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Research article

BODY WATER INDICES AS MARKERS OF AGING IN MALE MASTERS SWIMMERS

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ABSTRACT
The association of age and weekly swim training distance with body water, lean tissue, fat mass and regional adiposity was examined in 27 male masters swimmers. Subjects ranged in age from 25.3 to 73.1 years (mean age = 47.7 ± 11.1 years). Weekly swim distances, estimated from self-reported swim logs, were from 3 400 to 17 500 m and averaged 10 016 ± 4 223 m. Total body water (TBW), and extracellular water (ECW) were predicted from multi-frequency bioelectrical impedance analysis and intracellular water was estimated by difference. Lean soft tissue, bone mineral content, fat mass, and percent body fat were estimated from dual-energy X-ray absorptiometry. Measures of skinfold thickness, waist circumference, and abdominal sagittal diameter provided an indication of regional adiposity. Total body water, ECW, and ICW mean values (ranges) were as follows: 47.4 ± 4.6 L (37.9-56.9 L), 19.6 ± 1.8 L., (16.4-24.8 L), and 27.8 ± 3.2 L (21.5-34.4 L). Mean percent body fat levels were 21.9 ± 6.6% and ranged from 10.3 to 34.9%. Age was negatively associated with ICW ($p = 0.02$) and with the ICW/TBW ratio ($p = 0.00$). Multiple-linear regression analysis backward method suggested that both lean tissue and fat mass were predictors of ICW although the association with fat mass did not reach statistical significance ($p = 0.00$ and $p = 0.06$ for lean and fat mass respectively). There was a tendency for greater lower abdominal thickness with increasing age ($p = 0.08$), but no other associations were observed between age or with swimming and body composition variables. Changes in ICW and the ration of ICW to TBW appeared to be the strongest marker of aging in this group of adult male competitive swimmers.

KEY WORDS: Total body water, intracellular water, exercise, body bomposition, dual-energy X-ray absorptiometry, bioelectrical impedance analysis.

INTRODUCTION

Recreational swimming is a popular sport among post-collegiate males both for its therapeutic value and for the perceived benefits of maintaining lean tissue mass and promoting a reduced level of body adiposity (Richardson and Miller, 1991; United States Masters Swimming, 2005). Numerous studies with older endurance athletes engaged in a variety of sports have suggested that exercise training protects against the age-related losses of muscle mass and function (Hawkins et al., 2003; Richardson and Miller, 1991; Wiswell et al., 2001) and helps maintain a leaner body composition (Maharam et al., 1999; Tuuri et al., 2002; Wiswell et al., 2001). Body water which occupies approximately 74% of the lean tissue and 25% of adipose tissue may also fluctuate in response to aging and exercise (Ellis, 2000; Martin et al., 1994; Ritz, 2000).

Changes in total body water (TBW) and the intra- and extracellular components as a result of aging have been examined with sometimes conflicting findings. In a literature review of cross-sectional, in-vivo isotope dilution studies, Watson and colleagues (1980) examined the TBW volumes of 458 men between the ages of 17 and 86 years. Total body water was reported to remain relatively constant through early adulthood and then to gradually decline at a rate of approximately 0.3 kg/y until reaching a plateau in 80-to-90 year old subjects. Whether the relative proportions of intracellular water (ICW) and extracellular water (ECW) volumes are altered by age and physical activity is not clear (Schoeller, 1989). Some investigators have found slightly greater volumes of ECW in older individuals (Ellis, 2000; Shock and Watkins, 1963) while others have reported reduced levels of this water compartment (Fulop et al., 1985). The findings regarding ICW have been more consistent with most researchers reporting decreased levels of ICW in elderly subjects when compared to younger participants (Fulop et al., 1985; Shock and Watkins, 1963).

The association between body hydration and amount of physical activity is also not certain. When a group of young, elite athletes were compared to recreational sportsmen of similar age, significantly higher levels of TBW and ICW-to-ECW were noted (Battistini et al., 1994). However, in older men who participated in a short-term endurance exercise program only in an increase in plasma volume was observed, and levels of TBW, ICW, and ECW did not appear to change (Pickering et al., 1997).

Although swimming is considered an endurance-type exercise, it has been reported among adolescent athletes that swimmers store greater levels of fat than runners or bikers despite similar amounts of daily training caloric expenditure (Flynn, 1990; Thorland et al., 1983). Swimming has been shown to be relatively ineffective in reducing body fat levels when used as part of weight loss programs (Clarke and Vaccaro, 1979; Katch, 1969). Suggested reasons for the increased adiposity with swimming include factors related to water immersion during exercise, use of more active muscle mass, or other metabolic differences (Flynn, 1990). While some information regarding the body composition of female masters swimmers has been reported (Tuuri et al., 2000), little is known about body water volumes, lean and fat masses, and regional adiposity of male post-collegiate recreational swimmers.

Studies with master swimmer athletes provide a cross-sectional model to use to examine the association of both age and physical activity with body composition parameters. These adults continue to be physically active as they age and regularly participate in the same type of exercise training. It was hypothesized that subject age and weekly swim training distance would be associated with volumes of body water, amounts of lean tissue and fat mass, and regional adiposity.

METHODS

Participants

Twenty-seven adult male competitive swimmers volunteered to participate. All men were members of United States Masters Swimming (USMS) teams in the state of Louisiana and had been actively training for swimming competition under the guidance of a USMS coach for at least one year. With the exception of one subject with hypertension, no participants reported a history of myocardial infarction, diabetes, or hypertension. Swimmers were excluded if they were taking any medications that would interfere with normal body hydration or if they had any artificial bone or joint replacements. Subjects ranged in age from 25.3 to 73.1 years and average swim training volume in the two weeks prior to measurement was 10 015 ± 4 223 m·wk^{-1} (range = 3 400 – 17 500 m·wk^{-1}). All men reported that at least 50% of their structured exercise time was spent swimming. In addition to swimming, four lifted weights (14.8%), three ran (11.1%), two played tennis (7.4%), and eight participated in a combination of these activities (29.6%).

Procedures

Subjects were measured during a single measurement session. They were asked to refrain from exercising on the day of testing and to avoid caffeine-containing beverages and the consumption of large meals prior to measurement. Average weekly swim distances were estimated from self-reported swim/exercise logs that the participants kept for two weeks prior to testing. All subjects gave written consent in accordance with the ethical standards of the Louisiana State University and Pennington Biomedical Research Center Institutional Review Boards.

Subjects were weighed and measured for height without shoes. The men were assessed with an INSCALE digital platform scale (Indiana Scale Co, Inc, Terre Haute, IN) and height was taken with a Holtain wall-mounted stadiometer (Holtain Ltd, Croswell, Crymych, UK). Measurement of waist circumference, abdominal sagittal diameter, and skinfold thickness measures were obtained following previously published guidelines (Clasey et al., 1999; Lohman et al., 1988; National Institute of Health, 2000). Levels of subcutaneous fat deposits on the trunk (subscapular, suprailiac, and abdomen) and on the extremities (triceps, biceps, and calf) were

Table 1. Physical characteristics of male masters swimmers (n = 27).

	Mean (±SD)	Range
Age (yr)	47.7 (11.1)	25.3 – 73.1
Height (m)	1.79 (.05)	1.67 – 1.88
Weight (kg)	80.3 (10.7)	68.2 – 111.6
DXA fat mass (kg)	17.0 (7.6)	7.0 – 35.2
DXA lean soft tissue (kg)	54.6 (5.6)	46.4 – 70.2
DXA bone mineral content (kg)	3.2 (.4)	2.3 – 4.1
DXA percent body fat (%)	21.9 (6.6)	10.3 – 34.9
BIA total body water (L)	47.4 (4.6)	37.9 – 56.9
BIA intracellular water (L)	27.8 (3.2)	21.5 – 34.4
BIA extracellular water (L)	19.6 (1.8)	16.4 – 24.8

DXA = Dual-energy x-ray absorptiometry; BIA = multi-frequency bioelectrical impedance analysis.

assessed by one trained investigator (KW) using a Lange skinfold caliper (Cambridge Scientific Industries, Inc., Cambridge, MA). Measures of waist circumference and abdominal sagittal diameter provided an indication of intra-abdominal fat deposition as both have been shown to be strong predictors when validated against computed tomography (Clasey et al., 1999). A flexible, fiberglass tape was used to measure waist circumference, and the abdominal sagittal diameter was determined using a Holtain slide gauge anthropometer (Holtain Ltd, Croswell, Crymych, UK).

Total body water and extracellular water were estimated from multi-frequency bioelectrical impedance analysis (BIA) using a Xitron Hydra ECF/ICF Model 4200 (Xitron Technologies, Inc. San Diego, CA). The intracellular water volume was calculated as the difference between TBW and ECW. Resistance and reactance were measured and the reciprocal impedance and phase angle calculated at each of 50 measured frequencies from 5 kHz to 1 MHz based upon complex modeling equations formulated from the Hanai mixture theory (Hanai, 1968). Research with the Xitron apparatus has shown a correlation between predicted and isotope dilution determinations of extracellular fluid volumes to range between 0.96 and 0.89, with SEE ranging between 0.97 L to 0.88 L respectively (De Lorenzo et al., 1997; Patel et al., 1994; Van Loan et al., 1963). Subject height (cm), weight (kg), and gender were entered into the apparatus and then they rested quietly in the supine position for five minutes before the impedance test began. The area of skin on the right hand and foot to which the electrodes were applied was wiped with 70% isopropyl alcohol and self-adhesive, pre-gelled electrodes were applied. Two current source electrodes were positioned with one distal to the metacarpophalangeal joint and one behind the toes. Two detection electrodes were placed on the wrist over the ulna head and on the ankle at the level of and between the medial and lateral malleoli.

Body fat mass, lean soft tissue, and bone mineral content were estimated from total body DXA scans using a wide angle fan-beam Hologic QDR 4500 apparatus (Hologic, Inc., Bedford, MA). Following daily quality assurance measurements, subjects were scanned in the supine position wearing lightweight, loose fitting clothing after removing all jewelry and metal objects. The scans for both studies were analyzed after adjusting for anatomical cut regions by one trained investigator (GT). The QDR-4500 DEXA (Hologic Co, Waltham, MA), has been reported to overestimate fat-free tissue and underestimate bone mineral and fat masses when compared to the former QDR-2000 model (Hologic Co, Waltham, MA) and to four-component analysis (Deurenberg-Yap et al., 2001; Schoeller et al., 2005). Because the QDR 2000 compares well with four-component models (Jebb et al. , 1995) the data collected with the QDR 4500 was converted to reflect those obtained from a QDR 2000 Hologic apparatus. The conversion algorhythms used were developed by the Pennington Biomedical Research Center after measuring 38 individuals twice with both Hologic instruments. The R^2 values for lean soft tissue and fat mass algorhythms were all greater than or equal to 0.94 (unpublished data).

Statistical analysis

Data were examined using SPSS statistical software (Version 11.0 SPSS for Windows, SPSS Inc., Chicago, IL). All subjects were represented for each test. Descriptive characteristics were expressed as mean values, standard deviations (SD), and ranges. Relationships between the two predictor variables, age and weekly swim distance, with body composition criterion variables were examined using Pearson product-moment correlation coefficients. Multiple-linear regression backward method examined the contribution of lean tissue, fat mass, and bone mineral content to the prediction of total body water and body water fractions. The level of significance was set at $p < 0.05$.

RESULTS

Physical characteristics of the male swimmers are presented in Table 1. The range in percent body fat was wide with the average score being approximately 22%. Body mass index (BMI) scores ($kg{\cdot}m^{-2}$) varied from 21.9 to 31.6 with a mean value of 25.1 ± 2.6. When compared to the United States National Institute of Health standards, 15 of the male swimmers were considered to be at a healthy weight (BMI ≥ 18.5 and < 25; 57%), 10 had BMI scores classifying them as overweight (BMI ≥ 25 and < 30; 36%), and two were considered obese (BMI ≥ 30; 7%) (National Institute of Health, 2000). Volumes of body water also varied widely but the intracellular-to-total body water was maintained at a mean ratio of approximately 59.0% ± 0.2 (range 0.55 - 0.62).

Anthropometric indicators of regional adiposity included measures of trunk and extremities skinfold thicknesses, abdominal sagittal diameter, and waist circumference. Skinfold thickness mean values and ranges were as follows: subscapular, 14.28 ± 5.2 mm, 5.3 – 24.7 mm, suprailiac, 8.9 ± 3.5 mm, 3.7 – 19.7 mm, abdomen, 18.1 ± 5.9 mm, 5.7 – 31.7 mm, triceps, 8.6 ± 2.9 mm, 4.3 – 16.5 mm, biceps 4.7 ± 1.9 mm, 2.2 – 9.8 mm, and calf 9.1 ± 4.0 mm, 3.2 – 19.7 mm. Abdominal sagittal diameter averaged 12.9 ± 3.1 cm and varied from 8.0 to 19.2 cm. Differences in waist circumference ranged from the smallest measurement of 80.0 cm to the largest of 112.0 cm (mean, 91.0 ± 8.7 cm). Four men had waist circumference values greater than 102 cm which placed them in the NIH-defined "high risk category" (National Institute of Health, 2000).

Examination of the data using Pearson's r correlation coefficients revealed associations between age and body water, but no relationships were observed between swim training distance and the measured body composition variables. Age had a negative relationship with intracellular water ($r = -0.44$; $p = 0.02$) (Figure 1) and with the intracellular-to-total body water ratio ($r = -0.74$, $p = .00$). In addition, the association between age and abdominal sagittal diameter approached significance ($p = 0.08$). As shown in Table 2, the level of estimated intracellular water was positively correlated with lean tissue and bone mineral content but not with fat mass. Lean tissue mass appeared to be moderately correlated with both bone mineral content and fat mass ($r \geq 0.57$).

Multiple-linear regression using the backward method examined the contribution of lean tissue, fat mass, and bone mineral content to the prediction of total body water and the intra- and extracellular fractions. As shown in Table 3, the amount of lean tissue estimated from DXA scan was a strong predictor of total body water and of extracellular water estimated from bioelectrical impedance analysis. The best model to predict intracellular water volumes included consideration of both lean tissue and fat mass (adjusted $R^2 = 0.58$), although the probability that fat mass contributed to the

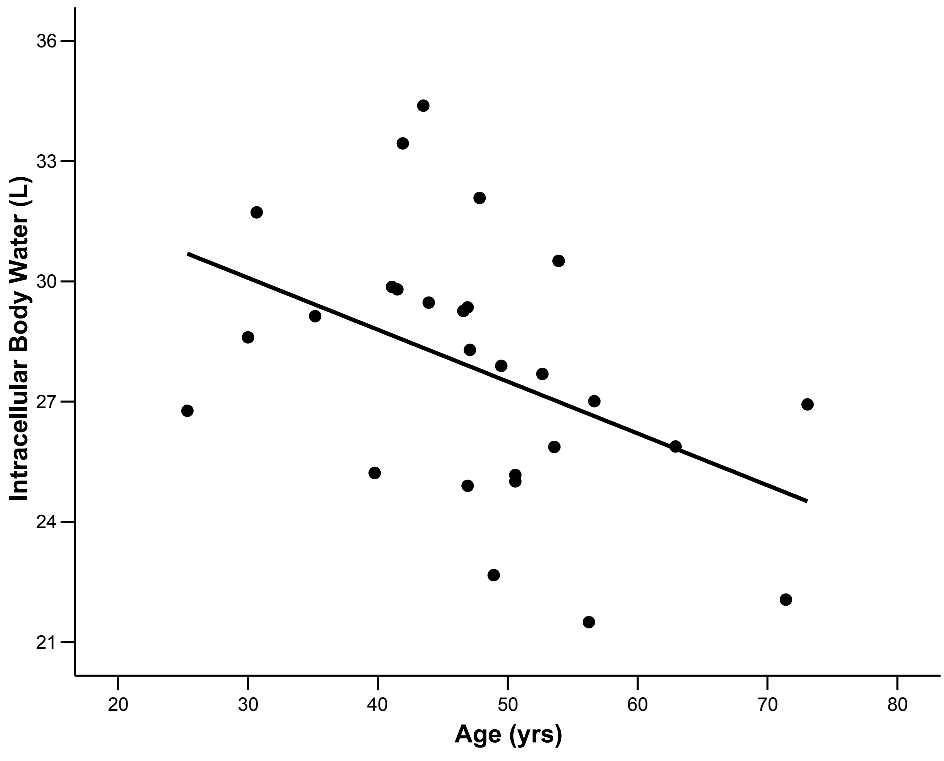

Figure 1. Intracellular water and age in male swimmers. The equation for the regression line is $y = 33.967 – 0.442x$. The regression coefficient, $r^2 = 0.20$ ($p = 0.02$).

Table 2. Bivariate correlation matrix among age and body composition variables.

	Age	TBW	ICW	ECW	LTM	BMC
TBW	-.25	1.0				
ICW	-.44*	.96**	1.0			
ECW	.14	.85**	.66**	1.0		
LTM	-.11	.88**	.74**	.93**	1.0	
BMC	-.08	.62**	.60**	.52**	.63**	1.0
FM	.04	.38*	.22	.56**	.57**	-.04

TBW = Total body water; ICW = Intracellular water; ECW = Extracellular water; LTM = Lean tissue mass; BMC = Bone mineral content; FM = Fat mass; Body water estimated from multi-frequency bioelectrical impedance analysis; Body lean, bone, and fat estimated from dual-energy X-ray absorptiometry.
* $p < 0.05$, ** $p < 0.01$

variance score only approached significance ($p = 0.06$). Lean mass appeared to have a greater impact on intracellular water than fat and their influences on hydration were in opposite directions.

DISCUSSION

The results of this investigation suggest that in adult male competitive swimmers change in body water fractions are the most obvious marker of growing older. With increasing age, the volume of ICW appears to decline and the ICW-to-TBW ratio becomes smaller. The amount of weekly swim training distance did not seem to be related to TBW or to the ICW and ECW fractions. Body water estimated in this study from multi-frequency bioelectrical impedance analysis appeared similar to reported values obtained using more direct methods such as isotope dilution (Battistini et al., 1994; Ellis, 2000; Pickering et al., 1997). In a recent review by Ellis (2000), average ICW volumes for men were reported to vary from 27.6 L in 20 to 29 year-olds to 19.9 L for those 70-79 years of age, ECW, from 17.8 L in 20 to 29 year-old subjects to 21.6 L in those 70 to 79 years of age, and TBW, from 45.4 L in 20-29 year-olds to 41.6 L in 70-79 year-old men. The average swimmer TBW and ICW volumes in the present study were lower than those noted in young elite and non-competitive male volleyball athletes (Battistini et al., 1994) (mean age 23.5 ± 5.7 years and 22.4 ± 4.8 years respectively), but volumes were higher than those reported about a group of elderly men with a mean age of 62 ± 2 years (Pickering et al., 1997).

No associations between swimming and body water components were observed in this group of male athletes. These findings were similar to those reported by Pickering et al. (1997) where they studied changes in body composition in older men as a result of participation in an exercise intervention program. After 16 weeks of training and four months of detraining, no change in TBW, ECW, or ICW were observed. Battistini and colleagues (1994) also examined the relationship of physical activity training with body water but did not use an intervention protocol. Instead, they studied differences in body composition between young elite and non-competitive athletes. This group of investigators observed that elite athletes had more TBW, ECW, and a greater ECW-to-TBW ratio than

Table 3. Backward method multiple-linear-regression analysis of the associations of body water with significant predictor variables in male swimmers (n = 27).

	β	SE	P	Adjusted R^2
[1]**Total body water (L)**				.77
DXA Lean mass (g)	.88	.00	.00	
[2]**Intracellular water (L)**				.58
DXA Lean mass (g)	.91	.00	.00	
DXA Fat mass (g)	-.30	.00	.06	
[3]**Extracellular water (L)**				.85
DXA Lean mass (g)	.93	.00	.00	

1. Total body water model: $F_{1, 26} = 85.7$, $p < 0.00$; Fat mass and bone mineral content were not significant predictors in this model.
2. Intracellular water model: $F_{2, 26} = 18.9$, $p < 0.00$; Bone mineral content was not a significant predictor in this model.
3. Extracellular water model: $F_{1, 26} = 150.6$, $p < 0.00$; Fat mass and bone mineral content were not significant predictors in this model.

their amateur counterparts. The inconsistency in findings between the two studies may be explained due to differences in study design, subject age, and type of physical activity training.

The observed associations between ICW and lean tissue and the suggested relationship with adipose mass imply that changes in these bodycomponents accompany aging. Amounts of lean soft tissue, bone, and fat assessed by DXA however, did not appear to be related to subject age. These inconsistencies in findings may be related to the fact that DXA assessment does not directly measure body water. As the DXA x-ray beam passes through the subject, the number and energy of the photons in the beam are reduced or attenuated. The amount of beam reduction is determined largely by tissue density and thickness and can be quantified. The denser the tissue, the more electrons it contains and the number of electrons in the tissue determines the agility of the tissue to absorb photons in the x-ray beam. Fat mass and lean soft tissue are estimated using assumed constant attenuations for pure fat and bone mineral-free lean tissue at two x-ray energy levels of 40 kV and 70 kV (Lohman and Chen, 2005). The ratio of attenuation at the lower energy relative to the higher energy for the low and high energy x-rays is a function of the proportion of fat and lean in each pixel. Unlike computed tomography and magnetic resonance imaging, DXA estimates a measure of fat rather than adipose tissue. Analysis by DXA does not have the capability to estimate the amount of water within the adipocyte or within the lean tissue. Fluctuations in intracellular water but not lean tissue or fat mass suggest that while their amounts and fractions per pixel may not change, the makeup of the tissue in which they are found may vary with age.

Approximately 73% of lean mass is composed of water although no individual organ or tissue has a water percentage equal to 0.73. This average value results from considering the amounts and hydration levels of the various tissues that make up the FFM. It includes low hydration components such as the skeleton and skin as well as high hydration components such as the skeletal muscle and visceral organs (Wang et al., 1999). Because DXA is not sensitive to levels of body water it may not be able to distinguish changes in type of lean tissue. The conflict between loss of intracellular water suggested from multi-frequency BIA and lack of change in lean tissue mass assessed by DXA may be partially explained by the fact that not all fat-free mass is equally hydrated (Wang et al., 1999) and the loss in intracellular water may reflect a greater proportional loss of well-hydrated skeletal muscle.

Lipid and water are thought to occupy approximately 90% of the adipose cell but a wide variation in the proportion of each has been reported (Martin et al., 1994). In a study of male cadavers, Martin and colleagues (1994) found an average water fraction within the adipocyte of approximately 25% but noted that water volumes varied widely and reflected, in an opposite direction, the amount of stored fat. They observed that with increasing total body fatness, adipose cell lipid fraction increased while the cell water fraction decreased. A possible explanation for the inconsistency in findings in this study may be due to the fact that DXA cannot determine the characteristics of the adipose cell surrounding the stored lipid. In addition, the observed trend toward increased lower abdominal thickness with increasing age ($p = 0.08$) (as measured by abdominal sagittal diameter) suggests that abdominal visceral fat stores may be increasing with age. The fatty acid composition of stored fat has been reported to be site-specific with higher amounts of saturated fat stored in abdominal areas as compared to gluteal regions (Hudgins and Hirsch, 1991). Perhaps aging is associated with a shift in the type and distribution of this body composition component.

Total body adiposity levels in this group of swimmers were comparable to reported values for men. The mean percent fat from the current study of 21.9 ± 6.6% was similar to that of 21.3 ± 8.6% reported by Clark and colleagues (1993) in a body composition study of 35 adult men. The average master swimmer percent fat was higher than that of 16.4 ± 4.4% reported from a group of master athletes who were primarily runners (Wiswell et al., 2001). In addition, when assessed using body mass index scores, members of this group of swimmer athletes were less likely to be overweight or obese as compared to the average U.S. male (Freid et al., 2003; National Center for Health Statistisc, 2004).

Regional adiposity measurements also suggested that these swimmers were leaner than the average American male. Mean waist circumference was smaller than the National average of 96.3 cm (National Center for Health Statistics, 2004). Subcutaneous fat deposits estimated from skinfold thickness were also smaller (Statistics, 2004). Mean skinfold values were less than the reported 19.0 mm for the subscapula, 22.5 mm for the suprailiac, and 13.4 for the triceps of the average American man. While the subscapula and triceps values were less than the national averages by 4.7 and 4.8 mm respectively, the suprailiac skinfold thickness, which is a measure of lower trunk adiposity, was 13.6 mm smaller. Previously reported data has shown that the sum of six skinfolds (three trunk + three extremites) and the sum of three trunk skinfolds increase in men as they age (Malina, 1996). In the current study which used the same skinfold sites, no relationships were observed between age and the sum of trunk, extremities, or total skinfolds. In these adult male athletes, age was associated with a trend toward greater thickness in the lower abdomen, but not with the amount of weekly swim training distance. A positive relationship between increased abdominal thickness and age was also noted in female masters swimmers (Tuuri et al., 2002).

The study is limited by its cross sectional design and the fact that all subjects were volunteers. This non-probability sampling method may have introduced bias. In addition, weekly swim distance was estimated from a self-reported swim log which depended upon the subject's cooperation and truthfulness. Estimation of swim distance was, however, assisted by the fact that pool lengths are standard distances of either 25 yards or 25 meters and swimming laps could be easily counted. Swimming intensity was not measured and dietary intake information was not collected. Although each swimmer swam at least 50% of his structured exercise time, subjects did report participating in other types of physical activity which may have influenced their body composition. In addition, using algorhythms to convert data obtained from a Hologic 4500 DXA to that of a Hologic 2000 DXA may have introduced error in the estimation of percent body fat, as well as lean, fat, and bone masses. Because this group of male swimmers was small, results should not be generalized to men participating in other sports or representing other age groups.

CONCLUSION

In this group of adult male competitive swimmers changes in body water and the relative proportion of ICW and ECW fractions appear to be important markers of aging. Intracellular water which is negatively associated with age was positively influenced by the amount of lean tissue mass. It may also have been negatively related to level of body fat. Despite observed fluctuations in intracellular water with aging, noted by multi-frequency BIA assessment, no changes in lean mass were reported from DXA measurement. Future research needs to examine the reasons for these inconsistent findings including the possibility that the composition and type of lean tissue and adipose mass may change as a result of aging.

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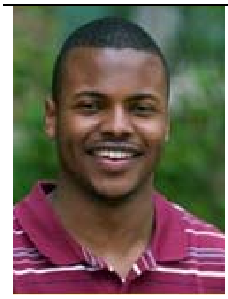

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KEY POINTS

In adult male masters swimmers:

- Subject age was negatively associated with the volume of intracellular water and with the intracellular-to-total body water ratio.
- There was a trend for age to be positively related to lower abdominal thickness.
- Weekly swim training distance was not associated with body water, lean tissue, fat mass or regional adiposity.
- Lean tissue mass appeared to be a strong positive predictor of total body water and the intra- and extracellular fractions.
- There was a trend for fat mass to be a negative predictor of intracellular water volume.

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