Journal of Athletic Training 2017;52(1):45–50
doi: 10.4085/1062-6050-51.12.26

www.natajournals.org

original research

Seasonal Effects on Body Composition, Muscle Characteristics, and Performance of Collegiate Swimmers and Divers

Erica J. Roelofs, MA; Abbie E. Smith-Ryan, PhD; Eric T. Trexler, MA; Katie R. Hirsch, MA

Applied Physiology Laboratory, Department of Exercise and Sport Science, University of North Carolina at Chapel Hill

Context: Previous researchers have indicated the importance of body composition and muscle quality in athletic performance. However, body composition and muscle-quality measures in swimmers and divers over a training season have yet to be evaluated.

Objective: To identify changes in body composition and muscle characteristics over a competitive season and identify relationships between these variables and performance in National Collegiate Athletic Association Division I swimmers and divers.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: A total of 17 collegiate swimmers and divers (age = 18.6 ± 0.7 years, height = 175.8 ± 4.0 cm, body mass = 69.7 ± 7.0 kg).

Main Outcome Measure(s): At preseason and postseason, body composition in each participant was assessed using dual-energy x-ray absorptiometry. Echo intensity and muscle cross-sectional area were determined from an ultrasound panoramic scan of the vastus lateralis muscle. Race times were obtained from the university athletic Web site.

Results: Lean mass ($P = .016$), arm lean mass ($P = .008$), and muscle cross-sectional area ($P = .03$) were higher at postseason, whereas body fat percentage ($P = .041$) and echo intensity ($P = .0007$) were lower at postseason. Performance improved from preseason to postseason in all event groups (sprinters, distance swimmers, and divers; $P < .05$).

Conclusions: Body composition and muscle characteristics improved through 1 training season, which may have implications for performance. Quantifying body composition and muscle characteristics may be beneficial for professionals who work with athletes in order to improve performance and prevent injury.

Key Words: ultrasound, echo intensity, dual-energy x-ray absorptiometry, athletes

Key Points

- Increasing muscle size and improving muscle quality may benefit swimming and diving performance.
- Identifying the optimal balance between lean mass and fat mass is likely to be important for maximal performance.
- Performance changes tend to follow changes in muscle mass, so tracking the latter during the season may be helpful.

In competitive athletics, quantifying body composition and muscle characteristics may be beneficial for athletes, as well as coaches, athletic trainers, and nutritionists who work closely with athletes. These measurements are important components for determining training modalities and volumes to achieve optimal performance, prevent injury, and provide rehabilitation postinjury. In swimmers, it is especially important to track lean mass (LM) and bone density due to the low-impact nature of the sport. However, despite the large number of competitive swimmers and divers, few investigators have examined the relationships among body composition, muscle characteristics, and performance. By measuring body composition and muscle characteristics, professionals working with swimming and diving athletes can determine appropriate dry-land, resistance-training exercises to improve athletes' performance.[1]

Enhanced athletic performance is often associated with decreased body fat.[2] Previous researchers[3] identified LM as a primary determinant in swim performance; however, other investigators[4] found swimmers' performance was unimpeded by a higher level of body fat, suggesting that it may be advantageous due to higher buoyancy. Yet excessive body fat may hinder performance by increasing drag force in the water.[5] The physiological demands of swimming are significantly different than those of diving, and thus, body composition may differ between these athletes. Additional research on the relationships between body composition and swimming and diving performance is needed to help determine optimal levels for maximizing performance, preventing injury, and ensuring overall health in competitive athletes.

Quantifying characteristics of muscle cross-sectional area (mCSA) and echo intensity (EI) by ultrasound, in combination with body-composition assessments, may also help professionals working with these athletes to determine appropriate training strategies. Muscle size, as measured by mCSA, has been correlated with muscle strength and

Table 1. Participants' Preseason Measurements Stratified by Sex, Mean ± SD

Sex	n	Age, y	Body Mass, kg	Height, cm	Fat, %
Males	8	18.6 ± 0.7	73.9 ± 4.3	178.1 ± 3.1	15.4 ± 2.5
Females	9	18.7 ± 0.7	65.3 ± 6.9[a]	173.8 ± 3.5[a]	23.1 ± 2.4[a]

[a] Different than males.

power[6] and with power output, leg strength, and swimming performance.[3] Echo intensity may indicate muscle quality through a grayscale analysis: brighter images reflect higher EI values, which represent more intramuscular fat and connective tissue within the muscle belly.[7,8] Increased intramuscular fat and connective tissue, as demonstrated in the elderly, may increase the risk of injury and decrease functionality.[6] Assessing mCSA and EI may facilitate training program design, decreasing the risk of injury while improving performance outcomes.[9]

To date, few authors have examined collegiate swimmers' and divers' body-composition changes over a competitive season. Tracking changes in muscle mass during a season may be helpful, as these changes are likely to follow performance changes. Therefore, the primary purpose of our study was to identify changes in body composition and muscle characteristics in National Collegiate Athletic Association (NCAA) Division I swimmers and divers over a competitive season. The secondary purpose was to identify relationships among changes in body composition, muscle characteristics, and performance over a competitive season stratified by event groups of sprinters, distance swimmers, and divers.

METHODS

Participants

A total of 17 Division I swimming and diving athletes (8 males, 9 females) participated in this study (age = 18.6 ± 0.7 years, height = 175.8 ± 4.0 cm, body mass = 69.7 ± 7.0 kg). A sample size of 17 participants using a repeated-measures factor for 3 groups with an effect size of 0.6 would result in power of 0.86. Calculations were performed using G*Power statistical software (version 3.1.9.1; Heinrich-Heine-Universität Düsseldorf, Germany). Descriptive statistics, stratified by sex, are presented in Table 1. Before testing, all participants signed an informed consent approved by the university's biomedical institutional review board, which approved all methods. Race times and diving scores for each athlete's primary individual event were obtained from the university athletic Web site. Preseason performance was recorded from the first meet in September, whereas postseason performance was recorded from the championship meet and NCAA championship meet in March.

Experimental Design

Each participant was tested in preseason (late August) and postseason (after the NCAA championships in March), with each session lasting 30 minutes. At preseason testing, all athletes had just completed summer off-season training. They reported to the laboratory after fasting for 2 hours and not exercising for at least 8 hours. Upon arrival, height was measured using a stadiometer (model PE-AIM-101; Perspective Enterprises, Portage, MI), body mass was measured using a digital scale (model 2101 KL; Health-o-meter, McCook, IL), and a questionnaire about general health history was completed to ensure compliance with the preassessment guidelines. Body composition was measured using whole-body dual-energy x-ray absorptiometry (DEXA; model Discovery W; Hologic, Inc, Bedford, MA, and software version 3.3; APEX Biologix, Salt Lake City, UT) to determine bone mineral content (BMC), bone mineral density (BMD), fat mass (FM), LM, segmental LM, and body fat percentage (%fat). Muscle cross-sectional area and EI were measured using ultrasound (model LOGIQ-E B-mode; GE Healthcare, Wauwatosa, WI) to obtain a panoramic scan of the vastus lateralis (VL).

Procedures

Dual-Energy X-Ray Absorptiometry. Each participant had a full-body DEXA scan performed by the same trained technician. Before testing, participants removed all metal, thick clothing, and heavy plastic to reduce interference with the scan. Age, height, body mass, sex, and ethnicity data were entered into the computer, and participants lay supine in the center of the scanning table. The BMC, BMD, FM, LM, leg LM, %fat, and trunk fat were determined. From the BMD, Z scores were calculated and recorded using the software. Previous DEXA test-retest reliability values in our laboratory were intraclass correlation coefficient (ICC) = 0.98 and standard error of measurement (SEM) = 0.85 for FM, ICC = 0.99 and SEM = 1.07 for LM, and ICC = 0.98 and SEM = 1.06 for %fat.

Ultrasound. The ultrasound settings (frequency = 26 Hz, gain = 68, depth = 4.5 cm) were kept consistent for each scan. Before the scan, the participant lay supine for 5 minutes. During the VL mCSA measurement, the right leg was extended and relaxed on the examination table with a foam pad strapped to the midpoint of the thigh to standardize measurements. The ultrasound probe (model 12L-RS; GE Healthcare) was held perpendicular to the tissue and swept across the skin from the lateral VL border to the medial fascial separation with equal pressure. The same technician performed all scans. The EI was determined from the panoramic scan by using grayscale imaging software (version 1.37; ImageJ, National Institutes of Health, Bethesda, MD) in the standard histogram function of pixels ranging from 0 to 255 (Figure). Before the EI measurement, the number of pixels within 1 cm was assessed to calibrate the image. To measure the EI, the technician traced the outline of the participant's VL along the fascial border to capture only the muscle as seen in the Figure. In our laboratory, muscle characteristics test-retest reliability values for EI were ICC = 0.74 and SEM = 4.58 arbitrary unit (au) and for mCSA were ICC = 0.87 and SEM = 2.12 cm^2.

Statistical Analysis

We used repeated-measures analyses of variance (ANOVAs) to identify changes in body composition (FM, LM, leg LM, %fat) and muscle characteristics (mCSA and EI) before and after the competitive season. Repeated-measures ANOVAs were also used to evaluate changes in body composition and muscle characteristics

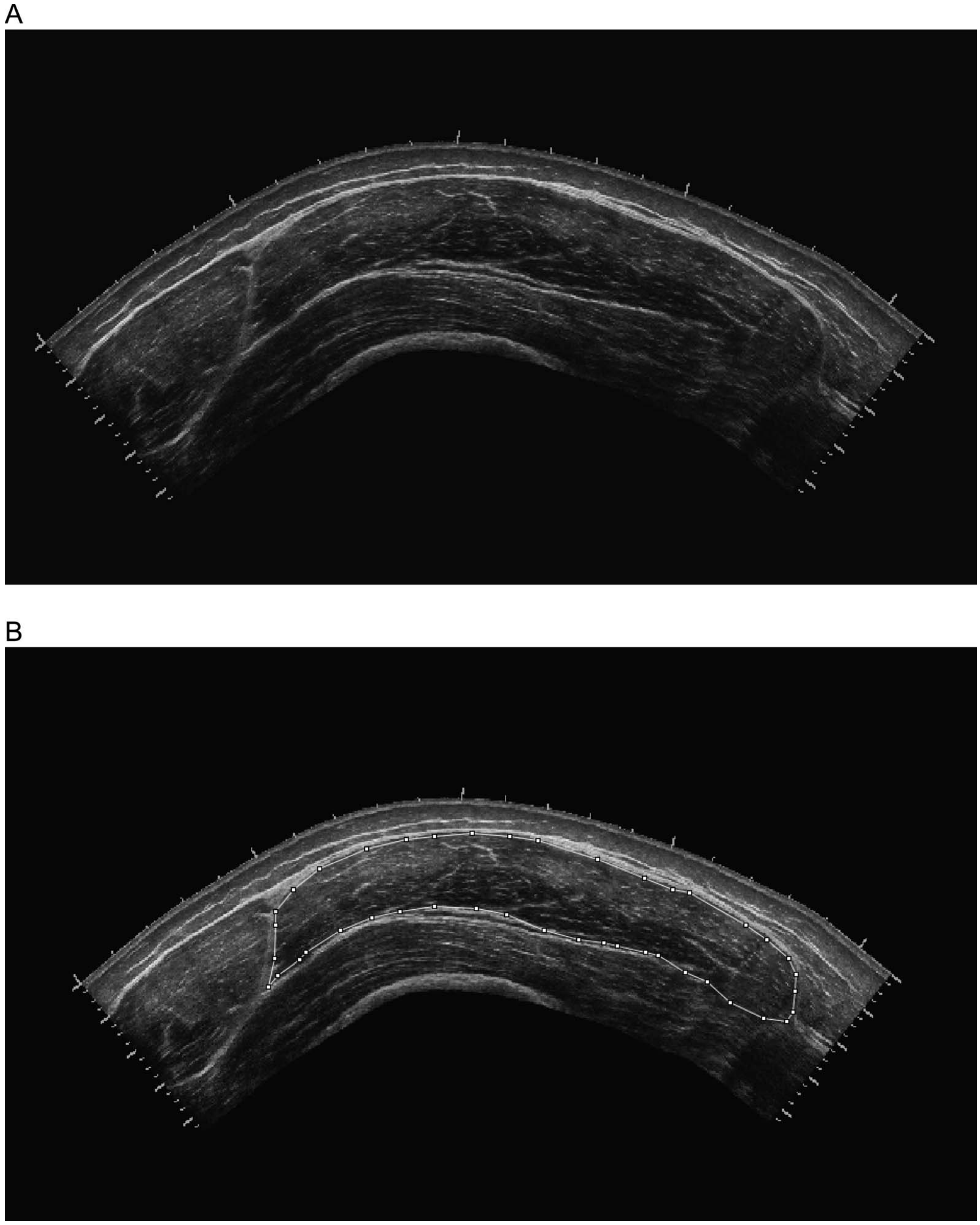

Figure. A, Panoramic ultrasonographic scan of the vastus lateralis. B, Analyzing a panoramic scan of the vastus lateralis with Image-J software (National Institutes of Health, Bethesda, MD) to determine muscle cross-sectional area and echo intensity.

when stratified by sex and event group. Pearson product moment correlations were calculated to determine relationships between changes in body composition, muscle characteristics, and performance. One-way ANOVAs were conducted to analyze the changes among event groups. All analyses were completed using SPSS (version 20; IBM Corp, Armonk, NY) with an α level of $P < .05$.

RESULTS

Body Composition

The LM ($\Delta = 1.04$ kg, 95% confidence interval [CI] = 0.3, 1.92 kg; $P = .016$) and arm LM ($\Delta = 0.29$ kg, 95% CI = 0.1, 0.48 kg; $P = .008$) were higher at postseason, whereas %fat was lower at postseason ($\Delta = -1.01$%, 95% CI = –1.9%, –0.12%; $P = .041$). Although not significant, FM ($\Delta = -0.61$ kg, 95% CI = –1.32, 0.08 kg; $P = .104$) and trunk FM ($\Delta = -0.2$ kg, 95% CI = –0.53, 0.12 kg; $P = .24$) decreased, whereas BMC ($\Delta = 0.026$ g·cm^{-1}, 95% CI = –0.005, 0.05 g·cm^{-1}; $P = .136$) and body mass ($\Delta = 0.82$ kg, 95% CI = –0.8, 1.17 kg; $P = .09$) increased at postseason. Leg LM did not differ from preseason to postseason ($\Delta = -0.01$ kg, 95% CI = –0.3, 0.28 kg; $P = .95$). When stratified by sex, LM ($\Delta = 1.4$ kg, 95% CI = 0.065, 2.74 kg; $P = .042$) and arm LM ($\Delta = 0.5$ kg, 95% CI = 0.27, 0.65 kg; $P = .001$) improved in females; %fat demonstrated no difference ($\Delta = -1.5$%, 95% CI = –0.22%, 3.17%; $P = .07$). In males, body composition did not change from preseason to postseason ($P > .05$). Average BMD Z scores were –0.12 ± 0.8 for females and –0.26 ± 1.3 for males.

Table 2. Athletes' Preseason and Postseason Measurements by Event Group, Mean ± SD

Measurement	Event Group					
	Sprinters (n = 11)		Distance Swimmers (n = 3)		Divers (n = 3)	
	Preseason	Postseason	Preseason	Postseason	Preseason	Postseason
Body mass, kg	69.1 ± 8.1	70.3 ± 8.4[a]	70.1 ± 3.05	68.8 ± 5.1	71.4 ± 7.1	72.7 ± 6.9[a]
LM, kg	52.0 ± 7.4	53.2 ± 7.1	53.9 ± 7.8	54.2 ± 7.0	55.8 ± 7.6	57.0 ± 8.4
Arm LM, kg	6.2 ± 1.4	6.6 ± 1.4[a]	6.9 ± 1.9	6.8 ± 1.4	7.1 ± 1.6	7.5 ± 1.6
Leg LM, kg	18.0 ± 2.4	18.1 ± 2.5	17.7 ± 3.0	17.6 ± 2.5	19.3 ± 1.0	19.2 ± 1.9
Fat mass, kg	13.6 ± 2.8	13.4 ± 2.5	12.9 ± 5.0	11.0 ± 2.3	12.5 ± 2.5	11.7 ± 3.5
Trunk fat mass, kg	5.3 ± 1.3	5.4 ± 1.1	5.1 ± 1.7	4.4 ± 0.5	4.9 ± 1.1	4.5 ± 1.0
Fat, %	20.2 ± 3.7	19.5 ± 3.1	18.9 ± 8.3	16.6 ± 4.9	17.5 ± 5.2	16.5 ± 5.9
Bone mineral content, g/cm	2.3 ± 0.3	2.4 ± 0.3	2.1 ± 0.2	2.1 ± 0.2	2.8 ± 0.3	2.8 ± 0.3
Muscle cross-sectional area, cm^2	23.8 ± 3.9	27.4 ± 3.1[a]	28.5 ± 9.6	30.4 ± 4.1	28.8 ± 6.3	27.2 ± 2.4
Echo intensity, au	74.9 ± 6.2	62.9 ± 4.8[a]	65.7 ± 5.4	62.5 ± 7.3	72.5 ± 7.5	60.8 ± 1.0

Abbreviations: au, arbitrary unit; LM, lean mass.

[a] Different from preseason measurement ($P < .05$).

In the sprinters event group, body mass ($\Delta = 1.2$ kg, 95% CI = 0.12, 2.4 kg; $P = .03$) and arm LM ($\Delta = 0.4$ kg, 95% CI = 0.15, 0.58 kg; $P = .004$) increased; body mass also increased in divers ($\Delta = 1.3$ kg, 95% CI = 0.75, 1.78 kg; $P = .009$). Distance athletes showed no changes from preseason to postseason for any variables. In every group, LM increased nonsignificantly, and FM, %fat, and trunk fat decreased from preseason to postseason (Table 2).

Muscle Characteristics

At postseason, mCSA was higher ($\Delta = 3.34$ cm^2, 95% CI = 0.4, 4.3 cm^2; $P = .031$) and EI was lower ($\Delta = -10.41$ au, 95% CI = –14.3, –6.55 au; $P = .0007$). When stratified by sex, mCSA ($\Delta = 4.6$ cm^2, 95% CI = 2.9, 6.5 cm^2; $P = .0003$) and EI ($\Delta = -15.8$ au, 95% CI = –11.28, –20.38 au; $P = .00004$) improved in females. Males displayed no significant changes; however, EI improved ($\Delta = -4.3$ au, 95% CI = –0.25, –8.85 au; $P = .06$).

In the sprinters at postseason, mCSA increased ($\Delta = 3.6$ cm^2, 95% CI = 1.32, 5.8 cm^2; $P = .005$) and EI decreased ($\Delta = -12.0$ au, 95% CI = –6.5, –17.48 au; $P = .001$). In the divers and distance swimmers, mCSA and EI did not differ from preseason to postseason (Table 2).

Body Composition, Muscle Characteristics, and Performance Relationships

In the sprinters event group, performance improved from preseason to postseason ($\Delta = -4.08$ seconds, 95% CI = –2.4, –5.7 seconds; $P = .0002$). Change in body mass was correlated with changes in LM ($R = 0.823$, $P = .002$) and arm LM ($R = 0.684$, $P = .02$). The change in LM across the season was negatively correlated with the change in %fat ($R = -0.705$, $P = .015$) and positively correlated with the changes in arm LM ($R = 0.727$, $P = .011$) and leg LM ($R = 0.723$, $P = .012$). In the distance swimmers, performance improved from preseason to postseason ($\Delta = -20.2$ seconds, 95% CI = –5.15, –35.3 seconds; $P = .029$). Improved performance was correlated with changes in BMC ($R = 1.0$, $P = .012$) and LM ($R = -1.00$, $P = .015$), such that greater changes in LM were correlated with greater improvements in performance. In the divers (n = 3), performance improved from preseason to postseason ($\Delta = 53.7$ points, 95% CI = 33.3, 74.1 points; $P = .008$). The relationships between the change in BMC and the change in arm LM ($R = 0.993$, $P = .077$) and between the change in FM and the change in body mass ($R = 0.996$, $P = .057$) were not significant. Performance did not correlate significantly with mCSA ($R = 0.995$, $P = .066$) or EI ($R = -0.996$, $P = .060$). Improvements in performance were different among all groups.

DISCUSSION

The body composition of athletes is an important determinant of health and performance.[10] Given the nonimpact nature of swimming, concerns have been raised about potential low BMD and long-term health implications such as osteoporosis.[11] Previous researchers reported that swimmers may exhibit lower BMC and higher %fat values than athletes in other sports[12] and similar BMC to the sedentary population.[13] Most collegiate swimming programs incorporate dry-land training to improve fitness and provide appropriate stimulus for bone and muscle development; to date, little information exists on the effects of a collegiate swimming season on body composition and BMC.

We demonstrated improvements in LM, arm LM, %fat, mCSA, and EI from preseason to postseason. When stratified by event, each group improved in performance, and the divers' performance was significantly related to LM. Females improved in LM, arm LM, and muscle size and quality across the season. Although the values were not significant, males increased LM and arm LM and decreased FM, %fat, and EI across the season. These changes in body composition and muscle characteristics were likely due to the dry-land training as well as to the swimming and diving training itself. Taken as a whole, our results support the importance of improving LM and muscle size and quality for enhancing athletic performance.

In a similar study examining body composition in female Division I collegiate swimmers, Carbuhn et al[13] also found that LM increased during the season. Pyne et al[14] noted decreases in body mass and skinfold thickness and an increase in LM from preseason to 2 weeks before the end of the season in male competitive swimmers. Although the findings were not significant in the current study, males increased in body mass ($\Delta = 0.9$ kg, $P = .15$), which appeared to be largely attributable to an increase in LM ($\Delta = 0.8$ kg, $P = .23$). Previous investigators[12,15] reported that swimmers tended to have higher %fat values than athletes in other sports. Conversely, LM, %fat, and FM in female swimmers were statistically similar to those values in female athletes participating in softball, basketball, volleyball, swimming, and track jumping and sprinting.[13] Although we did not compare our values against those in other sports, body composition values (LM = 47.6 kg, FM = 15.05 kg, %fat = 23.1) were similar to those reported by Carbuhn et al[13] for females (LM = 48.5 kg, FM = 15.4 kg, %fat = 22.5). Ferry et al[11] compared elite female soccer players with elite swimmers and observed that soccer players had more LM in the lower limbs but less LM in the upper limbs than swimmers.

Swimmers have also demonstrated lower BMC values when compared with athletes in other sports.[13] However, Avlonitou et al[16] reported BMD values (as measured by DEXA) of female and male competitive swimmers that were similar to those of age-matched controls. Our DEXA measures of BMD also indicated that both male and female swimmers were in the healthy range for total body BMD Z scores compared with age-matched controls (females = –0.12 ± 0.8, males = –0.26 ± 1.3). In a study[11] comparing elite swimmers with elite soccer players, the latter had higher BMC and BMD levels of the hip and lumbar regions and of the whole body. In a similar study,[17] male jumpers had higher BMC and BMD levels than male aquatic athletes and healthy controls, but the levels of the aquatic athletes and controls did not differ. This may demonstrate the need for high-impact exercise to increase or maintain bone density and health.

Muscle characteristics as measured by ultrasound may be valuable in determining physiological differences among muscle strengths and sizes.[18] Ultrasound is a valid and effective tool to determine muscle characteristics in athletes.[19] After 21 weeks of resistance training, competitive football players had a mean VL mCSA of 38.7 ± 6.6 cm^2,[20] female resistance-trained athletes had a mean mCSA of 31.5 ± 6.2 cm^2,[21] and previously untrained males had a mean mCSA of 30.5 ± 5.7 cm^2.[22] At the end of the season in our study, the mean mCSA for females was 25.9 ± 2.3 cm^2, and the mean mCSA for males was 30.1 ± 2.6 cm^2. A combined group of male and female cross-country runners[23] had a lower mean mCSA than combined male and female swimmers in the current study (27.9 ± 3.2 cm^2). Muscle size is correlated with muscle strength and power.[6,24] Smaller muscle size and higher EI have also been associated with more intramuscular fat and connective tissue.[8] In our study, mCSA, EI, and performance improved from preseason to postseason. Muscular strength and power are essential components for success in swimming[25]; thus, the improvements in muscle characteristics were likely favorable for changes in performance. However, it is important to note that muscle characteristics were measured only in the VL. In swimming, the upper body musculature greatly contributes to force production and enhanced performance, and therefore, measurements of upper body muscle characteristics would be beneficial in future research.

Body composition measures are highly correlated with athletic performance.[26,27] In male and female swimmers, LM was significantly correlated with 100-m front-crawl performance.[28] Lean mass is a significant predictor of propulsion force, accounting for 86% of improvements in swimming performance.[29] In the same study, %fat did not influence performance or propulsion force. Because body fat has a lower density than water, a higher %fat may be beneficial due to increased buoyancy in water.[5] However, when artificial fat pads were added to competitive swimmers to increase their %fat by 2%, performance times were significantly slower, indicating that the addition of subcutaneous fat may increase the drag coefficient.[5] In our study, %fat changes were not related to changes in performance times. Additionally, the improved performance of distance swimmers was significantly correlated with BMC and LM, such that those who had greater increases in LM improved their performance more. In divers, the relationship between changes in mCSA and EI and performance trended toward significance, suggesting increases in muscle size and quality may positively influence performance. However, these results should be considered with caution due to the small sample size of the diver group. In contrast, sprinters' changes in body composition did not correlate with changes in performance. Overall, the relationships in this study support the association of increased muscle mass and quality with improvements in performance, but future researchers should examine these changes among and implications for groups, especially due to the different demands on divers versus swimmers. Training physiology may also have influenced the varied responses in body composition. Specifically, due to the anaerobic nature of sprint and dive training throughout the season, a greater stimulus may be needed to elicit changes in muscle size and quality compared with their aerobically trained distance-swim competitors. Despite this, our results support the importance of maintaining LM throughout a swim season, which should be considered when establishing training cycles.

Despite the positive findings of this study, limitations do exist. Although the lower body musculature is important to swimming performance, the upper body musculature greatly contributes to swim performance, too. Therefore, measuring muscle characteristics in both the upper and lower body would have enhanced the strength of the study. The differences among event groups are likely due to the small sample sizes in each. In the distance and diving groups, correlation coefficients must be interpreted cautiously, as the size of each sample (n = 3) may have increased the likelihood of a spurious finding. Nonetheless, the relationships observed may warrant additional research in larger samples. Additionally, performance was not measured in a controlled laboratory condition but was instead obtained from competitive meets during the collegiate season. Furthermore, some athletes competed in more than 1 event during a meet, potentially influencing performance in their primary event. Tapering toward the end of the season and wearing swimming gear to reduce hydrodynamic drag can also influence performance results from preseason to postseason. However, using performance measures from competitions may be valuable due to the real-life setting. The group differences in performance relationships could perhaps be due to the different physiological demands of the event groups of sprinters, distance swimmers, and divers.

Increasing muscle size and quality may help to improve swimming and diving performance. Incorporating dry-land, resistance-training exercises that directly target muscle mass during the season and off-season may be advantageous to achieve an optimal balance between LM and FM that is appropriate for competitive swimming. Tracking changes in muscle mass during a season may be beneficial, as these changes are likely to follow performance changes. Larger cohort evaluations, with observation of off-season training, would provide further evidence to characterize swimmers and performance.

ACKNOWLEDGMENTS

Our project was supported by the National Center for Advancing Translational Sciences, National Institutes of Health, through grant 1KL2TR001109. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

REFERENCES

1. Girold S, Maurin D, Dugue B, Chatard JC, Millet G. Effect of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. *J Strength Cond Res*. 2007;21(2):599–605.
2. Siders WA, Lukaski HC, Bolonchuk WW. Relationships among swimming performance, body composition and somatotype in competitive collegiate swimmers. *J Sports Med Phys Fitness*. 1993; 33(2):166–171.
3. Mameletzi D, Siatras T, Tsalis G, Kellis S. The relationship between lean body mass and isokinetic peak torque of knee extensors and flexors in young male and female swimmers. *Isokinet Exerc Sci*. 2003;11(3):159–163.
4. Stager JM, Becker TJ, Cordain L. Relationship of body composition to swimming performance in female swimmers. *J Swim Res*. 1984; 1(1):21–26.
5. Lowensteyn I, Signorile JF, Giltz K. The effect of varying body composition on swimming performance. *J Strength Cond Res*. 1994; 8(3):149–154.
6. Cadore EL, Izquierdo M, Conceição M, et al. Echo intensity is associated with skeletal muscle power and cardiovascular performance in elderly men. *Exp Gerontol*. 2012;47(6):473–478.
7. Fukumoto Y, Ikezoe T, Yamada Y, et al. Skeletal muscle quality assessed from echo intensity is associated with muscle strength of middle-aged and elderly persons. *Eur J Appl Physiol*. 2012;112(4): 1519–1525.
8. Pillen S, Tak RO, Zwarts MJ, et al. Skeletal muscle ultrasound: correlation between fibrous tissue and echo intensity. *Ultrasound Med Biol*. 2009;35(3):443–446.
9. Wanivenhaus F, Fox AJ, Chaudhury S, Rodeo SA. Epidemiology of injuries and prevention strategies in competitive swimmers. *Sport Health*. 2012;4(3):246–251.
10. Malina RM, Geithner CA. Body composition of young athletes. *Am J Lifestyle Med*. 2011;5(3):262–278.
11. Ferry B, Duclos M, Burt L, et al. Bone geometry and strength adaptations to physical constraints inherent in different sports: comparison between elite female soccer players and swimmers. *J Bone Miner Metab*. 2011;29(3):342–351.
12. Fleck SJ. Body composition of elite American athletes. *Am J Sports Med*. 1983;11(6):398–403.
13. Carbuhn AF, Fernandez TE, Bragg AF, Green JS, Crouse SF. Sport and training influence bone and body composition in women collegiate athletes. *J Strength Cond Res*. 2010;24(7):1710–1717.
14. Pyne DB, Anderson ME, Hopkins WG. Monitoring changes in lean mass of elite male and female swimmers. *Int J Sports Physiol Perform*. 2006;1(1):14–26.
15. Siders WA, Bolonchuk WW, Lukaski HC. Effects of participation in a collegiate sport season on body composition. *J Sports Med Phys Fitness*. 1991;31(4):571–576.
16. Avlonitou E, Georgiou E, Doukas G, Louizi A. Estimation of body composition in competitive swimmers by means of three different techniques. *Int J Sports Med*. 1997;18(5):363–368.
17. Taaffe DR, Suominen H, Ollikainen S, Cheng S. Calcaneal bone mineral and ultrasound attenuation in male athletes exposed to weight-bearing and nonweight-bearing activity: a cross-sectional report. *J Sports Med Phys Fitness*. 2001;41(2):243–249.
18. Melvin MN, Smith-Ryan AE, Wingfield HL, Fultz SN, Roelofs EJ. Evaluation of muscle quality reliability and racial differences in body composition of overweight individuals. *Ultrasound Med Biol*. 2014; 40(9):1973–1979.
19. McCreesh K, Egan S. Ultrasound measurement of the size of the anterior tibial muscle group: the effect of exercise and leg dominance. *Sports Med Arthrosc Rehabil Ther Technol*. 2011;3:18.
20. Melvin MN, Smith-Ryan AE, Wingfield HL, Ryan ED, Trexler ET, Roelofs EJ. Muscle characteristics and body composition of NCAA Division I football players. *J Strength Cond Res*. 2014;28(12):3320–3329.
21. Sipila S, Suominen H. Quantitative ultrasonography of muscle: detection of adaptations to training in elderly women. *Arch Phys Med Rehabil*. 1996;77(11):1173–1178.
22. Ahtiainen JP, Hoffren M, Hulmi JJ, et al. Panoramic ultrasonography is a valid method to measure changes in skeletal muscle cross-sectional area. *Eur J Appl Physiol*. 2010;108(2):273–279.
23. Roelofs EJ, Smith-Ryan AE, Melvin MN, Wingfield HL, Trexler ET, Walker N. Muscle size, quality, and body composition: characteristics of Division I cross-country runners. *J Strength Cond Res*. 2015; 29(2):290–296.
24. Arts IM, Pillen S, Schelhaas HJ, Overeem S, Zwarts MJ. Normal values for quantitative muscle ultrasonography in adults. *Muscle Nerve*. 2010;41(1):32–41.
25. Sharp RL, Troup JP, Costill DL. Relationship between power and sprint freestyle swimming. *Med Sci Sports Exerc*. 1982;14(1):53–56.
26. Potteiger JA, Smith DL, Maier ML, Foster TS. Relationship between body composition, leg strength, anaerobic power, and on-ice skating performance in Division I men's hockey athletes. *J Strength Cond Res*. 2010;24(7):1755–1762.
27. Silvestre R, West C, Maresh CM, Kraemer WJ. Body composition and physical performance in men's soccer: a study of a National Collegiate Athletic Association Division I team. *J Strength Cond Res*. 2006;20(1):177–183.
28. Helmuth HS. Anthropometric survey of young swimmers. *Anthropol Anz*. 1980;38(1):17–34.
29. Cochrane KC, Housh TJ, Smith CM, et al. Relative contributions of strength, anthropometric, and body composition characteristics to estimated propulsive force in young male swimmers. *J Strength Cond Res*. 2015;29(6):1473–1479.

Address correspondence to Abbie E. Smith-Ryan, PhD, Applied Physiology Laboratory, Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, 312 Woollen, CB #8700, Chapel Hill, NC 27599. Address e-mail to abbsmith@email.unc.edu.