Monitoring human health indices using 3D optical whole body scanning

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Background: Optical 3D (3DO) scanning has been proposed as an accessible self-assessment technology capable of estimating total and regional body composition and anthropometry measures, and ideally suited for remote environments (space, Antarctic region). Our objectives were to predict DXA body composition, serum lipid and diabetes markers, and functional strength from 3DO body scans using statistical shape modeling and automated anthropometry.

Methods: Four-hundred and seven healthy adults underwent whole-body 3DO and DXA scans, blood tests, and strength assessments in the Shape Up! Adults cross-sectional observational study. Four-hundred seventy-six automated anthropometry measures were acquired. Principal component analysis was performed on registered 3DO scans. Linear regressions were performed to estimate body composition, biomarkers, and strength.

Results: Eleven PCs for each sex captured 95% of body shape variance. 3DO body composition accuracy to DXA was: fat mass R2 = 0.88 male, 0.93 female; visceral fat mass R2 = 0.67 male, 0.75 female. 3DO body fat precision was: RMSE = 0.81 kg male, 0.66 kg female. 3DO visceral fat was as precise (%CV = 7.4 for males, 6.8 for females) as DXA (%CV = 6.8 for males, 7.4 for females). Multiple 3DO PCs were significantly correlated with serum HDL cholesterol, triglycerides, glucose, insulin, and HOMA-IR. 3DO PCs improved prediction of isometric knee strength (R2 = 0.67 male, 0.59 female; anthropometrics-only R2 = 0.34 male, 0.24 female).

Conclusion: 3DO predicted body composition with good accuracy and precision comparable to existing methods. 3DO PCs improve prediction of serum lipid and diabetes markers, and functional strength measurements.

References:

1. Ng et al.. 2016 European journal of clinical nutrition 70(11): 1265-1270. 2. NIH R01 DK109008, clinicaltrials.gov ID NCT03637855. 3. Allen, B et al. ACM SIGGRAPH 2003, pp. 587–594.

Body Composition and Circumferences can be automatically and accurately measured using 3D optical scans

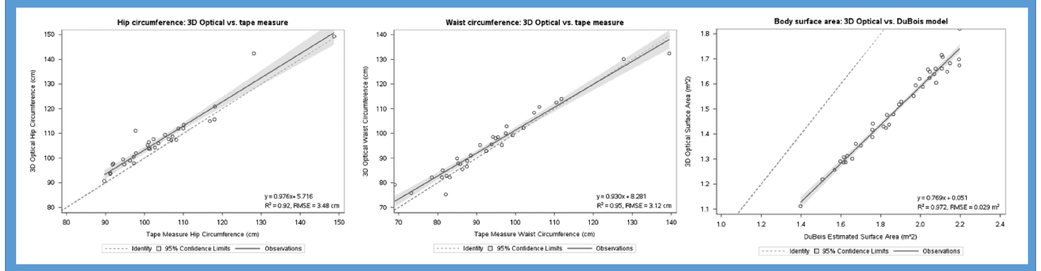

Fig1. (From left to right). Body circumferences and surface area for 3DO compared to the criterion measures. 3DO hip and waist circumferences compared to anthropometry, 3DO body surface area compared to DuBois equation. 3DO circumferences and surface area show high correlation. Biases may be the result of non-identical landmark positioning between the methods.

Fig 2. (From left to right) Fit 3D Proscanner; Hologic Discovery A DXA scanner.; 3D optical scan of a subject; corresponding DXA scans.

Fig 3. Average Male and Female in standard A Pose (above), first 3 principal components for +/- 3 standard deviations (below)

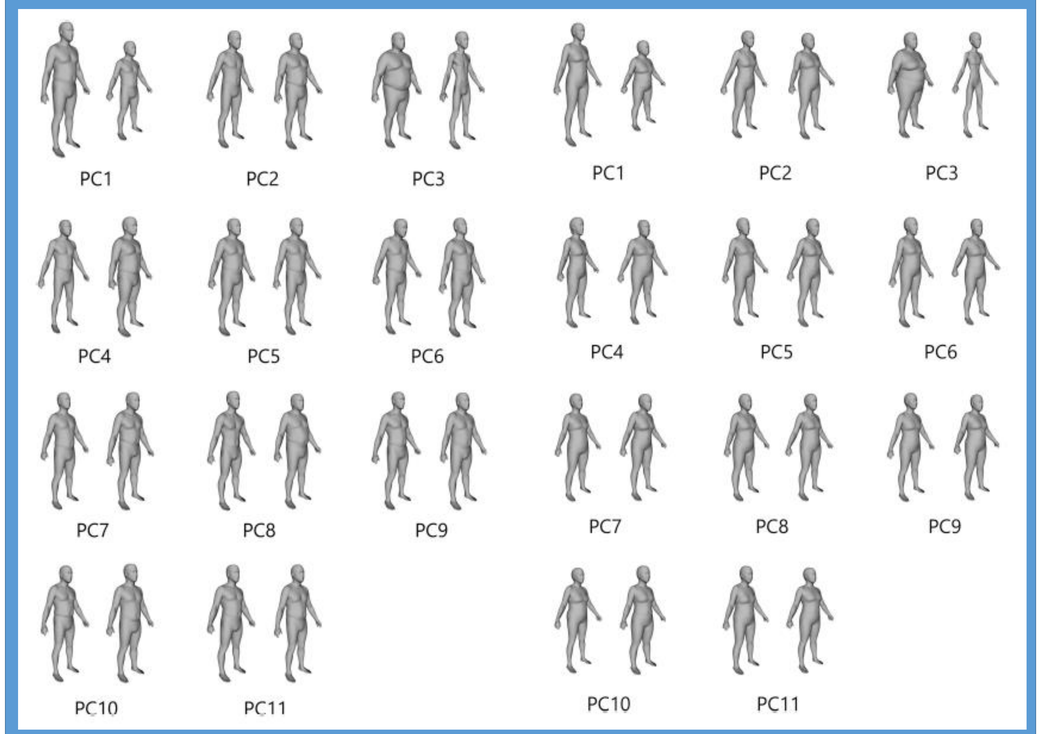

Fig 4. The first 11 principal components (PCs) that captured 95% of shape variance in males. Each component displays −3 SD to the left and +3 SD to the right.

Fig 5. The first 11 principal components (PCs) that captured 95% of shape variance in females. Each component displays−3 SD to the left and+3 SD to the right.

- We have previously shown that 3D optical systems can accurately measure several hundred automated measures of body circumferences and lengths (Fig 1, (1)). The Shape Up! Adults Study is an ongoing stratified cross-sectional observational study (2). 3D optical scans are ideal for remote locations where space is a premium and a need for self reliance.
- Fig 2. Participants underwent whole-body 3DO scans (Fit3D Proscanner), whole body dual-energy X-ray absorptiometry (DXA) scan (Discovery A, Hologic, Inc, Waltham, MA, USA), blood serum tests for diabetes and CVD biomarkers, handgrip and thigh strength tests.
- **3DO scan processing:** 3DO scans were processed to standardize the meshes following the methods of Allen (3), where 75 fiducial points are placed on identifiable landmarks, and then a standardized template mesh with 60,000 points is fit to the target mesh using a program called Ganger (Univ of WA).
- **Principal components** analysis was used to describe the variance of body shape for methods 1 and 2. PCA modes were used to estimate body composition. See Fig 4 & 5 for visual representations of each PC mode.

Results: See Tables 1 & 2.

Table 1. Step-forward linear regression to predict body composition, biomarkers, and strength.

Output variable	Sex	*n*	PC-only model	R^2	RMSE
Fat mass, kg	M	177	PC1, 2, 3, 4, 5, 8, 9, 10, 13, 15	0.88	3.38
	F	230	PC1, 2, 3, 4, 8, 9, 11	0.93	2.96
FFM, kg	M	177	(scale weight) − (predicted FM)	0.93	3.38
	F	230		0.90	2.95
Percentage fat, %	M	177	[(predicted FM)/(scale weight)] ×100	0.65	3.83
	F	230		0.70	4.10
FMI, kg/m^2	M	177	(predicted FM)/(height)^2	0.87	1.11
	F	230		0.93	1.13
FFMI, kg/m^2	M	177	(predicted FFM)/(height)^2	0.90	1.11
	F	230		0.88	1.12
Visceral fat mass, kg	M	177	PC2, 3, 6, 8, 9, 12, 13, 15	0.67	0.16
	F	230	PC1, 2, 3, 7, 10, 13, 14, 15	0.75	0.14
Trunk fat mass, kg	M	177	PC1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 13, 15	0.91	1.68
	F	230	PC2, 3, 4, 8, 9, 11, 13, 14, 15	0.94	1.43
Trunk FFM, kg	M	177	PC1, 2, 3, 4, 5, 6, 11, 15	0.90	1.94
	F	230	PC1, 2, 3, 4, 5, 7, 8, 10	0.87	1.72
Arms fat mass, kg	M	177	PC1, 2, 3, 4, 5, 8, 9, 10, 13	0.84	0.26
	F	230	PC1, 2, 3, 9, 14, 15	0.70	0.58
Arms FFM, kg	M	177	PC1, 2, 3, 4, 6, 7, 9, 11, 13, 15	0.76	0.52
	F	230	PC1, 2, 3, 4, 11, 15	0.67	0.33
Legs fat mass, kg	M	177	PC1, 3, 4, 5, 8, 9, 10, 12, 13	0.71	0.87
	F	230	PC1, 3, 9, 11, 14, 15	0.83	0.86
Legs FFM, kg	M	177	PC1, 2, 3, 4, 5, 6, 7, 11, 13, 15	0.89	0.76
	F	230	PC1, 2, 3, 4, 8, 10, 14, 15	0.83	0.71
HbA1c, %	M	164	PC3, 15	0.21	0.56
	F	215	PC3, 6, 10	0.14	0.45
Total cholesterol, mg/dL	M	165	—	0.00	41.10
	F	217	—	0.00	39.32
LDL cholesterol, mg/dL	M	163	—	0.00	31.66
	F	215	—	0.00	32.09
HDL cholesterol, mg/dL	M	165	PC3	0.13	12.89
	F	217	PC3, 4	0.13	14.81
Triglycerides, mg/dL	M	163	PC3, 6, 10	0.07	56.64
	F	215	PC3, 4, 15	0.14	46.47
Glucose, mg/dL	M	164	PC3, 7, 15	0.20	13.19
	F	215	PC3, 15	0.11	14.65
Insulin, mIU/L	M	144	PC2, 3, 14	0.40	7.71
	F	191	PC1, 2, 3, 6, 15	0.43	5.08
HOMA-IR	M	144	PC2, 3, 15	0.36	2.23
	F	191	PC1, 2, 3, 15	0.41	1.43
Handgrip left, kg	M	142	PC1, 6, 8, 9, 10, 13, 15	0.51	8.26
	F	189	PC1, 3, 4, 5, 9, 15	0.37	6.15
Handgrip right, kg	M	149	PC1, 6, 8, 9, 13, 15	0.38	8.99
	F	193	PC1, 3, 4, 5, 9, 12, 15	0.42	5.68
Isometric knee extension, N m	M	144	PC1, 2, 3, 8, 9, 10, 13, 15	0.63	40.74
	F	162	PC1, 3, 4, 5, 9, 11	0.56	23.54
Isokinetic knee extension, N m	M	141	PC1, 3, 4, 7, 8, 11, 13, 15	0.50*	49.95*
	F	187	PC1, 3, 5, 7, 9, 11, 15	0.38	28.76

Table 2. Test-retest precision from paired 3DO and DXA scans. 3DO is a precise technique.

	3DO PCA						DXA					
	Male			Female			Male			Female		
	n	%CV	RMSE	*n*	%CV	RMSE	*n*	%CV	RMSE	*n*	%CV	RMSE
FMI, kg/m^2	119	4.37	0.266	162	2.68	0.250	119	1.37	0.082	162	0.91	0.085
FFMI, kg/m^2	119	1.26	0.266	162	1.45	0.250	119	0.50	0.105	162	0.58	0.099
Fat mass, kg	119	4.30	0.809	162	2.67	0.655	119	1.36	0.251	162	0.91	0.223
FFM, kg	119	1.24	0.809	162	1.45	0.655	119	0.51	0.332	162	0.57	0.259
Percentage fat, %	119	4.69	1.010	162	2.92	0.987	119	—	0.277	162	—	0.308
Visceral fat mass, kg	119	7.40	0.033	162	6.78	0.028	119	6.80	0.030	162	7.40	0.031
Trunk fat mass, kg	119	5.14	0.466	165	2.88	0.321	119	2.66	0.239	165	2.00	0.222
Trunk FFM, kg	119	1.37	0.426	165	1.61	0.361	119	0.97	0.302	165	1.10	0.245
Arms fat mass, kg	119	4.76	0.054	161	3.45	0.055	119	3.02	0.034	161	2.73	0.043
Arms FFM, kg	119	3.11	0.135	162	2.45	0.059	119	1.64	0.072	162	1.82	0.043
Legs fat mass, kg	121	6.41	0.207	161	6.53	0.299	121	2.36	0.074	161	1.38	0.064
Legs FFM, kg	119	2.43	0.260	162	2.10	0.155	119	1.15	0.124	162	1.12	0.082

[1]Repeat 3DO and DXA scans were each performed with repositioning. FFM, fat-free mass; FFMI, fat-free mass index; FMI, fat mass index; PCA, principal component analysis; RMSE, root mean squared error; 3DO, 3-dimensional optical.