ORIGINAL ARTICLE

Relationship between physical strength measurements and anthropometric variables: multivariate analysis

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ABSTRACT

Muscular/ physical strength are fundamental in order to satisfy basic needs for survival and productivity, especially among labourer populations in developing countries. Anthropometric variables found to be one of the key determinants of strength; however, the overall relationship between physical body dimension and strength were yet to be explored. Aim of the study was to explore the relationship between strength and anthropometric variables.

Crosssectional data on strength (handgrip and back strength) and anthropometric measurements were taken from 536 healthy adult Santal labourers (Male=251, Female=285) of Birbhum district, West Bengal, India. Statistical analysis including Pearson's correlation and canonical correlation analysis (CCA) were used.

Strength measurements negatively correlated with age and positively correlated with most of anthropometric measurements. CCA between strength and anthropometry were 0.765 ($p<0.001$, explained 85.53% total variance) and 0.611 ($p<0.001$, explained 71.41% total variance) for males and females respectively. Cross-loading value of CCA indicates fat-free-mass, forearm circumference and weight for male and fat-free mass, chest circumference and wrist breadth for female were most important predictors of strength.

The CCA model indicate that fat-free mass, forearm circumference, weight, chest circumference and wrist breadth were the most important anthropometric variables related to overall strength measurements of Santal labourer population. However, further researches require for generalizing this model.

Key words: anthropometric measurements, canonical correlation analysis, fat-free mass, physical strength, Santal.

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INTRODUCTION

Human survival is largely dependent on the individual's ability to perform muscular work[1,2]. The advancement of technology, mechanization and automation in many sectors has greatly reduced the physical labour/ muscular work in humans. In spite of this, physical labour is still required in many work situations, especially in developing countries. In India, most of the unorganized sectors are poorly aided with modern technology and thus, physical labour is an integral part for the productivity. Therefore, the assessment of physical labour/ muscular strength and its determinants are necessary for better productivity, sustainable development and health as well as welfare of the labourers[3].

Strength is the capacity of an individual to exert force against some external object or resistance[4]. In other words, strength is the maximum force which can be exerted against an immovable object (static or isometric strength), the heaviest weight which can be lifted or lowered (dynamic strength), or the maximal torque which can be developed against a pre-set rate-limiting device (iso-kinetic strength)[5]. Handgrip strength and back strength tests are one of the simple, non-invasive methods for testing muscular/ physical strength of the individual/ population, which is also suitable for both epidemiological and clinical setup[6]. However, variation in terms of strength tests were reported between sexes[7], geographical regions, ethnicity[8], handedness of the participant[9], genetic endowment[10], socio-cultural background[11], anthropometric profile[12], age[13], physical training[14] and so on. Besides, posture (position of body and wrist) of exerting strength[15] and occupational exposure to certain hazardous substances[16] also affects strength of the individuals. Instead of that most of the scholars argued that strength tests can be used as a predictor for overall health and well-being[17], morbidity and mortality[18,19], nutritional status[20,21] and productivity of the workforce[22].

The relationship between strength measurements and anthropometric profile were demonstrated in several studies e.g. Malina[1] reported that excess body weight, fatness and endomorphic body shape negatively effects strength measurements. However, Kritz-Silverstein and Barrett-Connor[23] pointed out that over-weight individual had greater grip strength in both dominant and non-dominant hand than under-weight individual. Fuster and colleague[24] reported that grip strength was more related with body weight compared to height. However, Chandrasekaran and colleague[25] reported that both height and weight were equally associated with grip strength of an individual. Some studies found relationship between strength measurements and upper extremity measurements[12], measurements on wrists and hands[26], fat free mass[27] and body surface area[28]. Other studies reported that back strength was significantly associated with height, weight, BMI, hip circumference[29] and scapular skin-fold thickness[13]. Thus, studies (mentioned above) are not consistent in their findings, primarily to recognize the important anthropometric measurements for strength. Moreover, to our knowledge none of the study explores the overall relationship between strength and anthropometric profile. However, Schaik et al. (2019)[30] pointed out that the statistical analysis of such complex data can be overwhelming for end users, particularly for developing public health strategies at local level as well as save the cost of time-consuming or expensive data collection and thus, may generate new insights into the problem.

In view of the above, present study was conducted among the Santal labourer population of Birbhum district, West Bengal. The aim was to explore the relationship between strength measurements (viz. handgrip and back strength) and selected anthropometric variables of the adult Santal labourer population.

MATERIALS AND METHODS

Study participants: Data were collected as a part of a larger bio-medical project ('Health status of the stone mine/ quarry workers of Birbhum district, West Bengal') conducted on a group of Santal labourer residing in Suri sub-division of Birbhum district, West Bengal. Cross-sectional data on strength (handgrip and back strength) and anthropometric measurements were taken from 536 healthy adult Santal labourers (i.e. wage earner in stone mines and agricultural sectors) of both sex (251 males, 285 females) aged between 18 to 65 years. The study was restricted to single ethnic group (i.e. Santal) in order to avoid possible ethnic/ genetic effect (if any) in respect of variables under study.

Santals are the third largest marginal *(schedule tribe)* community and distributed in most of the districts of West Bengal[31]. Santals were classified as 'Pre-Dravidian' tribe. Their language, *Santali* belongs to the Mundari branch of Austro-Asiatic language family[32] and now they have their own script i.e. 'O*l-Chiki*'.

No statistical sampling was attempted for the selection of study participants. Individuals who persuaded to participate and voluntarily agreed with written consent were included in the present study without any bias. The research was conducted after prior approval from the Ethical Committee for the Protection of Research Risks to Humans, Indian Statistical Institute.

Data types: Strength data in terms of handgrip strength (on both hands) and back strength were collected through battery operated digital handgrip dynamometer and back strength dynamometer (manufactured by Takei Scientific Instrument Co. Ltd., Tokyo, Japan) respectively, following standard protocols for measurements.

In measuring handgrip strength, participants instructed to pull one arm of the dynamometer as close as possible with another arm fixed with palm, in standing position, using one's strength of a single hand. No part of upper or lower arm or hand may push against any object or any other part of the body. Handgrip strength measured in terms of scores observed on the dial of handgrip dynamometer and the highest score considered out of three satisfactory attempts. The measurements were taken on both the hands separately.

In of case back strength, participants instructed to stand in erect posture on the base of the dynamometer with straight arms and fingers extended downward as far as possible towards thigh. The chain (bar attached to the chain) was then fixed with the instrument so that it becomes 1 to 2 inches below one's fingertip. Then participant were asked to bent forward slightly and pull the bar, which is attached through chain with the base of the dynamometer. The tests done consecutively three times and the best score was recorded.

The IBP basic list of anthropometric measurements were included like height, sitting height, weight, diameters (bi-condylar of humerus, bi-condylar of femur, bi-acromial and bi-iliac), circumferences (forearm, medial calf, chest, waist and hip) skin-fold thickness (biceps, triceps, medial calf, subscapular and supra-iliac) as well as measurements on hand length and wrist breadth on both hands were taken using standard techniques and instruments[33]. Further, body mass index (BMI), fat mass (in kg) and fat free mass (in kg) were calculated using following formulae-

Body Mass Index (BMI) = Body weight (kg)/ Stature (m.) ^{2}
Surface area (SA)= 0.007466 ×Weight (kg) $^{0.425}$× Height (cm) $^{0.725}$
Fat Mass (kg) = (Fat %/ 100) ×Weight (kg), where Fat% = (4.201/D – 3.813) × 100 and D= 1.0890 – {0.0028× TSF (mm)}[34]
Fat Free Mass (kg) = Weight (kg) – Fat Mass (kg)

Due to the absence of written records of age in some of the individuals, the ages were estimated with reference to important local events and cross-checked with elderly individuals, which were further compared with the ages of individuals for whom age records existed.

Statistical analysis: Descriptive statistics computed for each variable under present study. Pearson's correlation analysis performed between strength measurements and anthropometric measurements to understand the bivariate relationship.

Canonical correlation analysis (CCA) performed to understand the overall relationship between strength (both grip and back strength as a whole) and anthropometric measurements of an individual. CCA indicates the relationship between two sets of variables i.e. first set consists of strength measurements [viz. Right Hand Grip Strength (RHGS), Left Hand Grip Strength (LHGS) and Back Strength (BS)] and the second set consists of all anthropometric measurements and age. Age of the participants was considered in the analysis as it influenced both strength and anthropometric measurements. The analysis proceeds by collapsing each subject's score on the variables in each set of variables into a composite score. The composite scores are derived in such a way that the relationship between two variable sets is maximized. Canonical correlation value is the bivariate correlation between two composite score. We consider first canonical function because it provides highest correlation value and can explain majority of variance of the depended set. Canonical loadings and cross-loadings value provides information about the most influential variables for each set, which influence the other sets.
All the statistical analyses have been done using SPSS software 16.0 (SPSS Inc., Chicago, IL, USA) and SAS software 9.0 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Table 1 shows descriptive statistics of age and strength measurements of Santal labourer population. The mean (with SD) age of the study participants was 35.10±13.17 and 32.80±11.01 for males and females respectively. In males, the mean values of handgrip strength were 18.58±6.38 (RHGS) and 17.76±6.29 (LHGS) and back strength was 101.80±22.47. In females, the mean values of handgrip strength were 8.59±3.09 (RHGS) and 8.42±3.01 (LHGS) and back strength was 53.47±15.82.

Table 1 Descriptive statistics of strength measurements of Santal labourer population

	Male (n= 251)				Female (n=285)			
	Mean	***SD***	***95% C.I.***		***Mean***	***SD***	***95% C.I.***	
Age (years)	35.10	13.17	33.47	36.74	32.80	11.01	31.51	34.08
Strength Measurements (kg)								
Right handgrip strength (RHGS)	18.58	6.38	17.78	19.37	8.59	3.09	8.23	8.95
Left handgrip strength (LHGS)	17.76	6.29	16.98	18.54	8.41	3.01	8.06	8.76
Back strength (BS)	101.80	22.47	99.01	104.60	53.47	15.82	51.63	55.32

Table 2 shows results of Pearson's correlation coefficients (r) between strength measurements and all anthropometric measurements including age among Santal labourer population. Statistically significant negative correlation found between age and all the three strength measurements (viz. RHGS, LHGS and BS). On the other, statistically significant positive correlation found between all anthropometric measurements and strength measurements except few (In males: BID for LHGS, SISKF for BS and in females: BID, WC, BSKF for RHGS, BID, WC, BSKF, MCSKF, SSSKF, SISKF for LHGS; BDH, BID, all skinfold measurements, FM for BS) for both males and females.

Table 2 Pearson's correlation coefficient (r) between strength measurements and anthropometric measurements including age among Santal labourer population

		Male (n=251)			Female (n=286)		
Measurements	Abbreviation	RHGS	LHGS	BS	RHGS	LHGS	BS
Left handgrip strength	LHGS	0.830**	-	-	0.765**	-	-
Back strength	BS	0.669**	0.628**	-	0.496**	0.481**	-
Age	AGE	-0.457**	-0.408**	-0.273**	-0.284**	-0.249**	-0.145*
Height	HT	0.342**	0.326**	0.278**	0.278**	0.315**	0.314**
Sitting height	STH	0.403**	0.357**	0.231**	0.151*	0.224**	0.205**
Weight	WT	0.551**	0.492**	0.442**	0.300**	0.324**	0.267**
Diameters							
Bi-condylar of humerus	BDH	0.226**	0.223**	0.241**	0.197**	0.256**	0.114
Bi-condylar of femur	BDF	0.284**	0.259**	0.247**	0.206**	0.271**	0.202**
Bi-acromial	BAD	0.271**	0.261**	0.270**	0.213**	0.203**	0.212**
Bi-iliac	BID	0.180**	0.116	0.139*	-0.079	-0.024	0.059
Length and breadth							
Hand length (right)	HLR	0.282**	0.311**	0.252**	0.230**	0.279**	0.192**
Wrist breadth (right)	WBR	0.381**	0.313**	0.332**	0.268**	0.350**	0.235**
Hand length (left)	HLL	0.281**	0.322**	0.281**	0.208**	0.266**	0.177**
Wrist breadth (left)	WBL	0.388**	0.334**	0.349**	0.172**	0.184**	0.136*
Circumference							
Forearm	MUAC	0.560**	0.497**	0.488**	0.202**	0.229**	0.199**
Medial calf	MCC	0.459**	0.378**	0.316**	0.200**	0.242**	0.173**
Chest (normal)	CCN	0.400**	0.339**	0.356**	0.317**	0.319**	0.226**

Measurements	Abbreviation	Male (n=251) RHGS	Male (n=251) LHGS	Male (n=251) BS	Female (n=286) RHGS	Female (n=286) LHGS	Female (n=286) BS
Waist	WC	0.251**	0.193**	0.209**	0.049	0.091	0.150*
Hip	HC	0.445**	0.374**	0.356**	0.172**	0.197**	0.190**
Skinfold thickness							
Biceps	BSKF	0.252**	0.252**	0.133*	0.094	0.089	0.077
Triceps	TSKF	0.234**	0.218**	0.171**	0.146*	0.123*	0.047
Medial calf	MCSKF	0.297**	0.291**	0.175**	0.156**	0.091	0.021
Subscapular	SSSKF	0.276**	0.234**	0.173**	0.143*	0.115	0.066
Supra-iliac	SISKF	0.170**	0.131*	0.091	0.122*	0.104	0.069
Indices							
Body mass index	BMI	0.396**	0.343**	0.319**	0.175**	0.181**	0.126*
Fat mass	FM	0.370**	0.342**	0.270**	0.213**	0.206**	0.116
Fat free mass	FFM	0.570**	0.505**	0.467**	0.309**	0.348**	0.319**

$*p\leq0.05$, $**p\leq0.001$

Table 3 shows the result of canonical correlation analysis (CCA) between two sets (i.e. Set 1 = strength measurements [RHGS, LHGS, BS] and Set 2= all anthropometric measurements and age) of variables. The CCA is restricted to deriving three functions because the dependent set contained the maximum number of three variables.

In males, the first canonical function shows 0.7657 correlations and 85.53% variance explained from the first canonical function. Similarly, the second and third function represented 8.53% and 5.94% respectively. Only the first correlation was statistically significant (p<0.001, F-test). Therefore, only the first function has been elaborated and noteworthy in the context of present study.

In females, the first canonical function shows 0.6107 correlations and 71.41% variance explained from the first canonical function. Similarly, the second and third function represented 17.98% and 10.61% respectively. Only the first correlation was statistically significant (p<0.001, F-test). Therefore, only the first function has been elaborated and noteworthy in the context of present study.

Table 3 Canonical Correlation Analysis (CCA) of strength measurements and anthropometric measurements including age of Santal labourer population

Canonical Function	Eigen Value	Variance %	Variance % Cumulative	Canonical Correlation	Square Can. Correlation	F value	p value
Males							
1	1.4168	85.53	85.53	0.7657	0.5862	4.180	<0.001
2	0.1413	8.53	94.06	0.3518	0.1238	1.170	0.234
3	0.0984	5.94	100.00	0.2993	0.0896	1.010	0.450
Females							
1	0.5949	71.41	71.41	0.6107	0.3729	2.670	<0.001
2	0.1498	17.98	89.39	0.3609	0.1303	1.280	0.108
3	0.0884	10.61	100.00	0.2850	0.0812	1.00	0.471

Table 4 shows the loadings and cross-loadings of the variables for the first canonical function in canonical correlation analysis for both males and females. Canonical loadings depict correlation between observed variables (dependent/ independent) with the same set of canonical variate (dependent/ independent set). On the other, the canonical cross-loadings show correlation between observed variables (dependent/ independent) with the opposite set of canonical variate (dependent/ independent set).

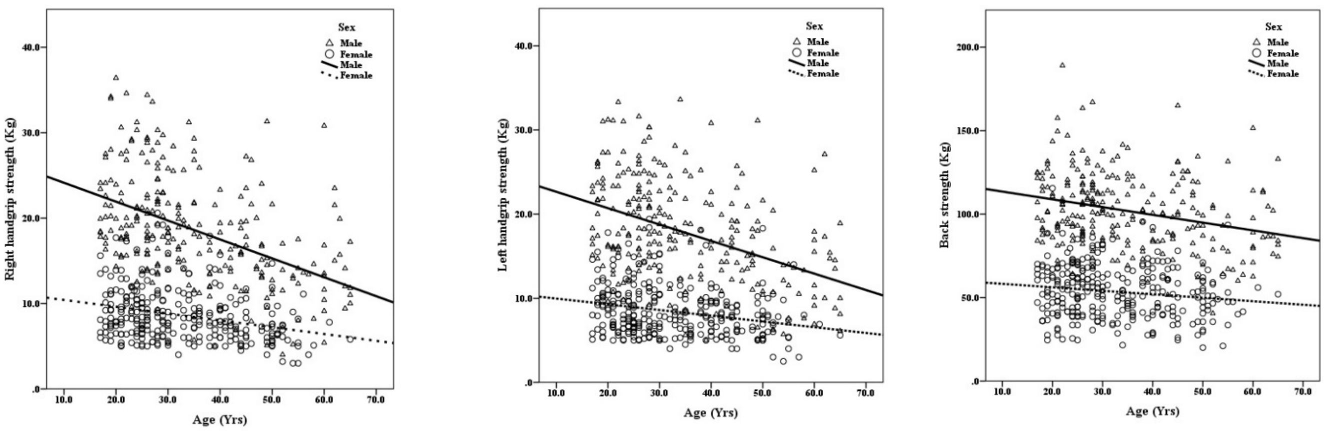
In males, the loading of the variables for first function reveals that most important variables for anthropometric set was fat free mass (loading: 0.759) followed by forearm circumference (loading: 0.752) and weight (loading: 0.733). On the other, loading values of the variables for first function reveals that all the strength measurements were more or less equally contributing for the strength set (RHGS loading: 0.979, LHGS loading: 0.898, and BS loading: 0.773). The cross-loadings of the variables for first function reveals that most important variables for strength were the following anthropometric measurements- fat free mass (cross-loading: 0.581), forearm circumference (cross-loading: 0.576) and weight (cross-loading: 0.561).

In females, the loading of the variables for first function reveals that most important variables for anthropometric set was fat-free mass (loading: 0.591) followed by chest circumference (loading: 0.559), weight (loading: 0.555) and wrist breadth (loading: 0.551). On the other, loading values of the variables for first function reveals that left handgrip strength (loading: 0.947) and right handgrip strength (loading: 0.928) both were more or less equally contributing for the strength set. The cross-loadings of the variables for first function reveals the most important variables for strength were the following anthropometric measurements- fat free mass (cross-loading: 0.361), chest circumference (cross-loading: 0.342), weight (cross-loading: 0.339) and wrist breadth (cross-loading: 0.336).

Table 4 The loadings and cross-loadings of the variables for the first canonical function in canonical correlation analysis

	Variables	Males		Females	
		Loadings	Cross-loadings	Loadings	Cross-loadings
		Dependent variables (Strength)			
Dependent Set	RHGS	**0.979**	**0.750**	**0.928**	**0.567**
	LHGS	**0.898**	**0.688**	**0.947**	**0.578**
	BS	**0.773**	**0.592**	**0.571**	0.349
		Independent variables (Anthropometric)			
Independent Set	AGE	-0.585	-0.448	-0.461	-0.282
	HT	0.461	0.353	0.536	0.327
	STH	0.513	0.393	0.343	0.209
	WT	**0.733**	**0.561**	**0.555**	**0.339**
	BDH	0.323	0.246	0.397	0.243
	BDF	0.384	0.294	0.427	0.261
	BAD	0.379	0.290	0.372	0.227
	BID	0.225	0.172	-0.076	-0.046
	MUAC	**0.752**	**0.576**	0.387	0.236
	MCC	0.588	0.450	0.393	0.240

Variables	Males		Females	
	Loadings	Cross-loadings	Loadings	Cross-loadings
CCN	0.535	0.409	**0.559**	**0.342**
WC	0.326	0.250	0.138	0.084
HC	0.584	0.447	0.333	0.203
BSKF	0.327	0.250	0.162	0.099
TSKF	0.309	0.237	0.229	0.140
MCSKF	0.388	0.297	0.205	0.125
SSSKF	0.352	0.269	0.222	0.136
SISKF	0.209	0.160	0.196	0.120
RHL	0.399	0.305	0.452	0.276
WBR	0.505	0.386	**0.551**	**0.336**
LHL	0.409	0.313	0.422	0.258
WBL	0.522	0.399	0.315	0.193
BMI	0.524	0.401	0.313	0.191
FM	0.490	0.375	0.364	0.222
FFM	**0.759**	**0.581**	**0.591**	**0.361**



Right handgrip strength (RHGS) and age

Left handgrip strength (LHGS) and age

Back strength (BS) and age

Figure 1 Shows changes in strength measurements with age in either sex of Santal labourer population

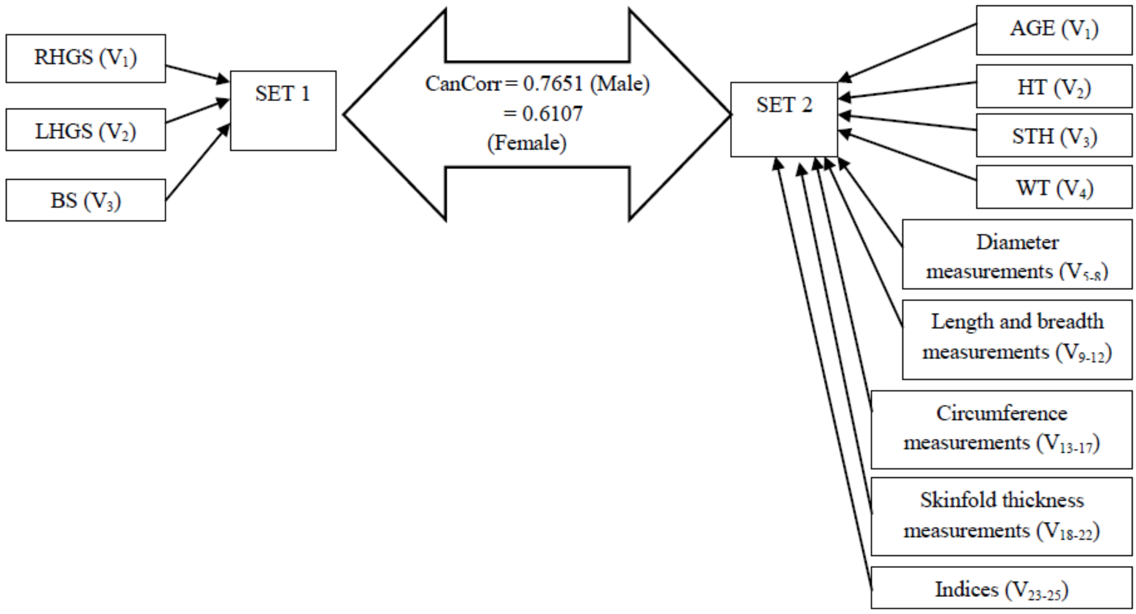


Figure 2 Shows relationship (CCA) between strength measurements and anthropometric measurements of Santal labourer population

DISCUSSION

The aim of the present study was to know the relationship between strength measurements and anthropometric variables of adult Santal labourer population of Birbhum district, West Bengal. The individuals of the present study were from same ethnic origin, have more or less similar socio-economic condition. The test protocols for collection of data were similar for all the individuals. All the data were collected by single investigator (BM) with single set of instrument.

The result of present study depicts higher values in strength measurements in males compared to females. Similar findings reported in most of the previous studies[35,36] and they noted that may be due to advantages in amount of muscle mass and contractile tissue in males as compared to females. Secondly, the advantages of height and forearm length in males favoured them for greater lever arm for force generation. Finally, the nature of daily activity is more strenuous in males that facilitate more developed and stronger muscles than females. However, the pattern of strength measurements were similar in boys and girls up to puberty, and there after it diversified from one another as a result of predominant adipose deposition in girls and increases in muscle mass in boys[37,38]. Strength measurement reaches its peak during the middle age and then gradually declines with increment of age irrespective of sex[39].

The result of present study indicate that the mean value of handgrip and back strength of both male and female participants were much lower as compared to male agricultural labourers of Jalpaiguri district[40], female construction labourer of Jalandhar[41] and brickfield workers of Hooghly district[42,43]. The lower values in strength measurements of the present population may be associated with their poor nutritional and socio-economic condition as noted elsewhere[44]. Chilima and Ismail[45] also pointed out that poor grip strength of Malawian sample significantly related with their poor nutritional condition (indicated by low BMI). Further, Pieterse and colleague[46] added that poor grip strength among the Rwandan refugees was associated with long and/ or short-term effect of poor living condition, which is common in most of the developing countries. In a large-scale study, Leong et al.[8] stated that people of South East Asia generally have lower strength measurements compared to other parts of the world that attributes to their poor nutritional and socio-economic condition.

The results of Pearson's correlation analysis indicate that strength measurements negatively correlated with age. Therefore, strength measurements gradually decline with advancement of age. Empirical studies on Japanese-American[47] and U.K.[48] also figure out that grip strength declines one to two percent annually. Rosenberg[49] and Chen et al.[50] explained that aging process associated with decrease in hormonal level, loss of muscle fibres and muscle mass that resulting changes in muscle strength. Moreover, the steadiness in hands decreases with increase in age that also resulting decline in strength parameters[51].

On the other, handgrip (both hands) and back strength was positively correlated with most of the anthropometric measurements that is also found in earlier studies[52-55]. Similarly, Roy and Pal[13] reported that the mean value of anthropometric measurements were greater in higher strength group compared to their lower counterpart, indicative of strong positive correlation among the variables. In addition, More and Vyavahare[55] suggested that the knowledge on strength and anthropometric traits might have an impact on productivity and rehabilitation, particularly among the people who exploiting their physical/ muscular strength for earning.

The results of canonical correlation analysis indicate that present model explained around 85% and 71% variability of the strength data from anthropometric variables for males and females respectively. The model also depicts that in males, most significant predictors of strength measurements were fat-free mass, forearm circumference and weight. In females, most significant predictors of strength measurements were fat-free mass, chest circumference, weight and wrist breadth. Similar to the present finding, Roberts and colleague[56] noted that forearm circumference of the adult naval personnel were significantly associated with their strength. Further, studies confirmed that anthropometric measurements related to upper extremities[12,54] especially measurements on hands[51] were most important predictors of strength measurements. Rice et al.[57] explained that may be due to the muscles that are used to produce grip force are primarily located in the forearm regions. Besides, strong association between strength components and fat-free mass were also reported by some studies[19,58]. Jurimaea et al.[59] and de Souza et al.[60] found that fatfree mass had greatest influence on strength parameters. Studies[42,43] conducted on labourer population narrated that greater daily physical activity associated with lower body fat deposition, resulting increase in strength parameters. Similar to the present finding, the relationship between strength measurements and weight were documented in many studies[61,62]. They elucidate that strength measurements were highest in normal weight individual followed by under-weight and obese. The reason may be energy deficiency in under-weight individual, while fatty infiltration in muscle and changes in distribution of type I and II muscle fibres are the reason behind lower strength among obese individual.

However, the result of the present study cannot be claimed to be universal because of the limitations of present study - (a) study was restricted to a particular occupational group with cross-sectional in nature, (b) single ethnic/ genetic (endogamous) group, (c) other uncontrollable factors like diurnal variation, temperature, humidity and other concomitants were not consider. Therefore, future studies in different populations (ethnic/genetic) and different occupational groups with larger sample size, considering all the limitations of the present study would provide better insights into the present problem.

CONCLUSION

In sum, the result of present study provides a sample of healthy adult Santal labourer population on strength measurements that may use for epidemiological/ clinical and rehabilitation purposes. It examined the overall relationship between strength and anthropometric measurements. Strength measurements share a strong relationship with anthropometric measurements along with age. Fat-free mass, forearm circumference, weight, chest circumference and wrist breadth were the most important anthropometric measurements that were found to be related with the overall strength measurements.

ABBREVIATIONS

RHGS: Right hand grip strength; LHGS: Left hand grip strength; BS: Back strength; HT: Height; STH: Sitting height; WT: Weight; BDH: Bi-condylar diameter of humerus; BDF: Bi-condylar diameter of femur; BAD: Bi-acromial diameter; BID: Bi-iliac diameter; HLR: Hand length (right); WBR: Wrist breadth (right); HLL: Hand length (left); WBL: Wrist breadth (left); MUAC: Mid-upper arm/ Forearm circumference; MCC: Medial calf circumference; CCN: Chest circumference (normal); WC: Waist circumference; HC: Hip circumference; BSKF: Biceps skinfold; TSKF: Triceps skinfold; MCSKF: Medial calf skinfold; SSSKF: Subscapular skinfold; SISKF: Supra-iliac skinfold; BMI: Body mass index; FM: Fat mass; FFM: Fat free mass; CCA: Canonical Correlation Analysis.

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