Predicting Muscular Strength with 3D Optical in a Diverse Adult Population

Devon CATALDI [1], Jonathan BENNETT [1], Brandon QUON [1], Lambert LEONG [1],
Yong En LIU [1], Nisa KELLY [1], Steven B HEYMSFIELD [2], John A SHEPHERD [1]
[1] University of Hawaii Cancer Center, Honolulu HI, USA;
[2] Pennington Biomedical Research Center, Baton Rouge LA, USA

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Background

Lower limb muscular strength is a well-known predictor of all-cause mortality and physical function in adults. Assessment of lower limb muscle strength using the criterion isokinetic dynamometer method is expensive and often not accessible in clinical or field settings. Accessible alternatives to the dynamometer would allow for broader screening of the risk and consequences of frailty, including falls and fractures. Recently, 3-dimensional optical (3DO) scanners have been investigated as an alternative to manual anthropometry and other body composition measures for health assessment. 3DO whole-body scans have the potential for predicting strength due to their ability to produce over 200 variables of total and regional anthropometric measurements such as limb length and girth. Our previous studies have found only modest 3DO anthropometry and isokinetic knee extension; female: R^2=0.24, RMSE=31.28, male: R^2=0.34, RMSE=54.51 (1). Bioelectrical impedance (BIA) is another standard clinical tool for estimating body composition, such as skeletal muscle (SMM), phase angle (PhA), which could be a potential complementary tool to 3DO given its ability to give valid estimates of muscle strength.

Objective

Our objective is to identify the optimum estimate of lower limb strength using a combination of 3DO anthropometry measures and BIA.

Methods

1. Experimental Design

This analysis was part of Shape Up! Adults, an ongoing stratified cross-sectional observational study (NIH R01 DK109008, clinicaltrials.gov ID NCT03637855). Participant's demographics were taken, such as sex, age, height, weight, BMI and ethnicity. Shape Up! Adults study participants were stratified by age (18–40 y, 40–60 y, >60 y), ethnicity (non-Hispanic white, non- Hispanic black, Hispanic, Asian, and native Hawaiian or Pacific Islander), sex, BMI [(in kg/m3) <18, 18–25, 25–30, >30], and geographic location (San Francisco, CA; Baton Rouge, LA; or Honolulu, HI). Participants in Shape Up! Adults were excluded if they could not stand without aid for 2 min, could not lie flat for ten min without movement, had metal objects in their body, or had significant body shape–altering procedures (e.g., liposuction, amputations, breast augmentation or reduction). Female participants were also excluded if pregnant or breastfeeding. All participants were examined at either the University of California, San Francisco (UCSF), Clinical and Translational Science Institute, the Pennington Biomedical Research Center (PBRC), or the University of Hawaii Cancer Center (UHCC) Body Composition Laboratory. The institutional review boards approved the study protocol at each site. Participants included in the present sample were recruited between October 2015 and September 2020. All participants gave written informed consent. Participants underwent whole-body 3DO scans, BIA for body composition assessment, as well as thigh strength tests.

2. Whole-body 3DO scanning (3DO)

Each participant underwent two 3DO whole-body surface scans, with repositioning, on a Fit3D ProScanner version 4 (Fit3D Inc., San Mateo, California). Participants followed a standard positioning protocol and wore skin-tight undergarments to minimize the effects of clothing on observed body shape. The ProScanner uses a light-coding depth sensor to capture 3D shape as the participant rotates 360° on the scanner platform. Each scan took approximately 40 seconds to complete. Before statistical analysis, all 3DO scan data were transferred from the measurement sites and stored securely at UHCC. All downstream analyses were performed on the reconstructed 3D meshes provided by Fit3D in Wavefront .obj format.

3. Bioelectrical Impedance (BIA)

Subjects were tested on a segmental multi-frequency BIA system (S10, InBody Co., Ltd, Seoul, South Korea). Touch-type electrodes were attached between the heel and the ankle bone of the participants' right and left feet and on their right and left middle finger and thumb. Participants would lie supine for approximately 20 seconds per scan. Impedance, resistance, reactance and phase angle of the right arm, left arm, right leg, left leg, and the trunk was measured at frequencies of 5, 50, and 250 kHz.

4. Strength assessments

Isokinetic right leg strength was measured using a Biodex (Biodex System 4, Biodex Medical Systems Inc., Shirley, NY, USA) or HUMACNORM (Computer Sports Medicine Inc) dynamometer. Before measurements, participants walked on a treadmill to warm up for ≤5 min. As shown in Figure 1, participants were fastened into the dynamometer system with a seatbelt to measure right leg strength through knee extension. The participants then practiced at an endurance of 50% of maximal effort for isokinetic testing. Resistance was set at 60°/s. After practicing each measurement, participants performed a set of 5 repetitions at maximal effort. Peak torque was recorded as the maximum torque (in newton meters) achieved during the repetitions.

Figure 1 HUMAC NORM Muscle Dynamometer

5. Statistical Analysis

Stepwise linear regressions were performed to derive linear models for each outcome of the 3DO and BIA variables. P values <0.10 were included in the testing model and had to have a P value of 0.05 to stay in the model. Four models (eight when separated by sex) were created to predict strength; a=demographics, b=demographics and 3DO, c=demographics and BIA, d=demographics, 3DO and BIA. Results were reported as adjusted R^2, and root means square error (RMSE). All statistical calculations were performed using SAS 9.4 (SAS, Cary, North Carolina, USA).

Results

This analysis included 526 participants (283 female). The demographic characteristics of the population are shown in Table 1. There were four variables used within the demographics model, 243 variables used in the 3DO model and 28 variables used in the BIA model. Table 2 shows the summary of each model's performance. The demographics-only model performed poorly: (1a) Female: adjusted R^2=0.34, RMSE=26.3; (2a) Male: adjusted R^2=0.22, RMSE=49.25. The strongest predictor variable was height for both males and females. The 3DO model performed slightly better than previously reported: (1b) Female: adjusted R^2=0.40, RMSE=25.17; (2b) Male: adjusted R^2=0.50, RMSE=39.48. The strongest predictor variable was thigh girth for females and waist girth for males. The BIA model performed slightly better than the 3DO models: (1c) Female: adjusted R^2=0.39, RMSE=25.43; (2c) Male: adjusted R^2=0.51, RMSE=39.16. The strongest predictor variable was SMM for females and 50 kHz PhA for males. The combination of the 3DO and BIA model performed the highest of all models: (1d) Female: adjusted R^2=0.54, RMSE=22.02; (2d) Male: adjusted R^2=0.57, RMSE=36.72. The strongest predictor variable was SMM for females and 50 kHz PhA for males. All male models performed better than female's

Prediction capability was increased in all models when females and males were combined into one cohort. The demographics-only model was the lowest outcome: (3a) adjusted R^2=0.45, RMSE=42.16. The demographics and 3DO model outperformed demographic model: (3b) adjusted R^2=0.55, RMSE=38.12. The demographics and BIA model outperformed the 3DO model: (3c) adjusted R^2=0.57, RMSE=37.31. The combination of demographics, 3DO and BIA, produced the highest overall model: (3d) adjusted R^2=0.62, RMSE=34.97.

Table 1 Simple Descriptive Statistics of Population

Variable	N	Mean	SD	Min	Max
Female					
Age (year)	286	47.04	16.19	18.00	89.00
Height (cm)	286	162.24	6.59	144.10	181.00
Weight (kg)	286	70.96	20.46	35.40	152.70
BMI (kg/m2)	286	26.91	7.36	14.16	51.86
Isokinetic Peak Torque Away (N/m)	286	87.31	32.35	17.50	189.20
Male					
Age (year)	244	44.80	16.16	18.00	79.00
Height (mm)	244	175.26	7.71	147.20	192.25
Weight (kg)	244	87.38	20.29	40.60	173.50
BMI (kg/m2)	244	28.36	5.97	16.96	52.55
Isokinetic Peak Torque Away (N/m)	244	149.34	59.24	11.00	339.20
Female and Male					
Age (year)	530	46.01	16.20	18.00	89.00
Height (mm)	530	168.23	9.64	144.10	192.25
Weight (kg)	530	78.52	21.95	35.40	173.50
BMI (kg/m2)	530	27.58	6.79	14.16	52.55
Isokinetic Peak Torque Away (N/m)	530	115.87	55.98	11.00	339.20

Abbreviations: SD standard deviation, BMI body mass index

Table 2 Linear Regression Model Summary Stratified by Sex

Model	Parameter	Test		Valid	
		Adj. R^2	RMSE	Adj. R^2	RMSE
	Female				
1a	age, height	0.34	26.30	0.38	25.18
1b	age, height, bust to bust length, right foot width, torso across chest horizontal	0.40	25.17	0.28	27.11
1c	age, right leg 50KHZ reactance, skeletal muscle mass	0.39	25.43	0.21	28.39
1d	waist to hip front, breast to breast length, right foot width, torso across chest horizontal, right leg 50KHZ reactance, skeletal muscle mass	0.54	22.02	0.21	28.32
	Male				
2a	age, BMI, height	0.22	49.25	0.17	66.06
2b	waist tilted down girth, waist natural height, right bust cup vertical length, left acromion length, right forearm girth, hip top girth, left low knee girth, right upper thigh girth,	0.50	39.48	0.54	49.33
2c	height, right arm extra cellular water, left arm 50KHZ phase angle, trunk 50KHZ phase angle	0.51	39.16	0.36	58.25
2d	neck base fit height, left acromion length, right upper thigh girth, left arm 50KHZ phase angle, trunk 50KHZ phase angle	0.57	36.72	0.20	65.10
	Male and Female				
3a	BMI, weight	0.45	42.16	0.47	37.37
3b	height, neck length horizontal, acromion to acromion width, abdomen width, right elbow girth, right forearm girth, right wrist girth, right upper thigh girth	0.55	38.12	0.60	32.64
3c	age, left arm 50KHZ reactance, left leg 50KHZ impedance, right arm 50KHZ impedance, basil metabolic rate	0.57	37.31	0.58	33.12
3d	BMI, abdomen width, right upper thigh girth, left leg extra cellular water, left leg 50KHZ phase angle, intra cellular water, left leg 50KHZ reactance	0.62	34.97	0.60	32.36

Model names: 1=female, 2=male, 3=female and male. a=demographics, b=demographics and 3DO, c=demographics and BIA, d=demographics, 3DO and BIA

Conclusion

Using 3DO anthropometry alone or BIA alone produces low-reliability models for strength predictions. The combination of 3DO and BIA better-predicted strength than either measure alone. Strength predictions appear to be more accurate in males than in females, but further investigation is needed.

References

1. Ng BK, Sommer MJ, Wong MC, Pagano I, Nie Y, Fan B, et al. Detailed 3-dimensional body shape features predict body composition, blood metabolites, and functional strength: the Shape Up! studies. The American journal of clinical nutrition. 2019;110(6):1316-26.