.
16. Chatterjee S and 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 Hum Ergol (Tokyo)* 1991; 20: 41–50.
17. Vaz M, Hunsberger S and Diffey B. Prediction equations for handgrip strength in healthy Indian male and female subjects encompassing a wide age range. *Ann Hum Biol* 2002; 29: 131–141.
18. Ertem K, Harma A, Cetin A, et al. An investigation of hand dominance, average versus maximum grip strength, body mass index and ages as determinants for hand evaluation. *Isokinet Exerc Sci* 2005; 13: 223–227.
19. Anakwe RE, Huntley JS and McEachan JE. Grip strength and forearm circumference in a healthy population. *J Hand Surg Eur Vol* 2007; 32: 203–209.
20. Li K, Hewson DJ, Duchêne J, et al. Predicting maximal grip strength using hand circumference. *Man Ther* 2010; 15: 579–585.
21. Montalcini T, Migliaccio V, Yvelise F, et al. Reference values for handgrip strength in young people of both sexes. *Endocrine* 2013; 43: 342–345.
22. Koley S and Singh AP. An association of dominant hand grip strength with some anthropometric variables in Indian collegiate population. *Anthropol Anz* 2009; 67: 21–28.
23. Koley S, Singh J and Singh Sandhu J. Anthropometric and physiological characteristics on Indian inter-university basketball players. *J Hum Sport Exerc* 2010; 5: 389–399.

24. Mohan V, Shamsaimon NSB, Japri MIB, et al. Forearm circumference and hand length predicts maximal hand grip strength among Malaysian population. *Middle-East J Sci Res* 2014; 21: 634–639.
25. Bandyopadhyay A. Body composition and hand grip strength in male brick-field workers. *Malays J MedSci* 2008; 15: 31–36.
26. Wadsworth CT, Krishnan R, Sear M, et al. Intrarater reliability of manual muscle testing and hand-held dynametric muscle testing. *Phys Ther* 1987; 67: 1342–1347.
27. Shah UN, Sirajudeen MS, Somasekaran PK, et al. The association between hand grip strength and hand dimensions in healthy Indian females. *IJCRR* 2012; 4: 36–42.
28. Fallahi AA and Jadidian AA. The effect of hand dimensions, hand shape and some anthropometric characteristics on handgrip strength in male grip athletes and non-athletes. *J Hum Kinet* 2011; 29: 151–159.
29. Leong DP, Teo KK, Rangarajan S, et al. Reference ranges of handgrip strength from 125,462 healthy adults in 21 countries: a prospective urban rural epidemiologic (PURE) study. *J Cachexia Sarcopenia Muscle* 2016; 7: 535–546.
30. Angst F, Drerup S, Werle S, et al. Prediction of grip and key pinch strength in 978 healthy subjects. *BMC Musculoskelet Disord* 2010; 11: 94.
31. Shin H, Panton LB, Dutton GR, et al. Relationship of physical performance with body composition and bone mineral density in individuals over 60 years of age: A systematic review. *J Aging Res* 2011; 2011: 191896.
32. Lad UP, Satyanarayana P, Shisode-Lad S, et al. A study on the correlation between the body mass index (BMI), the body fat percentage, the handgrip strength and the handgrip endurance in underweight, normal weight and overweight adolescents. *J Clin Diagn Res* 2013; 7: 51–54.
33. Thompson B. Stepwise regression and stepwise discriminant analysis need not apply here: a guidelines editorial. *Educational and Psychological Measurement* 1995; 55: 525–534.
34. Cooper C. *Fundamentals of hand therapy (second edition): clinical reasoning and treatment guidelines for common diagnoses of the upper extremity*. St Louis: Elsevier Mosby, 2013.
35. Hunter JM, Schneider LH, Mackin EJ, et al. *Rehabilitation of the hand: surgery and therapy*. St Louis: Mosby, 1990.
36. Jürimäe T, Hurbo T and Jürimäe J. Relationship of handgrip strength with anthropometric and body composition variables in prepubertal children. *Homo* 2009; 60: 225–238.
37. Rice VJ, Williamson TL and Sharp M. Using anthropometry and strength values to predict grip strength. *Advances in Occupational Ergonomics and Safety* 1998; 2: 378–381.
38. Chandrasekaran B, Ghosh A, Prasad C, et al. Age and anthropometric traits predict handgrip strength in healthy normals. *J Hand Microsurg* 2010; 2: 58–61.