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Body composition changes in female bodybuilders during preparation for competition

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Objective: To determine anthropometric and body composition changes in female bodybuilders during preparation for competition.
Design: There was an attempt to match subjects in the control and experimental groups for height and percentage body fat (%BF) for the initial test of this longitudinal study.
Subjects: Five competitive bodybuilders ($\overline{X} \pm$ s.d.: 35.3 ± 5.7 y; 167.3 ± 3.7 cm; 66.38 ± 6.30 kg; 18.3 ± 3.5 %BF) and five athletic females ($\overline{X} \pm$ s.d.: 30.9 ± 13.0 y; 166.9 ± 3.9 cm; 55.94 ± 3.59 kg; 19.1 ± 3.3 %BF) were recruited from advertisements in a bodybuilding newsletter and placed on sports centre noticeboards.
Interventions: The following measurements were conducted 12 weeks, 6 weeks and $3-5$ d before the bodybuilders' competitions: anthropometric profile, body density by underwater weighing, total body water via deuterium dilution and bone mineral mass from a dual-energy X-ray absorptiometry scan. A combination of the last three measurements enabled the %BF to the determined by a four compartment model.
Results: A significant ($P \leq 0.001$) 5.80 kg body mass loss by the bodybuilders as they prepared for competition was primarily due to a reduction in fat mass (FM; -4.42 kg; 76.2%) as opposed to fat-free mass (FFM; -1.38 kg; 23.8%). The decreases in body mass and FM over the final 6 weeks were greater than those over the first 6 weeks. Their %BF decreased ($P < 0.001$) from 18.3 to 12.7, whereas the values for the control group remained essentially unchanged at $19.1-19.6$ %BF. These body composition changes by the bodybuilders were accompanied by a significant decline ($P < 0.001$) of 25.5 mm ($76.3-50.8$ mm) in the sum of eight skinfold thicknesses (triceps + subscapular + biceps + iliac crest + supraspinale + abdominal + front thigh + medial calf).
Conclusions: Although the bodybuilders presented with low %BFs at the start of the experiment, they still significantly decreased their body mass during the 12 week preparation for competition and most of this loss was due to a reduction in FM as opposed to FFM.
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Descriptors: four-compartment body composition model; dual energy X-ray absorptiometry; somatotype
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Introduction

Bodybuilding is a sport in which competitions are judged solely on physical appearance and posing ability. The major aim is to develop an overall symmetrical physique which exhibits both muscular size and definition. Many bodybuilders spend most of the year in a hypertrophy phase where the combination of training and diet is aimed at increasing muscle mass. When preparing for competition they increase training volume and decrease energy intake to minimize subcutaneous body fat and enhance muscular definition. While anthropometric and body composition profiles of competitive female bodybuilders have been reported in the literature (Carlson *et al*, 1988; Elliot *et al*, 1987; Freedson *et al*, 1983; Heyward *et al*, 1989; Johnson *et al*, 1990; Kleiner *et al*, 1990, 1994; Sandoval *et al*, 1989; Walberg-Rankin *et al*, 1993), only four of these groups (Heyward *et al*, 1989; Kleiner *et al*, 1990, 1994; Sandoval *et al*, 1989) specified that their data were collected just before competition. Furthermore, only one study (Heyward

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Contributors: GEP and AGB recruited the subjects, collected and analysed the data and helped to write the paper; RTW conceived the study, secured the research funding, supervised the project and wrote the paper; JD conducted all the anthropometric measurements; BEC supervised the DEXA scans; FL supervised the deuterium assays.
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et al, 1989) examined anthropometric and body composition changes in female bodybuilders during preparation for competition. However, they measured their subjects before they started dieting and 24–48 h prior to competition so that it is unknown whether the rate of change was constant over this period. Also, no information is available on the application of multicompartment body composition models to female bodybuilders. These models are theoretically more valid than traditional two-compartment ones because they control for biological variability in some of the four (water, protein, bone mineral and non-bone mineral) chemical components of the fat-free mass (FFM). The aims of this study were therefore to: (a) measure changes in the anthropometric profiles and body composition of female bodybuilders during preparation for competition by testing them at 12 weeks, 6 weeks and 3–5 days prior to the event; and (b) assess the application of two-, three- and four-compartment body composition models to female bodybuilders.

Methods

Subjects
Five competitive female bodybuilders ($\overline{X} \pm$ s.d.: 35.3 ± 5.7 y; 167.3 ± 3.7 cm; 66.38 ± 6.30 kg), who had been training for 4–10 y (6.8 ± 2.9 y), volunteered for this study. Five athletic females ($\overline{X} \pm$ s.d.: 30.9 ± 13.0 y; 166.9 ± 3.9 cm; 55.94 ± 3.59 kg) were recruited as a control group. For the initial test there was an attempt to match the subjects in the two groups for height and percentage body fat (%BF). This project was approved by the Flinders Medical Centre's Committee on Clinical Investigation. Informed consent was obtained in accordance with the established protocol for human subjects.

Protocol
All tests were conducted when the subjects were post-absorptive, euhydrated and had not exercised for 36 h. Control was exerted for within-subject biological variability by administering all tests on the same morning. Each bodybuilder and her assigned control subject were tested 12 weeks, 6 weeks and 3–5 days before the former's competition.

Experimental treatment
The days and time spent aerobic training 12 weeks prior to the bodybuilders' competitions were 5.8 ± 1.1 days/week and 344 ± 110 min/week, respectively. Approximately 4 weeks prior to competition the aerobic training time was almost doubled to 590 ± 139 min/week by working out in the morning and evening. One bodybuilder reported no increase but she performed a substantial amount (490 min/week) of aerobic training throughout the 12 weeks. The days and time spent weight-training during the 12 weeks were 5.0 ± 1.2 days/week and 342 ± 164 min/week, respectively. Two to three sets of 10–12 RM (maximal resistance for 10–12 repetitions) were performed for each body part plus a final set of 6 RM. None of the bodybuilders reported an increase in the volume of weight-training over the 12 wk but four of them stated that either the resistance or number of repetitions decreased as body mass was lost. Although diet diaries were not completed, four of the bodybuilders stated that they did not reduce their energy intake over the 12 weeks, which was estimated as 6.41 ± 0.80 MJ/day, whereas one subject decreased from 10.5 to 5.04 MJ/day.

Competitive success
The five bodybuilders achieved the following results in their competitions: second in the open physique division of the South Australian Bodybuilders' Association 1998 championships; fourth in the novice physique category of the South Australian Bodybuilders' Association 1998 championships; first in the 1998 over 52 kg physique class of the South Australian titles of the Australian Natural Bodybuilding Organisation; first in the 1999 over 52 kg physique division of the South Australian titles of the Australian Natural Bodybuilding Organisation; and second in the 1999 tall physique category of the national championships of the Australian Natural Bodybuilding Organisation.

Anthropometry
All measurements were taken in accordance with the recommendations of Norton *et al* (1996) by an ISAK (International Society for the Advancement of Kinanthropometry) level three anthropometrist. Body mass was measured to the nearest 20 g and stretch height was determined with a wall stadiometer. Two trials were recorded at each skinfold site with Harpenden calipers and the average was used if they differed by <10%. Otherwise, a third trial was conducted and the median value was used in further calculations. Other anthropometric measurements were conducted with a flexible steel tape and Mitutoyo vernier calipers as adapted by Carter (1980). Somatotype was determined using the Heath-Carter anthropometric method (1980) and the mean group somatotype was calculated by averaging each component (endomorphy, mesomorphy and ectomorphy). The linear measurements for all anthropometric equipment were checked against standard rods and the downscale jaw pressure of the Harpenden calipers was 8.09–7.74 g/mm^2 for jaw gaps of 5–40 mm (Carlyon *et al*, 1998). Electrobalance authenticated masses were used to calibrate the weighing scale over the physiological range of measurement.

Hydrodensitometry
Our procedure for measuring body density (BD) by underwater weighing, with the gas volume in the respiratory system being measured by O_2 dilution, has been described previously (van der Ploeg *et al*, 2000). The %BF was estimated by the two compartment model of Brožek *et al* (1963), which assumes that the densities of the fat mass (FM) and FFM at 36°C are 0.9007 and 1.1000 g/cm^3, respectively:

$$\%BF = \frac{497.1}{BD} - 451.9$$

FFM was then obtained by subtraction. Our latest reliability and precision data on 12 subjects produced an intraclass correlation coefficient (ICC) of 0.998 and a technical error of measurement (TEM) of 0.4 %BF.

Total body water (TBW)
This was estimated by deuterium (^2H_2O) dilution. The background concentration of ^2H_2O in the body fluids was determined from saliva samples which were collected on arrival at the laboratory. A 40 mg ^2H_2O/kg dose, which was adjusted to $\sim$100 ml with distilled water, was then ingested through a straw. The container was furthermore rinsed three times with $\sim$33 ml of distilled water, which was also drunk by the subject. Equilibrium saliva samples were collected 3.5 h later and the subjects were not allowed to eat, drink, urinate or exercise during the intervening period. Precautions were taken to minimize isotopic fractionation.

A Europa Scientific Geo 20−20 (Europa, Crewe, Cheshire, UK) isotope ratio mass spectrometer, which was calibrated against Vienna Standard Mean Ocean Water (V-SMOW) and International Atomic Energy Agency (IAEA) enriched standards 302A and 302B, was used to measure the ^2H_2O concentrations in the batch doses and saliva samples (Dighton *et al*, 1997). The isotope dilution space was calculated in accordance with the recommendations of Schoeller *et al* (1986), who advocate a 4% correction factor for the exchange of deuterium with nonaqueous hydrogen. Our latest reliability and precision data for two TBW trials on alternate days ($n = 10$) yielded an ICC of 0.998 and a TEM of 0.28 kg.

Body composition was also estimated via the two-compartment model, which assumes that the FM is anhydrous and 72% of the FFM of a normally hydrated subject is water:

$$\text{FFM (kg)} = \frac{\text{TBW (kg)}}{72} \times 100$$

The FM was then calculated by subtraction and represented as a percentage of the body mass.

Dual-energy X-ray absorptiometry (DEXA)
All measurements (Mazess *et al*, 1990) were conducted at the Royal Adelaide Hospital's Department of Nuclear Medicine with a Lunar DPX-L total body scanner (Lunar Corporation, Madison, WI) which was operated in the medium scan mode ($\sim$20 min) using version 1.3 Z software. The phantom supplied by the manufacturer was used to calibrate the machine daily. The subjects were measured while wearing two-piece bathing suits. Duplicate trials on 12 subjects yielded ICCs of 0.998, 0.995 and 0.995 and TEMs of 27, 59 and 75 g for bone mineral content (BMC), fat and lean tissue mass (FFM − BMC), respectively.

The BMC reported in the DEXA printout comprises ashed bone. One gram of bone mineral yields 0.9582 g of ash (Méndez *et al*, 1960) because labile components such as bound H_2O and CO_2 are volatilized during heating at over 500°C (Brožek *et al*, 1963; Méndez *et al*, 1960). The BMC or bone ash was therefore converted to bone mineral mass (BMM) by multiplying it by 1.0436 (Heymsfield *et al*, 1989, 1990).

Three- and four-compartment body composition models
The assumptions, derivations and formulae for these models have been outlined previously (Withers *et al*, 1998, 1999).

Statistical analyses

1. The sum of eight skinfold thicknesses plus the %BF, FM, FFM and FFM density data sets via the four compartment model were analysed via 3 (time: 12 weeks, 6 weeks and 3−5 days)×2 (group: bodybuilders and control) factorial design ANOVAs ($P \leq 0.05$) with repeated measures across time. The corrected degrees of freedom were used if the assumption of sphericity was violated. In the event of a statistically significant interaction, simple effects at each time were examined via independent *t*-tests ($P \leq 0.05$). One-way repeated measures ANOVAs were also used to determine within-group differences, with the preceding provision regarding the sphericity assumption and, in the event of a statistically significant *F*-ratio ($P \leq 0.05$), Tukey *post-hoc* analyses were conducted.
2. The effect of biological variability in FFM hydration was determined by plotting the %BF difference between the three-compartment model and the two-compartment hydrodensitometric model against the %BF from the four-compartment criterion model and regressing the % TBW in the FFM on FFM density. The effect of interindividual variability of the % BMM in the FFM was also elicited by plotting the %BF difference between the four- and three-compartment models against the %BF from the four-compartment criterion model and regressing the % BMM in the FFM on FFM density.
3. The somatotype data for each group at 12 weeks before competition were compared with that of 3−5 days before competition via Hotelling's T^2. This was because the number of subjects in each group only exceeded the number of dependent variables by two, thereby compromising the statistical power of a conventional 3×2 MANOVA.

Results

The descriptive statistics for the anthropometric and body composition data of the bodybuilders and control subjects are presented in Tables 1−4. Four of the 3×2 ANOVAs yielded significant interactions (sum of eight skinfolds, $P < 0.001$; %BF, $P < 0.001$; FM, $P < 0.001$; FFM, $P = 0.006$), some of which are emphasized in Figure 1. Subsequent independent *t*-tests between the bodybuilders

Table 1 Descriptive statistics ($\overline{X} \pm$ s.d.) for the anthropometric data of the five female bodybuilders

	Test 1[a]	*Test 2*[b]	*Test 3*[c]
Age (y)	35.3 ± 5.7	35.5 ± 5.7	35.6 ± 5.7
Height (cm)	167.3 ± 3.7	167.2 ± 4.1	167.4 ± 3.9
Mass (kg)	66.38 ± 6.30	64.26 ± 6.36*	60.58 ± 5.89†
Quetelet's index (QI)[d]	23.7 ± 2.7	23.0 ± 2.9*	21.7 ± 2.5†
Skinfold thicknesses (mm):			
Triceps	11.6 ± 3.8	9.7 ± 3.2	7.6 ± 2.8*
Subscapular	8.4 ± 1.5	7.3 ± 1.1*	6.1 ± 1.3†
Biceps	4.3 ± 0.4	4.0 ± 0.4	3.3 ± 0.4*
Iliac crest	6.1 ± 1.4	4.9 ± 0.6*	4.0 ± 0.8†
Supraspinale	6.1 ± 1.8	4.9 ± 1.2	3.8 ± 0.7*
Abdominal	8.2 ± 2.7	6.1 ± 1.5	4.8 ± 0.8*
Front thigh	19.8 ± 5.1	16.9 ± 3.9*	13.3 ± 3.2†
Medial calf	12.0 ± 3.4	10.2 ± 2.4*	8.0 ± 2.0†
Sum of all eight skinfolds	76.3 ± 8.3	64.0 ± 5.9*	50.8 ± 6.5†
Girths (cm):			
Arm (relaxed)	32.0 ± 3.1	31.5 ± 2.9	30.3 ± 3.1†
Arm (flexed and tensed)	33.5 ± 2.9	33.0 ± 2.5	31.9 ± 2.4†
Forearm (maximum, relaxed)	26.2 ± 1.7	25.9 ± 1.6	25.1 ± 1.6†
Chest (mesosternale)	93.4 ± 7.5	91.9 ± 7.3	89.2 ± 5.6†
Waist (minimum)	71.4 ± 5.3	69.7 ± 6.4*	67.3 ± 5.9†
Gluteal (maximum)	95.3 ± 3.4	93.2 ± 3.1*	89.9 ± 2.5†
Thigh[e]	58.6 ± 2.6	57.2 ± 2.4*	54.6 ± 1.9†
Thigh[f]	53.1 ± 3.7	52.1 ± 2.6	50.3 ± 2.2†
Calf (maximum)	36.4 ± 2.1	36.2 ± 2.2	35.3 ± 2.2†
Neck	33.1 ± 3.1	32.7 ± 3.1	31.9 ± 2.9†
Breadths (cm):			
Humerus	6.48 ± 0.09	6.42 ± 0.13	6.31 ± 0.10
Femur	9.05 ± 0.35	9.06 ± 0.31	8.96 ± 0.31‡
Somatotype:			
Endomorphy	2.7 ± 0.4	2.2 ± 0.3*	1.7 ± 0.2†
Mesomorphy	5.3 ± 1.2	5.2 ± 1.2	4.8 ± 1.1†
Ectomorphy	1.8 ± 1.0	2.1 ± 1.2	2.7 ± 1.2†

[a]12 weeks before competition; [b]6 weeks before competition; [c]3–5 days before competition; [d]QI = mass (kg)/height (m)^2; [e]1 cm distal to gluteal line; [f]mid trochanterion-tibiale laterale.
*Significantly different ($P \leq 0.05$) from test 1; ‡significantly different ($P \leq 0.05$) from test 2; †significantly different ($P \leq 0.05$) from tests 1 and 2.

Table 2 Descriptive statistics ($\overline{X} \pm$ s.d.) for the anthropometric data of the five female control subjects

	Test 1[a]	*Test 2*[b]	*Test 3*[c]
Age (y)	30.9 ± 13.0	31.0 ± 13.0	31.1 ± 13.0
Height (cm)	166.9 ± 3.9	167.2 ± 4.0	167.3 ± 4.0
Mass (kg)	55.94 ± 3.59	56.93 ± 4.20	57.51 ± 4.37
Quetelet's index (QI)[d]	20.1 ± 1.6	20.4 ± 1.5	20.6 ± 1.4
Skinfold thicknesses (mm):			
Triceps	11.6 ± 3.0	13.0 ± 4.7	11.8 ± 3.1
Subscapular	8.0 ± 2.1	8.5 ± 2.2	8.3 ± 1.9
Biceps	4.5 ± 0.9	4.8 ± 1.5	4.6 ± 0.9
Iliac crest	6.7 ± 2.0	8.4 ± 5.5	8.4 ± 5.2
Supraspinale	5.2 ± 1.5	5.5 ± 2.4	5.3 ± 1.9
Abdominal	9.2 ± 4.5	10.0 ± 5.2	9.6 ± 5.2
Front thigh	16.8 ± 5.9	17.9 ± 7.0	17.7 ± 5.7
Medial calf	8.9 ± 1.5	9.2 ± 2.2	9.3 ± 2.3
Sum of all eight skinfolds	70.8 ± 17.2	77.2 ± 23.2	75.0 ± 16.2
Girths (cm):			
Arm (relaxed)	25.4 ± 2.3	25.7 ± 2.1	25.8 ± 1.9
Arm (flexed and tensed)	26.2 ± 2.4	26.6 ± 2.2	26.7 ± 2.0
Forearm (maximum, relaxed)	22.8 ± 1.3	22.9 ± 1.3	23.0 ± 1.2
Chest (mesosternale)	85.9 ± 3.2	86.3 ± 3.2	87.2 ± 3.8
Waist (minimum)	65.7 ± 3.1	66.0 ± 3.5	66.6 ± 3.7
Gluteal (maximum)	90.0 ± 3.0	90.2 ± 4.0	90.5 ± 3.1
Thigh[e]	53.2 ± 2.5	53.8 ± 3.0	53.9 ± 2.4
Thigh[f]	48.0 ± 2.4	48.3 ± 2.9	48.5 ± 2.6
Calf (maximum)	34.6 ± 1.7	34.7 ± 1.7	34.9 ± 1.7
Neck	30.4 ± 0.9	30.5 ± 0.6	30.7 ± 0.6
Breadths (cm):			
Humerus	6.29 ± 0.18	6.29 ± 0.21	6.32 ± 0.25
Femur	9.01 ± 0.27	9.03 ± 0.29	9.04 ± 0.32
Somatotype:			
Endomorphy	2.5 ± 0.7	2.8 ± 0.8	2.6 ± 0.5
Mesomorphy	3.6 ± 1.2	3.6 ± 1.1	3.7 ± 1.2
Ectomorphy	3.4 ± 1.0	3.3 ± 0.9	3.2 ± 0.8

[a–f]Refer to Table 1

and the control subjects demonstrated that significantly lower values for the former only occurred at 3–5 days prior to competition for sum of eight skinfolds ($P = 0.025$), %BF ($P = 0.004$) and FM ($P = 0.018$); however, all three group comparisons indicated that the bodybuilders had significantly more FFM (test 1, $P = 0.015$; test 2, $P = 0.022$; test 3, $P = 0.049$) than the controls.

The bodybuilders' FFM via the four-compartment model did not significantly change over the testing period ($P = 0.061$). However, using the same body composition model, their FM and %BF showed significant ($P < 0.01$) differences between both pairwise comparisons with test 3 (Table 3). The decreases in %BF via the four-compartment model for the five bodybuilders were: 15.7–10.7 %BF, 18.3–12.2 %BF, 17.7–10.5 %BF, 15.3–12.9 %BF and 24.2–17.3 %BF. Furthermore, Figure 1 and Tables 1 and 3 emphasize that most of the 5.80 kg body mass loss for the bodybuilders came from the FM (4.42 kg; 76.2%) and not the FFM (1.38 kg; 23.8%). Individual FM decreases were 4.56 kg (71%), 4.62 kg (90%), 5.01 kg (96%), 2.10 kg (47%) and 5.82 kg (74%), while corresponding FFM decrements were 1.84 kg (29%), 0.50 kg (10%), 0.23 kg (4%), 2.40 kg (53%) and 1.94 kg (26%). The FM loss by the bodybuilders was accompanied by a 25.5 mm decline ($P < 0.001$; 76.3–50.8 mm) for the sum of eight skinfold thicknesses. The 3×2 ANOVA for the FFM density only provided statistical significance for the group main effect. The overall mean for the bodybuilders' FFM density in Table 3 was significantly lower ($P = 0.014$) than that for the control subjects which are presented in Table 4.

In Figure 2, the deviations from the horizontal dotted line at zero on the ordinate range from −3.6 to +4.9 %BF and represent the large errors that occur when there is no control for biological variability in TBW. Figure 3 also depicts the inverse linear relationship between FFM density and its water content. However, Figure 4 shows that controlling for inter-individual differences in BMM had little effect on %BF and there were therefore no significant correlations ($P \geq 0.126$) between %BMM in the FFM and FFM density. Individual differences between the two-compartment hydrodensitometric and three-compartment models accordingly exhibited significantly greater

Table 3 Descriptive statistics ($\overline{X} \pm$ s.d.) for the body composition data of the five female bodybuilders

	Test 1[a]	*Test 2*[b]	*Test 3*[c]
Percentage body fat			
2C[d] (body density)	18.9 ± 4.6	16.9 ± 4.9	12.4 ± 4.6†
2C (TBW[e])	16.2 ± 2.7	14.5 ± 1.9	11.2 ± 1.3†
3C	18.4 ± 3.3	16.6 ± 3.1	12.9 ± 2.4†
4C	18.3 ± 3.5	16.5 ± 3.3	12.7 ± 2.8†
DEXA[f]	15.3 ± 3.1	13.6 ± 3.0*	9.7 ± 2.1†
Fat mass (kg)			
2C (body density)	12.49 ± 3.01	10.85 ± 3.20*	7.46 ± 2.49†
2C (TBW)	10.74 ± 1.95	9.33 ± 1.60	6.79 ± 1.01†
3C	12.21 ± 2.29	10.69 ± 2.23*	7.78 ± 1.36†
4C	12.07 ± 2.32	10.59 ± 2.26	7.65 ± 1.48†
DEXA	10.11 ± 2.21	8.67 ± 2.15*	5.89 ± 1.39†
Fat-free mass (kg)			
2C (body density)	53.89 ± 6.56	53.41 ± 6.15	53.12 ± 6.69
2C (TBW)	55.65 ± 5.65	54.93 ± 5.36	53.79 ± 5.22*
3C	54.17 ± 5.91	53.56 ± 5.56	52.80 ± 5.70
4C	54.31 ± 6.23	53.66 ± 5.86	52.93 ± 6.05
DEXA	55.89 ± 5.87	55.16 ± 5.56*	54.55 ± 5.35†
TBW (l)	40.06 ± 4.07	39.55 ± 3.86	38.73 ± 3.76*
FFM hydration (%)	73.86 ± 1.47	73.77 ± 1.57	73.29 ± 1.86
BMM[g] (g)	2681 ± 129	2701 ± 141	2689 ± 137
%BMM/FFM	4.98 ± 0.49	5.07 ± 0.51	5.12 ± 0.53
Body density (g/cm^3)	1.0560 ± 0.0103	1.0605 ± 0.0109*	1.0706 ± 0.0104†
FFM density[h] (g/cm^3)	1.0980 ± 0.0040	1.0988 ± 0.0049	1.1007 ± 0.0059

[a]12 weeks before competition; [b]6 weeks before competition; [c]3–5 days before competition; [d]compartment; [e]total body water; [f]dual-energy X-ray absorptiometry; [g]bone mineral mass;

$$^{h}\ \frac{1}{\mathrm{BD}} = \frac{f_{\mathrm{FM}}}{0.9007} + \frac{f_{\mathrm{FFM}}}{\mathrm{FFM\ density}}$$

where $f_{\mathrm{FM}} + f_{\mathrm{FFM}} = 1$ and are from the 4C model.
*Significantly different ($P \leq 0.05$) from test 1; †significantly different ($P \leq 0.05$) from tests 1 and 2.

Table 4 Descriptive statistics ($\overline{X} \pm$ s.d.) for the body composition data of the five female control subjects

	Test 1[a]	*Test 2*[b]	*Test 3*[c]
Percentage body fat			
2C[d] (body density)	16.4 ± 3.1	17.0 ± 4.0	17.9 ± 2.9
2C (TBW[e])	19.2 ± 4.0	19.2 ± 2.8	18.9 ± 3.4
3C	19.1 ± 3.4	19.3 ± 3.2	19.5 ± 2.8
4C	19.1 ± 3.3	19.4 ± 3.2	19.6 ± 2.6
DEXA[f]	15.0 ± 5.5	15.8 ± 5.1	16.6 ± 5.1
Fat mass (kg)			
2C (body density)	9.26 ± 2.33	9.80 ± 3.03	10.37 ± 2.51
2C (TBW)	10.80 ± 2.66	11.02 ± 2.34	10.93 ± 2.59
3C	10.74 ± 2.45	11.11 ± 2.64	11.31 ± 2.44
4C	10.77 ± 2.40	11.14 ± 2.64	11.37 ± 2.36
DEXA	8.39 ± 3.33	9.02 ± 3.33	9.55 ± 3.34*
Fat-free mass (kg)			
2C (body density)	46.67 ± 1.80	47.13 ± 1.64	47.14 ± 2.13
2C (TBW)	45.13 ± 2.79	45.91 ± 2.43	46.58 ± 2.98
3C	45.19 ± 2.30	45.83 ± 2.06	46.21 ± 2.49
4C	45.17 ± 2.20	45.80 ± 2.00	46.14 ± 2.46
DEXA	47.18 ± 3.34	47.49 ± 2.69	47.56 ± 3.28
TBW (l)	32.49 ± 2.01	33.05 ± 1.75	33.54 ± 2.15
FFM hydration (%)	71.91 ± 1.09	72.15 ± 0.70	72.65 ± 1.42
BMM[g] (g)	2575 ± 204	2594 ± 194	2606 ± 184
%BMM/FFM	5.70 ± 2.71	5.66 ± 0.33	5.65 ± 0.33
Body density (g/cm^3)	1.0615 ± 0.0071	1.0602 ± 0.0090	1.0582 ± 0.0066
FFM density[h] (g/cm^3)	1.1083 ± 0.0039	1.1073 ± 0.0027	1.1054 ± 0.0043

[a–h] and *Refer to Table 3.

($P \leq 0.001$) variances than those between the three- and four-compartment models.

The category for the somatotype means of the control subjects changed little (test 1, mesomorph-ectomorph; test 2, central; test 3, balanced mesomorph) because the individual components varied minimally over the 12 weeks. The Hotelling's T^2 was therefore not statistically significant ($P = 0.11$). By comparison, the bodybuilders' progressive decrease and increase in endomorphy and ectomorphy, respectively, were reflected in changes from endomorphic mesomorph to balanced mesomorph and finally to ectomorphic mesomorph. The Hotelling's T^2 was therefore statistically significant ($P = 0.03$).

The largest skinfold thicknesses for the bodybuilders in the non-competitive and competitive states were at the front thigh (19.8 and 13.3 mm, respectively) and medial calf (12.0 and 8.0 mm, respectively). The greatest absolute losses over the 12 weeks occurred for the front thigh (−6.5 mm), medial calf (−4.0 mm) and triceps (−4.0 mm), whereas the biggest relative decrements were at the abdominal (−41.5%), supraspinale (−37.7%) and triceps (−34.5%) sites. All the bodybuilders' girth measurements declined during preparation for competition and all these losses were greatest during the final 6 weeks. The largest absolute decrements were for the maximal gluteal girth (−5.4 cm), chest (−4.2 cm), waist (−4.1 cm) and thigh (−4.0 cm; 1 cm distal to gluteal line); whereas the largest relative changes occurred for the thigh (−6.8%; 1 cm distal to gluteal line), waist (−5.7%), maximal gluteal girth (−5.7%), thigh (−5.3%; mid trochanterion-tibiale laterale) and relaxed upper arm (−5.3%).

Discussion

This is the first published information on four-compartment body composition model changes in female bodybuilders during preparation for competition. Our major finding is that lean female bodybuilders, whose 18.9 %BF via hydrodensitometry was similar to that of 18.5 %BF for 182 female representatives of 14 South Australian sports squads who were tested within 2 weeks of their respective national championships (Withers *et al*, 1987), were capable of further large %BF decrements during the 12 week build-up to competition. This was presumably achieved by increasing energy expenditure as four of the bodybuilders stated that they did not reduce their energy intake. Individual decreases in %BF via the four-compartment model during the bodybuilders' preparation ranged from 2.4 to 7.2%, with final body fat values of 10.7, 12.2, 10.5, 12.9

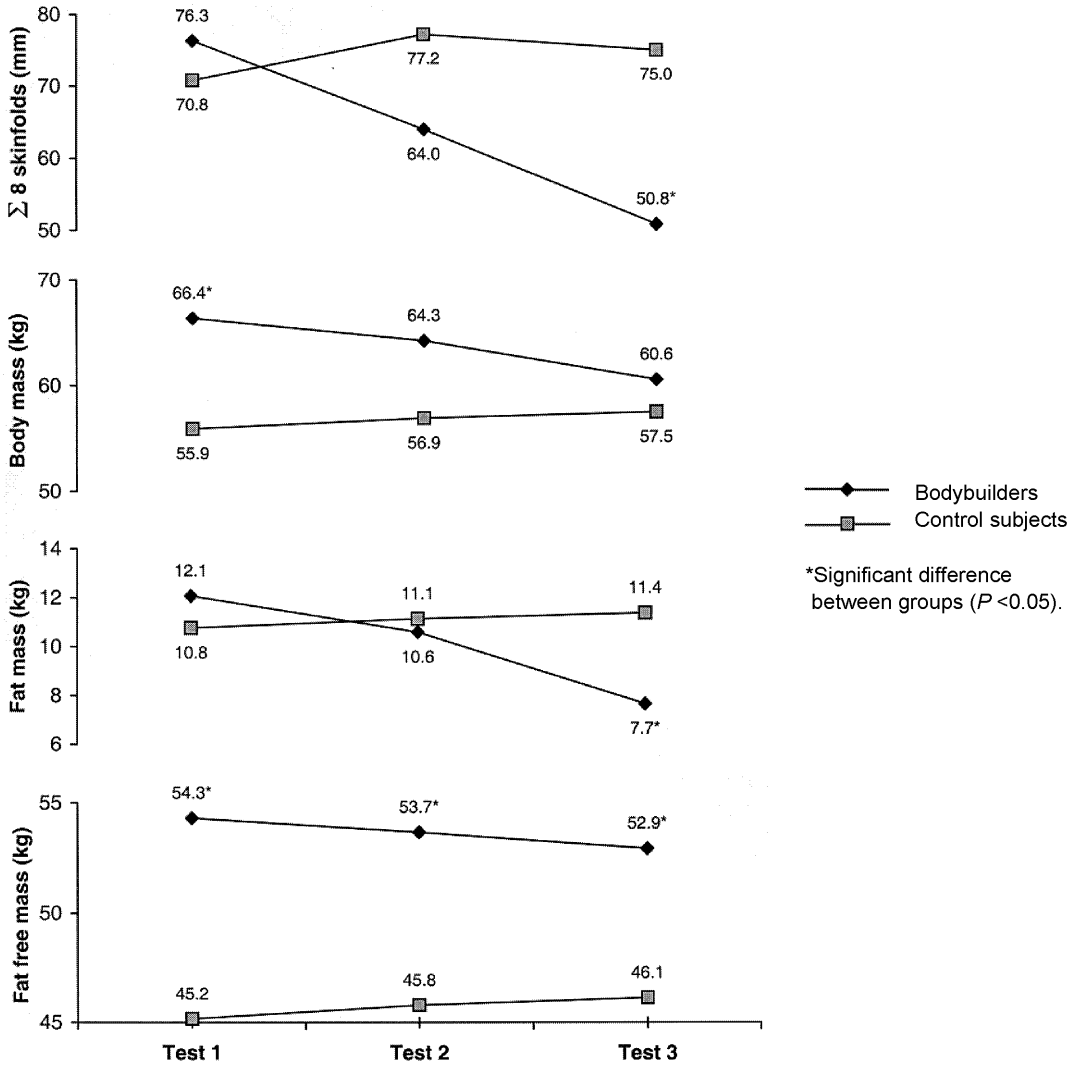

Figure 1 Temporal changes for the bodybuilders and control subjects (test 1, 12 weeks before competition; test 2, 6 weeks before competition; test 3, 3–5 days before competition).

and 17.3% obtained 3–5 days prior to competition. The values for four of the subjects were therefore only just above the sum of the hypothesized 4% essential fat and 5% gender-specific fat for the female with the balance of 1.5–3.9% comprising storage fat (Katch *et al*, 1980). Figure 1 emphasizes that most of these losses came from the FM and not the FFM. This figure also shows that the losses in body mass (Table 1, 12→6 weeks = −2.12 kg; 6 weeks→3–5 days = −3.68 kg) and FM (Table 3, 12→6 weeks = −1.48 kg; 6 weeks→3–5 days = −2.94 kg) were greatest during the final 6 weeks of preparation for competition, whereas the small FFM decrements (Table 3: 12→6 weeks = −0.65 kg; 6 weeks→3–5 days = −0.73 kg) were equally spaced. Furthermore, the greater decrease in FM in the final 6 weeks is emphasized by the Tukey *post-hoc Q* statistic of 7.74 ($P < 0.01$) compared with one of 3.91 ($P > 0.05$) for the initial period. Hence, the bodybuilders' physical training enabled most of their FFM to be preserved despite the fact that they were all in negative energy balance. Our findings are in accordance with those of Heyward *et al* (1989), whose two-compartment hydrodensitometric model showed that 81.7 and 18.3% of a 6.0 kg body mass decrement during preparation for a bodybuilding contest came from the FM and FFM, respectively.

The two-compartment hydrodensitometric model of Brožek *et al* (1963) separates the body into the FM and FFM. The latter comprises water, protein, bone mineral and non-bone mineral, whose respective densities and percentages (in parentheses) at 36°C are as follows: 0.99371 (73.72%), 1.34 (19.41%), 2.982 (5.63%) and 3.317 g/cm^3 (1.24%). The four-compartment body composition model is an improvement on the preceding two-compartment model because it controls for biological variability in both TBW and BMM. The masses and volumes of these two FFM

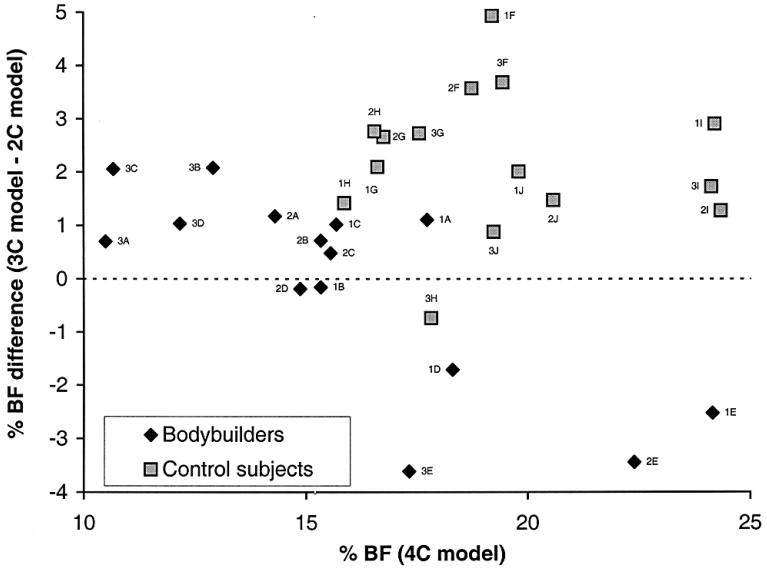

Figure 2 %BF difference between three- and two-compartment (C) models graphed against %BF via four-compartment model (numbers 1–3 denote test order and letters A–J refer to individual subjects).

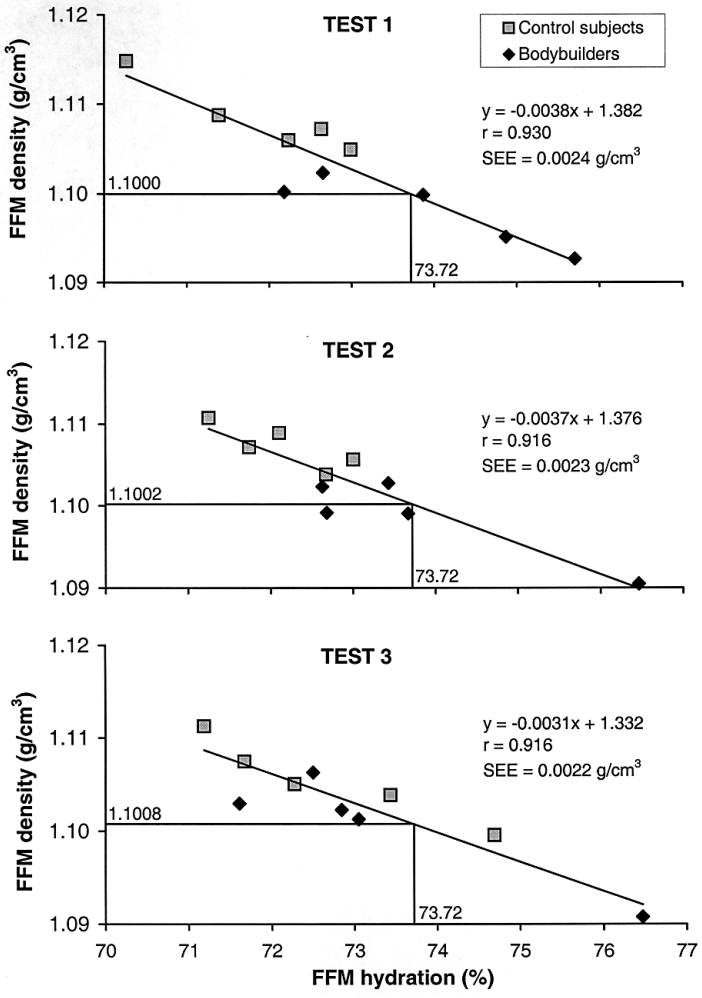

Figure 3 Relationship between FFM hydration and FFM density estimated via the four-compartment model.

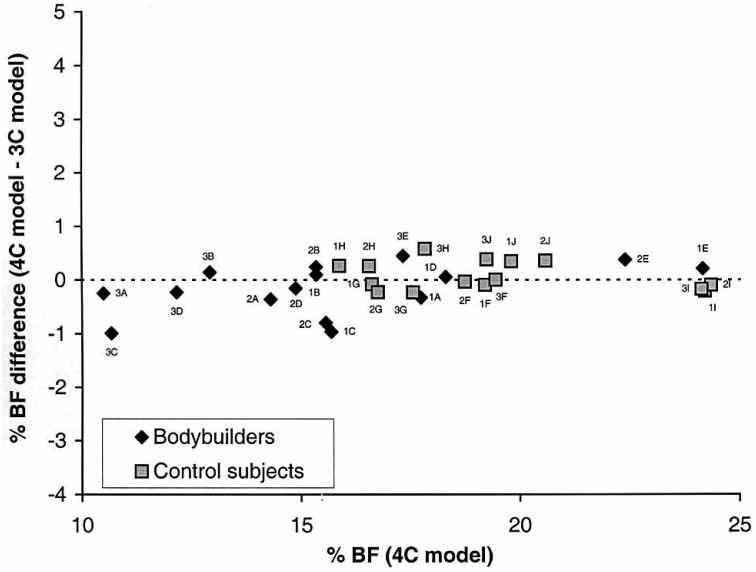

Figure 4 %BF difference between four- and three-compartment (C) models graphed against %BF via four-compartment model (symbols as defined in Figure 2).

components, which are measured by isotopic dilution and DEXA, respectively, are subtracted from those used to calculate whole body density via underwater weighing. This permits the remainder to be separated into fat and residual masses with assumed densities of 0.9007 (Fidanza *et al*, 1953) and 1.404 g/cm^3 (Allen *et al*, 1959; 37°C samples only), respectively. The foregoing enables us to appreciate why the bodybuilders' FFM density was lower ($P = 0.014$) than that for the control subjects. The data in Tables 3 and 4 indicate that their FFM contains a greater percentage of low density water and a smaller percentage of high density BMM than for the control subjects. Hence, the bodybuilders' %BFs via the two-compartment hydrodensitometric model are similar to those using the four-compartment model because their FFM densities, after control for biological variability in TBW and BMM, differed little from the two-compartment hydrodensitometric assumption of 1.1000 g/cm^3. Accordingly, their FFM hydrations approximated the 73.72% of the two-compartment hydrodensitometric model and Figure 4 demonstrates that our measured interindividual variability in BMM impacted little on %BF via the four-compartment model. However, the FFM densities of the control subjects were greater than 1.1000 g/cm^3, primarily because their FFM hydrations were less than 73.72%, and the two-compartment hydrodensitometric model therefore yielded lower %BF values than the four-compartment criterion model.

The three-compartment body composition model controls for inter-individual variability in the large and acutely variable TBW because the mass and volume of this component are subtracted from the mass and volume of the total body. This then enables the remainder to be partitioned into fat and fat free dry masses with assumed densities of 0.9007 (Fidanza *et al*, 1953) and 1.569 g/cm^3 (Brožek *et al*, 1963), respectively. The three-compartment model is therefore based on determinations of body density and TBW, whereas the two-compartment hydrodensitometric model is based only on the former measurement. The deviations from the horizontal dotted line at zero on the ordinate of Figure 2 represent the large errors that occur when no control is exerted for biological variability in TBW and the two-compartment hydrodensitometric assumption is made that the FFM contains 73.72% water. The variability of these errors was due to the wide range of FFM hydration, which Figure 3 indicates was from 70.3 to 76.5%. The 23 data points above the dotted line in Figure 2 all represented FFM hydrations below 73.72%. Their FFM densities were therefore greater than the two-compartment hydrodensitometric assumption of 1.1000 g/cm^3, because water has by far the lowest density of any of the four FFM components. Hence, their %BFs via two-compartment hydrodensitometry were lower than for the three-compartment model. The converse applies to the seven data points below the dotted line in Figure 2. Notwithstanding the lack of independence between the variables on both axes, Figure 3 clearly emphasizes the effect of FFM hydration on FFM density.

As mentioned previously, the two-compartment hydrodensitometric model of Brožek *et al* (1963) assumes that BMM comprises 5.63% of the FFM. However, Figure 4 emphasizes that biological variability in the BMM of our subjects impacted little on the %BF via the four-compartment model. Nevertheless, the lower mean values of 4.98–5.12% for the bodybuilders' BMM (Table 3) may be due to the disproportionate effect of bodybuilding in increasing skeletal muscle mass compared with the BMM, which consequently causes a dilution of the former within the FFM. We have previously reported the same phenomenon,

but to a greater extent, in elite male bodybuilders (Withers *et al*, 1996). Also, the two-compartment hydrodensitometric FFM hydration assumption of 73.72% is based on analyses of three male cadavers aged 25–46 y (Brožek *et al*, 1963), but the literature interestingly contains the following data for the FFM hydration of five male cadavers: 67.4, 70.4 (Forbes & Lewis, 1956); 77.56 (Mitchell *et al*, 1945); 62.1 (Shohl, 1939) and 72.62% (Widdowson *et al*, 1951). The mean of 72.0% approximates that of 72.2% ($n=15$) for our female control subjects which in turn is identical to the 72.2% we have reported previously for athletic females (Withers *et al*, 1998). The higher overall mean of 73.6% ($n=5$) for our female bodybuilders may be due to their proportionately greater skeletal muscle mass. Protein is a primary source of nonaqueous hydrogen exchange (Culebras & Moore, 1977) and a 1.04 correction factor when calculating TBW may therefore be too conservative for subjects with large skeletal muscles. Furthermore, the water content of skeletal muscle at 77.4–80.9% (Forbes, 1987) is greater than the two-compartment hydrodensitometric assumption of 73.72% for FFM hydration. Nevertheless, the five body composition methods in Table 3 all demonstrate similar mean changes in that the decreases between 12 and 6 weeks before competition ranged from 1.7 to 2.0 %BF and decrements for the final 6 weeks ranged from 3.3 to 4.5 %BF.

While the four-compartment body composition model is theoretically more valid than the two-compartment models because it controls for the biological variability in TBW and BMM, there is some concern that this extra validity may be offset by the propagation of error associated with the measurements of body density, TBW and BMM. A worst case scenario for this propagation of error can be calculated by assuming that the three measurements are made independently and are normally distributed. The propagated error is then equal to the square root of the sum of the error variances (Taylor, 1982):

$$\text{SD of total error} = \sqrt{\text{TEM}^2 + \text{TEM}^2 + \text{TEM}^2}$$

Our propagated error approximates 0.7 %BF (Withers *et al*, 1999). This is considerably less than that of 3.8 %BF for the two-compartment hydrodensitometric model (Siri, 1961), which is due to biological variability in the FFM density. The extra accuracy of the four-compartment model compared with the two-compartment model therefore appears not to be offset by the propagation of measurement error. Nevertheless, there is still concern about some of the assumptions which are made when estimating body composition via the four-compartment model (Withers *et al*, 1999).

Comparison with the %BF and anthropometric data in the literature is complicated by being unable to match the training status of the bodybuilders since two studies (Johnson *et al*, 1990; Freedson *et al*, 1983) reported no details, Carlson *et al* (1988) stated their subjects were 4.8 kg above contest mass, Walberg-Rankin *et al* (1993) tested 2 weeks prior to competition, Elliott *et al* (1987) measured their subjects 3 days after the event and four groups (Heyward *et al*, 1989; Kleiner *et al*, 1990, 1994; Sandoval *et al*, 1989) tested within 48 h of competition when the subjects were likely to be dehydrating, which would increase FFM density and thereby decrease the %BF via hydrodensitometry. Furthermore, only two (Heyward *et al*, 1989; Sandoval *et al*, 1989) of these latter four groups estimated %BF using the primary method of hydrodensitometry, but their residual volume (RV) measurements were conducted on land, which has been shown to yield a higher RV and hence lower %BF than when RV is measured with the subject immersed (Withers & Hamdorf, 1989). The pre-competition 12.4 %BF via two-compartment hydrodensitometry is therefore higher than those of 9.5 %BF and 8.4 %BF for Heyward *et al* (1989) and Sandoval *et al* (1989), respectively. Nevertheless, the lower %BF reported by Heyward *et al* (1989) is supported by their similar pre-competition value of 36.3 mm for the sum of five skinfolds (this study: 35.8 mm; triceps + subscapular + iliac crest + abdominal + front thigh) via Lange calipers which yield 10% higher values than the Harpenden calipers used in this study (Gruber *et al*, 1990). Sandoval *et al* (1989) also reported a lower value of 20.2 mm for the sum of three skinfolds (this study: 24.9 mm; triceps + iliac crest + front thigh) using Lange calipers. There are some interesting similarities between the present investigation and the only other longitudinal study in the literature by Heyward *et al* (1989). They reported a similar body mass decrement of 6.0 kg (−10.3%) compared with our 5.8 kg (−8.7%), but the duration ranged from 6 to 17 weeks for their 12 subjects whereas our decrease occurred over 12 weeks. Their sum of the five previously defined skinfold thicknesses declined by greater absolute and relative amounts (−24.1 mm, −39.9%) during preparation for competition than for our subjects (−18.3 mm, −33.8%) but our greatest absolute (−6.5 mm) and relative changes (−41.5%) for the thigh and abdominal sites, respectively, agree with the findings of Heyward *et al* (1989).

In summary, our data on a small sample of five female bodybuilders demonstrate that: (a) 12 weeks before competition their %BF approximated that of South Australian representative sportswomen who were tested within 2 weeks of their respective national championships; (b) despite their lean status, the training regimen during the next 12 weeks resulted in a 5.8 kg (−8.7%) decrement in body mass with most of this loss (−76.2%) coming from the FM; furthermore, the decreases in body mass and FM over the final 6 weeks were greater than those over the first 6 weeks, and (c) the whole body and FM losses were mirrored by a 33.4% decline in subcutaneous fat which was estimated from the sum of eight skinfold thicknesses.

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