Comparison of Body Composition Measurements Using a New Caliper, Two Established Calipers, Hydrostatic Weighing, and BodPod

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ABSTRACT

Int J Exerc Sci 2(1) : 19-27, 2009. Purposes: (1) To compare the Lafayette Instruments (LI) skinfold caliper to the Lange (L) and Harpenden (H) calipers using a diverse subject population. (2) To determine the validity of the LI caliper in a subset of subjects by comparing body compositions from skinfold thicknesses to those measured by hydrostatic weighing (HW) and air displacement plethysmography (ADP). (3) To compare measurements obtained by experienced (EX) and inexperienced (IX) technicians using all three calipers. Methods: Skinfold measurements were performed by both EX and IX technicians using three different calipers on 21 younger (21.2 ± 1.5 yrs) and 20 older (59.2 ± 4 yrs) subjects. Body compositions were calculated using the Jackson-Pollock seven-site and three-site formulas. HW and ADP tests were performed on a subset of subjects (10 younger, 10 older). Results: No significant differences existed between LI and L or H when measurements were made by EX. Further, the LI-EX measurements were highly correlated to both H-EX and L-EX. No significant differences existed in the subgroup between LI-EX and HW or ADP. Skinfold determinations made by EX and IX were similar. Conclusions: Similar body compositions determined using LI, H, and L suggest that LI determines body composition as effectively as H and L. High correlations between the three calipers support this notion. Similar results between LI and HW/ADP subgroup suggest that the LI caliper may be a valid method of measuring body composition. Overall, performance by IX was similar to EX and suggests similar ease of use for all three calipers.

KEY WORDS: Percent body fat, BodPod

INTRODUCTION

Estimated body composition is an important clinical indicator of health and health risk. By using a person's ratio of fat mass to fat-free mass, clinicians can make more informed decisions about topics ranging from dietary recommendations to exercise interventions (5). Several methods are available for body fat estimation. Each requires different equipment and technician training. The costs associated with each method also vary greatly (1).

Densitometry methods include hydrostatic weighing and air displacement plethysmography. Hydrostatic weighing (HW) has long been considered the gold standard of body composition. Air displacement plethysmography (ADP) is a more recently developed technique often determined using the BodPod technology. Both have given reliable body composition assessments and correlate highly with each other (2, 6, 9, 12). Unfortunately, both HW and ADP are often not feasible for clinical use because of the expensive equipment required (16).

Skinfold thickness measured by calipers is one of the most frequently used methods to estimate body composition in a clinical setting (16). Calipers are used to measure skinfold thickness at different sites. These thicknesses are entered into a regression equation to determine a subject's body density. A second equation is used to convert body density into percent body fat. Lange and Harpenden calipers are two of the many types of skinfold calipers that are available spanning a wide range of costs. The equations used in this study were derived and validated using Lange calipers and correlate highly with hydrostatic weighing in both men (7) and women (8). No significant differences are often reported between Lange and Harpenden calipers (5, 17), but Lange calipers have also been reported to give significantly higher skinfold thicknesses than Harpenden at five sites in a population of female athletes (10).

The Lafayette Instruments Company has manufactured a skinfold caliper (Lafayette Skinfold II, Model 01128) that compared favorably to the more expensive Lange caliper in preliminary measurements from our laboratory. Conversely, the Lafayette Skinfold II yielded body fat percentages higher than those determined using the Harpenden caliper. However, these experiments were performed on a small number of young, highly fit male and female subjects and may not provide an accurate assessment of the caliper.

The purpose of this study was three-fold: (1) To compare the Lafayette Instruments (LI) caliper to the Lange (L) and Harpenden (H) calipers using a diverse subject population, including people of different ages, genders, and physical activity status. (2) To determine the validity of the LI caliper in a subset of the above subjects by comparing body composition results to those measured with HW and ADP. (3) To compare the results obtained by both experienced (EX) and inexperienced (IX) technicians using all three calipers.

We hypothesized that our results would be similar to the preliminary data collected on a small number of highly fit male and female subjects, such that no significant differences would exist between LI and L but that H will be significantly different than LI. Based on the relationship between LI and the well-validated L, we predicted that LI would compare favorably with ADP and HW. Finally, we predicted that due to the skill required to make skinfold measurements, significant differences would exist between body compositions determined by EX and IX. This hypothesis was supported by previous research showing that skinfold thicknesses measured by an inexperienced technician were either higher (3) or lower (17) than those made by an experienced technician.

METHOD

Participants

Forty-one subjects were recruited from the university student body and surrounding community for body composition assessment. Subjects were recruited into one of four groups to ensure that a heterogeneous population was included in the study: 18-25 years of age and sedentary, 18-25 and physically active, 55-70 and sedentary, and 55-70 and physically active. Each group had a roughly equal number of males and females (overall, 20 males and 21 females). Physically active subjects self-reported a minimum of three days of endurance or resistance exercise per week for greater than thirty minutes during the previous six months. Physically inactive subjects were mostly sedentary and participated in no structured exercise. Daily activity for the younger subjects included walking to class.

Potential subjects completed a medical history questionnaire to screen for either current or past health issues that could have altered the study outcomes or placed subjects at risk while participating in the study. Of the 21 younger subjects included in the study, four reported suffering from asthma at the time of the study or in the past, while seven subjects reported allergies. Of the 20 older subjects, four reported asthma, four reported allergies, four reported high blood pressure, and seven reported high serum lipids. The Purdue University Institutional Review Board approved all experiments and informed consent was obtained from each participant before initiation of experiments.

Protocol

Both experienced and inexperienced technicians measured body composition on each subject using Lafayette Skinfold II (Lafayette, IN), Lange (Cambridge Scientific Industries, Inc, Cambridge, MD) and Harpenden (British Indicators LTD, Great Britain) calipers. Inexperienced technicians' previous experience with skinfold measurements was limited to a lab session of an exercise physiology course. Experienced technicians were required to have used skinfolds as a part of their previous employment or research. Inexperienced technicians received instruction in proper technique and site location from an experienced technician. Five different inexperienced technicians were employed throughout the study to prevent technicians from completing enough tests to be considered experienced. The greatest number of tests completed by one inexperienced technician was 19.

Skinfold thicknesses can be affected by hydration status and prolonged standing (14). In an effort to minimize these effects, skinfold measurements for each subject were made on a single day between 0600-1000 h. Subjects were asked not to eat after 2200h the night before testing, to refrain from exercise for 12 hours prior to testing, and to abstain from alcohol 24 hours prior to testing. The three calipers were used in random order to measure skinfold thickness on the right side of the body according to the American College of Sports Medicine guidelines (1). Skinfold thickness was measured at seven sites: triceps, suprailiac, thigh, chest, subscapular, midaxillary, and abdomen. Both the Jackson and Pollock seven-site (7, 8) and three-site (7, 8) skinfold formulas were applied to determine body density. The Siri formula (15) was used to convert body densities to body fat percentages.

On a separate day between 0600-1000 h, a subgroup of subject volunteers completed hydrostatic weighing (HW, EXERTECH, Dresbach, MN) and air displacement plethysmography (BodPod, Life Measurement Inc, Concord, CA). ADP tests were completed first and consisted of three stages. The first two stages were identical measurements of body volume. When a significant disparity occurred between the two trials, a third trial was performed. Tidal volume was measured during the last stage of each test to measure thoracic gas volume. The Siri equation (15) was again used to calculate percent body fat from body density.

Hydrostatic weighing was completed following ADP. In a large tank, a subject sat on a hydrostatic scale. Subjects were instructed to exhale completely, submerge their head, and stay as still as possible. Load cells interfaced with a computer allowed weight in water to be sampled over a three second period and an average to be calculated. An estimate of residual volume was made based on the subject's gender, height, and age (13). The Siri equation (15) was used to convert body density measurements to percent body fat.

Statistical Analyses

Analysis was performed using the SPSS 15.0 for Windows statistical analysis package. A priori significance was set at a level of $\alpha = .05$ for all statistical tests. An omnibus multivariate ANOVA was performed to determine the similarity of each caliper to the accepted standards of HW and ADP. Further, similarity in measurement between the three calipers, HW, and ADP was examined by Pearson's correlations. Tukey Honestly Significantly Different analysis was performed post hoc when appropriate. Ease of use was determined via correlation analysis of experienced versus inexperienced practitioners within each caliper determination of percent body fat. Differences between calipers, HW, and ADP were not investigated within subgroups of gender, age, or physical activity status as subjects were divided into these groups solely to ensure a heterogeneous population.

High correlation coefficients often lack a normal distribution and this was found to be true with this dataset. In order to complete statistical analysis, a Fishers Z-transformation and a Z-test (11) were performed.

RESULTS

The average age of the 21 younger subjects was 21.2 ± 1.5 yrs and average age of the 20 older subjects was 59.2 ± 4 yrs. Table 1 displays the body fat percentages determined by skinfold thickness using the seven- and three-site formulae, HW, and ADP for both the entire subject population and the HW/ADP subset.

Comparison of Calipers

Multivariate ANOVA of the body fat percentages determined using skinfold calipers revealed an insignificant omnibus F-test ($F = 2.90$, $p = 0.06$) demonstrating no differences between any of the calipers. However, further analysis was performed due to the trend toward significance in the

Table 1a. Average body fat percentages determined for all subjects by an experienced technician.

Method	7-Site % Body Fat (% ± standard deviation)	3-Site % Body Fat (% ± standard deviation)
LI	20.43 ± 6.43	21.31 ± 6.66
H	20.04 ± 6.42	20.80 ± 6.82
L	22.35 ± 6.71	23.18 ± 7.06

Table 1b. Body fat percentages determined for the HW/ADP subgroup by an experienced technician.

Method	7-Site % Body Fat (% ± standard deviation)	3-Site % Body Fat (% ± standard deviation)
LI	19.83 ± 6.59	20.51 ± 6.46
H	19.51 ± 6.56	19.99 ± 6.54
L	21.83 ± 6.84	22.35 ± 6.73

Table 1c. Body fat percentages determined by HW and ADP

Method	% Body Fat (% ± standard deviation)
HW	25.48 ± 9.47
ADP	25.23 ± 10.41

LI = Lafayette Instruments, H = Harpenden, L = Lange

omnibus test. Post-hoc pair wise comparisons on the 7-site data using Tukey HSD show mean differences in body fat estimates ranging from .38% to 2.30% with a standard error of 1.03% (Table 2).

Analysis of Pearson Product-Moment correlations revealed strong correlations (r = 0.97- 0.99) between the three caliper-determined body fat estimates in experienced practitioners. The 7-site formula yielded more strongly correlated body fat estimates than the 3-site formula (Table 3).

Measurements made by inexperienced practitioners did not have substantially different Pearson r values when compared to those made by experienced practitioners for any of the calipers. Further investigation using a Fisher's Z-transformation with a Z-test revealed significant differences in correlations between experienced and inexperienced practitioners when the seven-site equation was used but not with the three-site equation (Table 4).

Comparison of Calipers to HW and ADP

Estimates of body fat in the total sample when determined via all three calipers, ADP, and HW were not significantly different and strongly correlated (Table 5). Seven-site determinations for both

Table 2 Differences in caliper means by caliper type determined by Tukey HSD.

Type 1	Type 2	Mean Difference	P value
LI	H	0.38	0.93
LI	L	-1.93	0.15
H	L	-2.30	0.07

LI = Lafayette Instruments, H = Harpenden, L = Lange; Caliper means determined by seven-site formulas with skinfolds measured by experienced technicians.

Table 3. Correlations Comparing Body Fat Estimates for Using the Jackson-Pollock 7-site and 3-site Formulae

Caliper Correlation		
Experienced Technician	Seven-site	Three-site
LI & H	0.99	0.98
LI & L	0.99	0.98
H & L	0.99	0.97
Inexperienced Technician	Seven-site	Three-site
LI & H	0.97	0.97
LI & L	0.98	0.98
H & L	0.98	0.96

LI = Lafayette Instruments, H = Harpenden, L = Lange

Table 4. Fisher's Z-transformation and Z-test Scores for Caliper Correlations Comparing Experienced and Inexperienced Practitioners.

Seven-site	EX Z score	IX Z score	Z test
LI & H	2.65	2.09	-3.42 (p < .01)
LI & L	2.65	2.30	-2.15 (p = .03)
H & L	2.65	2.30	-2.15 (p = .03)
Three-site	EX Z score	IX Z score	Z test
LI & H	1.66	1.66	0.00 (p = 1.00)
LI & L	1.59	1.59	0.00 (p = 1.00)
H & L	1.53	1.42	-0.65 (p = .52)

LI = Lafayette Instruments, H = Harpenden, L = Lange

Table 5. Correlations for Experienced and Inexperienced Skinfold Technicians with Hydrostatic Weighing and ADP Using Three Formulae.

		seven-site EX	seven-site IX	three-site EX	three-site IX
HW	LI	0.82	0.85	0.71	0.75
	H	0.83	0.83	0.74	0.70
	L	0.82	0.85	0.69	0.72
ADP	LI	0.86	0.87	0.81	0.84
	H	0.87	0.90	0.85	0.84
	L	0.86	0.88	0.80	0.82

LI = Lafayette Instruments, H=Harpenden, L=Lange, HW=hydrostatic weighing Pearson's r values in subsample of subjects who performed additional testing where EX = experienced and IX = inexperienced practitioners.

inexperienced (r = .83 - .85) and experienced (r = .82 - .83) technicians yielded the strongest correlations with HW. Similar effects were seen with seven-site determinations and ADP (Table 5).

DISCUSSION

As has been previously described, skinfold measurements from 41 subjects using Lange and Harpenden calipers compared favorably to each other (5, 17) and HW and ADP (2, 6, 9, 12).

The Lafayette Instruments II caliper performed well in comparison to both the Harpenden and Lange calipers. No significant differences and strong correlations were found when comparing the LI caliper to hydrostatic weighing and ADP, suggesting that the LI caliper is a valid method for estimating body composition.

All three skinfold calipers had a tendency to underestimate body fat percentage when compared to hydrostatic weighing and ADP. While the underestimation could be due to the subjects' inability to exhale fully during submersion during hydrostatic weighing (5), this does not explain the underestimation by the calipers when compared to ADP. Body fat percentages determined by skinfold thickness are based on the assumption that a strong relationship exists between total body fat and subcutaneous fat (5). It is possible that the underestimation seen in this study resulted from an underprediction of intramuscular and abdominal fat (14).

Ease of use was assessed by comparing determinations of body fat by inexperienced and experienced practitioners. No significant differences were found between technician groups in an omnibus ANOVA. Further analysis using a Fisher's Z transformation and Z-test revealed that some of the calipers were performing differently ($p < .05$). However, when variables correlate almost perfectly, an extremely small difference in Pearson's r can yield Z-test values that are significant (11). We believe this is the case with the seven-site formula body fat determination in this population and that this difference may not truly reflect differences in the calipers.

The present study is not without limitations. First, our comparison of three calipers, hydrostatic weighing, and air displacement plethysmography employed a relatively small number of subjects. However, our results suggest that the Lafayette Instruments caliper should be included in a large-scale comparison study. Second, we chose to estimate residual volume instead of directly measuring it. This likely reduced the accuracy of body fat percentages determined by hydrostatic weighing, but we believe that our results are still meaningful and provide a useful comparison with the other methods.

The Lafayette Instruments Company has developed a new and relatively inexpensive caliper that performed well in comparison to the more expensive Lange and Harpenden calipers in a small, diverse subject population. The Lafayette Instruments caliper may underestimate body fat percentages when compared to ADP and hydrostatic weighing, but this underestimation was similar to the Lange and Harpenden calipers. The Lafayette Instruments caliper also displays ease-of-use similar to the Lange and Harpenden calipers as demonstrated by the lack of differences in measurements made by experienced and inexperienced technicians. Based upon these results, the Lafayette Instruments skinfold caliper should be included in the next large-scale body composition study. This study should both compare the LI caliper to other calipers on the market and determine the validity of the LI caliper in a much larger subject population.

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