Body Composition of NCAA Division I Collegiate Female Rowing Athletes

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ABSTRACT

BACKGROUND: With the rapid growth of NCAA female collegiate rowing, it is important to better understand the effects of training within this population. The primary objective was to explore body composition in female NCAA Division I collegiate rowers compared to matched controls. In a subset of rowers, we examined the effect of boat category and oar placement on body composition. Understanding body composition changes will better inform sport personnel regarding performance, and injury prevention/rehabilitation; especially given the asymmetrical motion of sweep rowing.

METHODS: A retrospective analysis was done on 91 female collegiate rowers, and 173 female age matched controls from the University of Texas at Austin. Dual X-ray absorptiometry (DXA) was used to measure total and regional body composition, and visceral adipose tissue (VAT). At the time of scanning, demographic information was collected; additionally, boat race category, and boat side information was collected for rowing participants. Two sample t-testing was used to analyze differences between rowing athletes and controls. One-way repeated measures analyses of variance (ANOVA), using pairwise post hoc testing with Bonferroni adjustments for multiple comparisons, was used to analyze differences across Fall, Winter, and Spring seasons. Univariate ANOVAs used to analyze differences between boat race categories. Paired t-testing used to analyze differences between oar side and non-oar side of the body.

RESULTS: Rowing athletes were shown to have significantly greater height and total body weight compared to controls (*p*<0.001, both). In addition, rowers had significantly greater lean mass (LM) (*p*<0.001), fat mass (FM) (*p*=0.037), bone mineral content (BMC) (*p*<0.001), and bone mineral density (BMD) (*p*<0.001). Controls presented significantly greater total body fat percentage ($p<0.001$), and VAT ($p=0.002$). Seasonal changes in rowing athletes demonstrated significantly greater total LM ($p=0.044$) and regional arm LM ($p<0.001$) in the Spring season compared to the Fall season. No significant differences were found between the four boat race categories for both total and regional body composition. In addition, no significant differences in total or regional body composition were found between the oar side and non-oar side of rowing athletes. **CONCLUSION**: We observed differences in body composition between rowers and age-matched controls. There were changes in body composition over the competitive season with an increase in lean mass during the competitive Spring Season. Body composition in rowers was unaffected by boat race category or between body sides. This information will help rowing personnel better understand sport-specific body composition of female collegiate rowers for training, injury, and performance.

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LIST OF ABBREVIATIONS

1V4: First Varsity Four

1V8: First Varsity Eight

2V8: Second Varsity Eight

BF%: Body Fat Percentage

BMC: Bone Mineral Content

BMD: Bone Mineral Density

DXA: Dual Energy X-Ray Absorptiometry

FFM: Fat Free Mass

FM: Fat Mass

LM: Lean Mass

NCAA: National Collegiate Athletic Association

NS: Non-Scoring

VAT: Visceral Adipose Tissue

CHAPTER 1: INTRODUCTION

Understanding and quantifying body composition provides better understanding of sport, especially as it relates to training and performance (Roelofs et al., 2020). Benefits of body composition measurements and analysis for nutritionists, coaches, and trainers, includes bettering the prevention of injuries, rehabilitation, and fueling for the sport. Previous research has shown the quantification of body composition is linked to injury, training efficacy, and performance (Fields et al., 2018). This research is aimed at National Collegiate Athletic Association (NCAA) Division I female rowing athletes.

A National Collegiate Athletic Association (NCAA) Division I female rowing season begins in the Fall and concludes in the Spring. Championship racing occurs at the end of the Spring season (e.g., Conference Championships, NCAA National Championships), and is determined by three boat race categories (NCAA, 2021). The highest scoring is the First Varsity Eight (1V8) boat race category, which is made of up of a team’s fastest combination of eight rowing athletes. The next highest scoring boat race is the Second Varsity Eight (2V8), which is made up of the next fastest combination of eight athletes. The final, and lowest, scoring boat race is the First Varsity Four (1V4), which consists of the next fastest combination of four athletes (NCAA, 2021).

All racing at this level of rowing only involves sweep style rowing. Sweep rowing consists of one oar per person that extends to one side of the boat in multi-athlete boats. It becomes a partially asymmetrical movement including the upper limbs, lower limbs, and trunk area (Maestu et al., 2005). If the oar extends to the left, the athlete is classified as a starboard side rower; if the oar extends to the right, they are classified as a port side rower. This asymmetry leads to differing joint angles, force production, and muscle activation between sides of an athlete's body (An et al., 2015; Buckeridge et al., 2012; Readi et al., 2015; So et al., 2007). In addition, it is possible that the asymmetry of the rowing movement will lead to asymmetric muscle development of the athlete. These apparent asymmetries present risks of injury, particularly when considering the repetitive nature of the sport (Arumugam et al., 2020).

Rowing racing and training involve the continued repetition of a complex whole-body movement considered a stroke cycle. The goal of rowing is to propel a boat through water as fast as possible, requiring both strength and endurance (Akça, 2014; Battista et al., 2007; Bourdin et al., 2004; Ingham et al., 2002; Kendall et al., 2011; Maestu et al., 2005; Riechman et al., 2001; Smith & Hopkins, 2012). During a standard 2000-meter race, rowers will complete approximately two-hundred and twenty stroke cycles. Power is produced throughout the whole body during the working phase of the stroke cycle. Whole body power is produced, although approximately 46% comes from the legs, 32% from the trunk, and 22% from the arms (Penichet-Tomas et al., 2021). Research has shown a link between power production and lean mass, which highlights the interest and importance of understanding body composition in this population (Akça, 2014; Battista et al., 2007; Jones & Thomas, 2011).

The primary purpose of this research is to analyze body composition measures of NCAA Division I collegiate female rowing athletes compared to matched controls. Following an understanding of how rowers differ from a control population, the purpose is to then examine how the body composition of NCAA Division I female collegiate rowing athletes differ based on rowing specific variables. The first of these is to examine how measures of body composition change across a single season. Additionally, this study sought to examine how body composition measures differ based on championship boat race category, and between oar side and non-oar side.

The following chapters of this thesis include a literature review, explanation of methodology, summary of results, as well as a discussion and conclusion: Chapter two of this thesis will summarize the current literature related to the sport of rowing, Division I collegiate female rowing, and body composition of collegiate female rowers. This chapter will also discuss and describe body composition methods and techniques. The relationship between specific aspects of the sport of rowing and body composition will also be explored.

Chapter three includes specific details on the methods of the study, including information relating to the study's population(s), procedures, body composition measures, and statistical analysis.

Chapter four summarizes the results of the study. Specifically addressing the results of each of the specific aim. Summarizing the comparison of body composition variables between the rowing population and control population. Associations of body composition variables and rowing specific variables including – season, specific boat race category, and body side distinction.

Chapter five is a discussion of the study results and corresponding hypotheses. The findings are discussed and presented with regard to the previously published research related to these topics.

Chapter six provides a conclusion to each of the research questions. In addition, this chapter provides implications of the findings, as well as strengths, limitations, and future research directions.

Research Questions and Hypotheses

Research Question:

How does the body composition of NCAA Division I collegiate female rowers compare to an age, sex, and BMI matched control group? Also, does body composition of NCAA Division I collegiate female rowers differ between season, boat ranking, and oar versus non-oar side distinction? This study seeks to answer the question of whether body composition of NCAA Division I female rowers differ compared to a matched control group. It will also look to answer if body composition of NCAA Division I collegiate female rowers differ between season, boat ranking, and oar side.

Specific Aim 1: Compare body composition of female rowers to age and BMI matched female controls.

Hypothesis: Rowers will show greater lean mass (LM) and bone mineral density (BMD). Controls will show higher fat mass (FM), body fat percentage (BF%), and visceral adipose tissue (VAT) levels.

Specific Aim 2: Compare body composition of rowers between the three (3) distinct seasons (Fall, Winter, Sprint) within a concurrent whole season.

Hypothesis: We will observe significant changes in body composition from Fall season to Spring season. Specifically, significant decrease in FM, significant increase in LM, and nonsignificant changes in VAT and BMD.

Specific Aim 3: Compare body composition of rowers within the three scoring boats (1V8, 2V8, 1V4) and those in non-scoring boats (NS).

Hypothesis: We will overserve greater regional and total-body LM in 1V8/2V8/1V4 compared to NS. Greater total body and regional FM levels in the NS boats compared to 1V8/2V8/1V4.

Specific Aim 4: Compare body composition of rowers by side-of-boat during Championship Season (oar side versus non-oar side).

Hypothesis: No significant differences in total body composition between oar side and non-oar side. Differences in regional LM will be observed between sides. Different regional bone mineral content (BMC) and BMD levels between sides

CHAPTER 2: LITERAURE REVIEW

Rowing as a Sport

Boat Structure and Racing:

The sport of rowing includes as many as 22 different boat and race categories – differing by sex, coxswain inclusion, weight class, boat size and rowing style (Smith & Hopkins, 2012). Two of the major distinctions in the sport are boat size(s) and rowing style(s). Boat size refers to the number of rowers in the boat; women's collegiate competition is limited to boat classes made up of four or eight rowers plus coxswain. Rowing style refers to the two distinct stroke types, sculling and sweep style used in women's collegiate competition. Sculling consists of two oars per rower, while sweep rowing consists of one oar per rower (Strahan et al., 2011). Each style of rowing consists of similar central phases (i.e., the catch, finish, drive and recovery) (Baudouin, 2002; Bourdin et al., 2004; Jürimäe et al., 2010; Readi et al., 2015; Smith & Hopkins, 2012; Strahan et al., 2011). However, there are significant biomechanical differences between the two styles.

Sides of a rowing boat are referred to using traditional nautical terms – starboard, oar extends to the rowers left, and port, oar extends to the rowers right. The nature of sweep rowing means that one rower will have an oar that extends to either the Port or Starboard side of the boat, classifying them as either a Port rower or Starboard rower. While rowing, all rowers face the same direction. However, depending on which direction their oar extends, there are differences in body mechanics while exerting force on the oar to move the boat. Sweep rowing involves asymmetrical movement in the upper limbs, lower limbs, and trunk area (Readi et al., 2015). Research by Strahan et al. (2011)

examined the differences in spinopelvic kinematics between sweep and sculling by using ergometers specific to each style of rowing. They reported that sweep rowing showed greater lateral bend and a greater magnitude of axial rotation at the catch position of the stroke, compared to the sculling style of rowing (Strahan et al., 2011).

A singular rowing season traditionally follows an academic year; the beginning of the season starts at the beginning of a new academic year. Specific start dates are University dependent but are generally between mid-August and mid-September. Fall season marks the beginning of a new training cycle, and championship racing occurs in the Spring. During the Fall months (September - November), races are longer, with 5 kilometers (km) as the most common distance. During the Winter season (December - February) racing is uncommon. This is when most coaches switch to off-season training hours, to stay compliant with NCAA scheduling rules (2020-2021 Division I Manual, NCAA). Spring season (March - May) is the time when traditional rowing racing occurs. Traditional racing is 2000 meters (m) in distance and times are event and course specific, generally ranging from 5.5-8 minutes.

Using the NCAA Championships as the model for competition framework, we can understand female collegiate racing structure. During championship racing there are three-point scoring event classes, these three races are used to determine final team standings. The three event classes are the 1V8, 2V8, and 1V4, in order of maximum earnable points. Traditionally a program's fastest combination of eight athletes will race in the 1V8 as this race is worth the greatest number of points. The second fastest combination of a different eight athletes race in the 2V8, worth the second most points. Worth the third most (least overall) number of points, the 1V4 is the final combination of four athletes. The points earned from these three races determine whole team placement. Typically, teams have more athletes than those who compete in these three event classes. These athletes' row in competitions but are classified as the non-scoring (NS) event class.

Rowing Performance Measures and Physiology

Several variables including aerobic and anaerobic power, physical (peak) power, and technique contribute to optimal rowing performance (Maestu et al., 2005). There is a heavier reliance on aerobic metabolism, accounting for 70% of energy production; compared to anaerobic metabolism, contributing ~30% (Droghetti et al., 1991). However, both contribute to and are important performance determinants (Roth et al., 1993; Akça, 2014). Rowing performance is traditionally measured through a 2000m time trial. Individual performance can be measured by either using single person boats or a rowing ergometer. The rowing ergometer offers more controlled conditions and may be more appropriate for athletes who predominately row sweep style, as a single person boat can only be rowed using the sculling style.

Research done by Ingham et al. (2002), sought to analyze determinants of 2000m rowing performance in male and female elite rowers. Testing was done under controlled conditions on a rowing ergometer, and they reported that power at maximal aerobic capacity (VO_2max), power at blood lactate accumulation (4mmol/L), max power, and VO_2 at the blood lactate threshold were of the most important predictors of rowing performance. Power at VO_2max, max power, and max force were shown to be the most correlated to 2000m ergometer performance ($r=0.95$; $P<0.001$). (Ingham et al., 2002). A study by Riechman et al. (2001) looked at 12 female international rowers. They observed that 30 second all-out power, fatigue index via a 30 second Wingate test, alongside VO_2max was predictive of rowing performance (Riechman et al., 2001).

The 2000m ergometer time trial is taken into consideration when selecting athletes for boat classes, but coaches also consider performance on the water (Akça, 2014; Smith & Hopkins, 2012). Athlete selection can be based on many factors including physicality, explosive strength, coordination, speed, muscular endurance, professional abilities relating to rowing technique, and mental qualities (Liu et al., 2020). Since physicality may serve as a factor in athlete selection, body composition could play an important role in understanding rowing performance. Body composition is also linked to several other factors that influence athlete selection, such as explosive strength. There are limited studies looking at the body composition based on athlete selection. This research would be one of the first to look at body composition differences between female collegiate athletes selected for different boat classes.

Rowing Motion and Mechanics

In the traditional 2000m race, rowers may take as many as 230 strokes (Pollock et al., 2008). During a single training bout, athletes may row 20km, translating to over 2,000 strokes. This results in over 2,000 cycles of the same repeated movement, and each of these repetitions are under load. This becomes an important factor to consider when thinking about the asymmetries of the stroke cycle and the potential injury risk associated with repeat repetitions.

The rowing stroke cycle is split into two phases: the drive phase and recovery phase. The drive phase is when the oar is in the water and the recovery phase occurs when the oar is out of the water. Since the drive phase is when work is being done and the rower is under load, it is of particular interest in understanding the mechanics of the rowing motion. This phase begins at the catch position. At the catch, the blade of the oar is placed in the water, the hips and knees are fully flexed, and the arms are fully extended to the front (Arumugam et al., 2020).

Rowing is a total body movement involving muscle of the lower body, upper body, and trunk. The rowing motion generally follows a sequential pattern through the working (drive) phase of the stroke. The drive phase begins with the extension of the knees followed by trunk extension (Nelson & Widule, 1983). So and colleagues discuss the initial movement of the drive being a slight extension of the back while allowing for the legs to extend (So., 2007). A major role of the trunk is to serve as a means to transmit the power generated from the legs and hips to the arms and into the oar which serves to propel the boat (Pollock et al., 2008). The final motion of the drive phase is to pull the hands into the body, putting the athlete at the finish position.

Understanding the sequence of the drive phase highlights the importance of examining both total, and regional body composition. Because the total body is involved, with regions playing more specific roles looking at total and regional with help to better understand how rowing related variables affect composition at these different levels.

Rowing Sides and Asymmetry

Understanding asymmetries may aid in injury prevention strategies or in ways to reduce the risk that comes with the loaded rotation during the drive phase of the stroke cycle. A small body of research has explored difference types of asymmetries in the lower and upper limbs of rowers. This research has predominately analyzed male rowers, so, there is little research exploring the asymmetry in the collegiate female population. However, the research that has been done shows differences between lower limbs as well as upper limbs. Limbs are expressed as either the oar side or non-oar side.

For a Port side rower, their right arm and leg would be oar side, as the oar extends towards their right; their left arm and leg would be non-oar side limbs. For Starboard rowers this would be switched, such that the left arm and leg would be oar side and the right arm and leg would be non-oar side. Research done by Mattes and Wolff (2019), found that initially, as the drive is initiated, the non-oar side produced more leg stretcher force. A steeper force increase was also shown in the oar side leg at the beginning of the drive phase (Mattes & Wolff, 2019). Transmitting this force to the oar is done via the trunk and arms. This has shown to be associated with unequal loading of the lumbar spine and pelvis (Mattes & Wolff, 2019). It could be hypothesized that different loading may induce different muscle mass development.

An analysis of the erector spinae muscles shows inherent asymmetries in muscle activation within the sweep style of rowing (Mattes & Wolff, 2019). Following the rotational movement of the oar, the trunk rotates towards the oar as the rower sets up the catch position to achieve the optimal oar angle. During the drive, while under load, the trunk and shoulders again rotates with the circular path of the oar (An et al., 2015; Buckeridge et al., 2012; Readi et al., 2015). This type of asymmetry alongside the number of stroke cycle repetitions completed during a given training bout may lead to asymmetrical tissue development over time.

There is limited research into understanding body composition changes that may arise from asymmetrical sweep rowing. Understanding differences in body composition between left and right sides of the body due to sweep rowing may be informative to injury risk.

Importance of Body Composition: Performance, and Injury Monitoring

Body composition assessments are beneficial for athletes, coaches, and other athletic personnel (Hart et al., 2015). Measures of body composition commonly include LM, FM, BMC BMD, and in some cases body water. Body composition measures are factors that are also commonly associated with performance and certain performance measures (Lukaski, 2017). This is especially true for several body composition measures such as LM, FM, and BMD. Understanding that body composition can be indicative of performance and the continuous modification of body composition during training, we begin to see the benefit of measuring body composition within a sport population.

Dual X-Ray Absorptiometry Body Composition: The Gold Standard

Dual X-ray absorptiometry (DXA) has grown to become what some consider to be the “gold standard” for body composition methods (Schubert et al., 2019). DXA is used to measure body composition within many populations including the athletic populations (Buehring et al., 2014). DXA scanners using a fan beam collimator are the more recent DXA scanner technology and more commonly used. This type creates a beam of x-rays with two different frequencies (high and low) (Blake & Fogelman, 1997).

These two frequencies are absorbed differently by tissue allowing it to differentiate BMC, FM, and LM (Bilsborough et al., 2014; Hart et al., 2015; Santos et al., 2010).

Due to its use of x-rays (versus gamma rays) it only produces a low dose of ionizing radiation (Bilsborough et al., 2014). Compared to CT scanning a DXA is a much safer option due to the level of ionizing radiation. In addition, compared to both CT and MRI imaging, DXA is a less expensive option (Hart et al., 2015). DXA has continually been shown to be reliable and validated for both total body and segmental body composition (Bilsborough et al., 2014; Burkhart et al., 2009; Hind et al., 2011; Santos et al., 2010; Svendsen et al., 1993; Toombs et al., 2012).

Body Composition and Rowing

The literature has shown that height and stature is important, as it allows for more mechanical force and creating more leverage (Adhikari & McNeely, 2015). It has also been shown that LM is correlated to rowing performance, as LM is linked to muscle strength and range of motion (Adhikari, 2015; Jürimäe et al., 2010).

Research was done by Mikulić (2008), examining anthropometric profiles of different levels of rowers. A sample of 53 rowers were split into three categories based on their age and international competitive achievements – elite junior, sub-elite, and elite. The difference between sub-elite and elite was the level of international competition achieved, as elite rowers had competed at either the Olympics or world championships. Anthropometric measures included height, weight, limb length, and body fat percentage using skin fold calipers and the Durnin and Womersley technique (Mikulić, 2008). The ratio of FM/fat-free mass (FFM) was calculated via skin fold caliper outcomes (FFM calculated by subtracting estimated body fat from total body mass). Participants also completed an incremental maximal test on the rowing ergometer.

The results show that elite rowers were significantly taller and heavier than the sub-elite rowers (Mikulić, 2008). This research demonstrates that body size plays a role in rowing performance, but specific tissue composition may not be the differentiating factor between sub-elite and elite caliber rowers. However, their participants included only male rowers at the senior (National team) level.

Previous research examining rowers, including with female collegiate rowers, focused on how body composition was related to 2000m ergometer performance (Esco et al., 2021; Battista et al., 2007; Majumdar et al., 2017). Previous researchers have examined how DXA derived body composition changed in collegiate rowers across a concurrent season (Young et al., 2013). However, this research only examined 5 female rowers, they did not VAT measures, nor did they analyze composition based on side of boat. Due to the small sample size, it is important to further analysis changes across a concurrent season using a larger sample size. Similarly, Morris and Payne (1996) examined seasonal variations in DXA derived body composition of lightweight rowers. Again, this research only examined 6 female rowers, and all were lightweight competitors (Morris & Payne, 1996). Because lightweight rowing requires rowers to be at a specific weight, the findings from this research are limited to lightweight rowers. It is important to examine changes across a concurrent season in non-weight restricted rowers.

Research is lacking exploring body composition of different levels of female rowers. Similarly, investigating how the body composition of female rowers differ from a like-age and sex matched controls will allow for an initial understanding of the overall body composition characteristics of collegiate female rowers. Fields and colleagues (2017), analyzed the body composition of NCAA collegiate athletes, including rowing, however there was no control comparison. This research was also done using air displacement plethysmography (Bod Pod body composition system) (Fields et al., 2017), which is a 2-compartment model of body composition, whereas the DXA is a 3-compartment model. The use of the DXA also allows for bone measures (BMC and BMD), regional composition, as well as a VAT measure.

The purpose of the current study is to further analyze DXA derived body composition outcomes of NCAA Division I collegiate female rowing athletes. To enhance to current understanding, this study will start by comparing body composition measures between rowing athletes and like aged, same sex controls Following this initial analysis, this study will then analyze how body composition changes across a single season, differ based on boat race category, and potential differences based on the sport's inherent asymmetries. Again, this will be the first research to examine DXA derived body composition by boat race category, and boat side. Previous research has examined changes across a season, however that research was limited by small sample sizes.

CHAPTER 3: METHODS

Subject Population

A total of 166 female NCAA Division I collegiate rowing athletes from The University of Texas at Austin participated in this study; and a total of 235 female controls from The University of Texas at Austin participated in this study. Participants were categorized by position of “Rower” or “Control”. Seasons were defined as Fall (Sep-Nov), Winter (Dec-Feb), and Spring (Mar-May). Rowers were further categorized by boat of 1V8, 2V8, 1V4, and NS.

Boat categories were originally identified by rowers on the day of their scan(s). These categories were then cross referenced and identified based on the boat category each rower was placed in for the final championship race of the select season. Sides were defined as Port (oar extends to the right of the shell) and Starboard (oar extends to the left of the shell). Those who identified as rowing both Port and Starboard were excluded from analysis. All procedures were approved by the University’s Institutional Review Board, and all participants signed an approved informed consent prior to participation.

Control population included for analysis were matched for age, sex, and BMI. Control participants outside the age range of 18-23 were excluded from analysis, and any non-female controls were excluded. To match BMI, the BMI range of the rowing population was established (19.7 – 30.2); any control participant with a BMI outside this range was excluded. With this exclusion criteria the total number of controls used for analysis was 208.

Dual Energy X-Ray Absorptiometry Measurements

A whole body DXA (GE Lunar iDXA, General Electric Medical System, Madison, WI, USA) scan was performed, measuring FM, LM, and BMC. LM includes muscle mass, organs, total body water and fat inseparable from these structures. Standard DXA protocols were followed. Prior to scanning, participants were instructed to remove all metal objects, thick clothing, and heavy plastic to reduce interference with the scan. On the day of the scan, age, height, weight, and ethnicity were recorded. Each participant then laid in a supine position in the center of the scanning table. Participants were scanned at The University of Texas at Austin, and all scan files were sent to one University where the same technician analyzed all scans using enCore^{TM} software (platform version 16.2, General Electric Medical Systems, Madison, WI, USA) to determine relative fat (percent body fat [%BF]), total LM, total FM, BMD, BMC, and visceral adipose tissue (VAT) mass. Regional measures were also determined including LM, FM, BMC, and BMD for arm, leg, and trunk.

Scan Selection

Control participants were scanned at only one time point. Rowing participants may have been scanned at multiple time points. When performing the analysis comparing rower against control, only rower participants with in-season (March, April, May) scans were used (n=91). If a rower participant had more than one in-season scan, the most recent in-season scan was used for analysis. When analyzing differences between seasons, only rowers who had subsequent scans in Fall, Winter, and Spring (within the same competitive year) were included in the analysis (n=38). When analyzing differences between different boat classes and between sides, in-season scans were used for the analysis (n=91). If a participant did not have boat data, they were excluded from the analysis examining differences between boat classes. If a participant did not have side data, they were excluded from the analysis examining differences based on side (n=78).

Statistical Analysis

Descriptive analysis was done looking at means and standard deviations for each variable of interest. Two-sample t-testing was used to assess differences between rowing athletes and controls. One-way repeated measures ANOVA, using pairwise post hoc testing with Bonferroni adjustments for multiple comparisons, was used to analyze differences across seasons (Fall/Winter/Spring) for total and regional body composition. Univariate ANOVAs were used to assess differences between boat race categories (1V8/2V8/1V4/NS) using Tukey's Honest Significant Difference (HSD) post hoc testing to determine significant differences while adjusting for multiple comparisons. Paired t-tests were used to assess differences between oar side and non-oar side regional body composition within the rowing population. Total and regional body composition measures included %BF, total LM, total FM, total BMC, total BMD, VAT, and arm, leg, trunk LM, FM, BMC, and BMD. All analyses were conducted using R Studio software (R Foundation for Statistical Computing, Version 4.1.1, Vienna, Austria) with an alpha level of $p \leq 0.05$. All figures were created using GraphPad Prism version 9.3.1 for Windows (GraphPad Software, San Diego, California USA).

CHAPTER 4: RESULTS

In total, 401 participants (166 rowing athletes, 235 control participants) were initially scanned at the University of Texas at Austin. The number included for analyses depended on the specific aim. Final subject number included in analysis is detailed below for each specific aim.

Rowing Athletes Compared to Control Participants

A total of 264 participants were included in the Specific Aim #1 analysis; 91 rowing athletes, and 173 control participants. Physical characteristics for both rowing and control populations are shown in Table 1. As expected, rowing and control populations were statistically different ($p<0.001$, both) in height (174.24±5.77cm vs. 164.12±6.48cm, respectively) and weight (75.19±8.17kg vs. 62.63±7.77kg, respectively).

Total body DXA composition averages by population are presented in Table 1. Total body analyses yield significant differences in LM (51.97±3.97kg vs. 41.12±5.00kg, $p<0.001$), FM (20.74±5.26kg vs. 19.34±4.93kg, $p=0.037$), and BMC (2.82±0.26kg vs. 2.37±0.29kg, $p<0.001$) (Figure 1). Total %BF was shown to be significantly lower in rowing athletes compared to control participants (0.27±0.05 vs. 0.31±0.05, $p<0.001$). Rowing athletes show a significantly higher BMD compared to control participants (1.24±0.09g/cm^2 vs. 1.14±0.09g/cm^2, $p<0.001$). VAT was shown significantly greater ($p=0.003$) in control participants (168.05±141.57g) compared to rowing athletes (105.04±133.44g) (Figure 2).

Differences in Rowing Athlete Body Composition by Season

A total of 38 rowing athletes were included in this analysis. Weight, total body DXA, regional DXA body composition, and VAT averages by season are presented in Table 2. BMD averages by season are presented in Table 3. Amongst the total composition measures, only LM was significantly different between seasons with Spring season LM (52.78±3.77kg) being significantly greater (*p*=0.044) than Fall season LM (52.07±3.50) (Figure 3).

Regional body composition results show a significant difference (*p*<0.001) between arm LM by season. Winter season arm LM (5.73±0.45kg) is significantly greater (*p*=0.002) than Fall season arm LM (5.55±0.45kg) (Figure 4). Additionally, Spring season arm LM (5.84±0.55kg) is significantly greater (*p*<0.001) than Fall season arm LM (5.55±0.45kg) (Figure 4). Seasonal results are shown in Table 2, showing no change in FM or BMC between Fall, Winter, and Spring.

Differences in Rowing Athlete Body Composition by Boat Race Category

Ninety-one rowing athletes were included for boat race category analysis; 31 categorized in the 1V8 category, 24 in the 2V8 category, 10 in the 1V4 category, 26 in the NS category. Height, weight, and results from total body DXA, regional DXA, and VAT averages for each boat race category are presented in Table 4. BMD averages are presented in Table 5. There were no significant total body or regional measures of LM, FM, BMC or BMD between any boat race categories (*p*>0.05).

Differences based on Boat Side

Data for oar side and non-oar side averages for regional body DXA results for rowing athletes is displayed in Table 6. A total of 78 rowing athletes were included in this analysis, 38 athletes were classified as Port rowers, 40 athletes were classified as Starboard rowers.

No significant (p>0.05) differences in regional LM, FM, BMC were observed between oar side and non-oar side (Table 6).

CHAPTER 5: DISCUSSION

This study expands on previous research by providing a specific comparison between the DXA derived body composition of female collegiate NCAA Division I rowing athletes and like age, same sex controls. Also, through the use of the DXA, this study added measures of BMC, BMD, and VAT. This study also expands on rowing specific body composition by providing an analysis of changes across a season, differences between boat classes, and an analysis of potential asymmetries with a large sample size and regional DXA analysis. The current study observed significant differences in total body composition measures, and VAT between rowing athletes and controls. As hypothesized, differences were observed in height, weight, LM, FM, BMC, BMD between rowing athletes and controls.

We also observed significant differences only between the Fall season and Spring season for total body LM and arm LM. This is against what was hypothesized, as we expected greater differences in body composition between seasons. NCAA Division I collegiate rowers generally train year-round, taking small amounts of time off from training. Leaving little time for detraining to occur, body composition may have already been established and is being maintained through continued training. Looking across a single season may limit the ability to see effects of concurrent training. Examining across several years may allow for significant changes to surface. Level of experience is a major factor in analyzing changes across season. Lastly, we observed no significant differences in body composition measures between boat race categories nor between boat side. This is also opposed to what was hypothesized, as we expected boat racing categories and oar side to impact body composition resulting in differences.

Rowing Athletes Compared to Control Participants

On average, measures of height and weight were similar to those found in previous studies looking at the demographics of female collegiate rowers (Walsh et al., 2020). Differences in height and weight between rowing athletes and controls point out the demands and biomechanics of the sport. Previous research has shown that larger (height and weight) rowing athletes tend to be faster (Barret & Manning, 2004; Yoshiga & Higuchi, 2003). A taller individual can produce a longer stroke creating more opportunity to add speed to the boat (Yoshiga & Higuchi, 2003; Secher, 1983; Ingham et al., 2002). More mass allows for greater force application on the oar handle and producing more whole-body power production. Rowing performance increases with body size driven by increases in fat-free mass (Yoshiga et al., 2003; Majumdar at al., 2017). Research demonstrates that heavy weight rowers produce greater force and power relative to light weight rowers (Owen et al., 2002; Majumdar et al., 2017). Sanada and colleagues (2009) demonstrated that rowing exercise may have positive effects on preventing lifestyle-related diseases (Sanada et al., 2009). Those results were shown in older rowers; however, the results of the current research reflect this showing significantly lower VAT in college aged rowing athletes compared to matched controls.

This is the only study to compare DXA derived body composition outcomes between female collegiate rowers and matched controls. The LM and FM of rowing athletes found in this study (51.97 ± 3.97kg and 20.74±5.26kg, respectively) were similar to that found in previous studies using DXA to determine the body composition of NCAA collegiate female rowers (50.10 ± 5.50kg and 21.8±7.3kg) (Fields et al., 2017).

Total weight of rowers (75.19±8.17kg) was similar to that found in this previous research as well (72.00±11.40kg) (Fields et al., 2018).

Rowing Athlete Body Composition by Season

Seasonal analysis showed significant differences (*p*=0.044) between total LM from Fall season (52.07±3.50kg) to Spring season (52.78±3.77kg). This change in total LM is shown to be driven by an increase in arm LM. Arm LM was the one regional composition measure that was shown to significant increase (*p*<0.001) from Fall season (5.55±0.45kg) to Spring season (5.84±0.55kg). This is different then what was hypothesized. Because the majority of power is produced by the legs during the rowing stroke, it was hypothesized that a significant change in leg LM would occur. (Penichet-Tomas et al., 2021). One hypothesis for the difference in arm LM is due to the change in speed focus across a season. As a season progresses more focus is put on higher intensities and greater boat speed. Research has shown that sub-elite rowers can sustain greater power in a 30 second bout of arm cranking compared to lower level rowers (Lawton et al., 2012). This may show that with greater capacity for boat speed comes greater arm force production, indication potentially greater arm LM.

Research looking at a change in LM from four time points across a season in lightweight female rowers showed similar results (Morris & Payne, 1996). DXA derived LM showed insignificant changes between pre-season, early competition, and post-season. However, this research did show a significant decrease in DXA derived FM from pre-season to early competition. Another study by Young and colleagues (2014) examined body composition outcomes in female college-level rower after a season of concurrent training. This study found that LM increased significantly at midseason and postseason time points compared to preseason (Young et al., 2014). However, this research only analyzed the DXA outcomes of five collegiate club (non-NCAA) rowers.

One possible explanation for the lack of significant differences in leg and trunk LM between seasons may be due to the interference phenomenon. This phenomenon addresses issues surrounding training both strength and aerobic power simultaneously (Docherty & Sporer, 2000). Research suggests simultaneous strength and aerobic power compromises strength training compared to strength training alone. Alternately, aerobic power during this type of concurrent training is relatively unaffected (Docherty & Sporer, 2000). Successful rowing training requires both extensive and intensive endurance training, and accounts for the majority of total training. Strength training also plays a role in successful training, but only accounts for roughly 16-20% for 18-21-year-old rowers (Mäestu et al., 2005). While strength training may compliment the important endurance training, it may not have the same hypertrophic effect of strength training alone; underscoring the lack of significant differences between Fall, Winter, and Spring.

Body Composition by Boat Racing Category

The current study observed no significant differences in total body or regional body composition between the different boat race categories. These results are in opposition to what was originally hypothesized as the past research has led to the understanding that larger athletes tend to be faster (Barret & Manning, 2007). The 1V8 boat race category is typically where most collegiate rowing coaches place their fastest athletes, as this category is worth the most points at championship events.

Previous research has demonstrated aerobic variables being stronger predictors of performance in varsity (non-novice) rowers (Kendall et al., 2011). It can be hypothesized that a lack of significant differences in composition measures between race categories is due to rowers in these categories being differentiated by aerobic variables such as VO_2max.

Body Composition by Side of Body

Our body composition analysis between the oar side and non-oar side of collegiate rowers yielded no significant results. No trends were apparent when reviewing the specific regional body composition averages. Despite research showing muscular activation and biomechanical asymmetries, the question becomes if these lead to strength and body composition asymmetries. Previous research shows significant asymmetries in joint angles, force, and acceleration (Fohanno et al., 2015). Research by Readi and colleagues show that sweep rowers asymmetrically activate their low back muscles (Readi et al., 2015). Research by Parkin and colleagues (2001) analyzed if rowing athletes show greater asymmetry than age, height, and weight matched controls. Researchers found that there were no significant differences in the strength of the quadriceps or hamstrings caused by rowing side position (Parkin et al., 2001). Though there are asymmetries due to rowing side position, they do not appear to cause strength asymmetries (Parkin et al., 2001). This may explain why the current research did not show any differences between oar side and non-oar side body composition differences.

Importance and Implications of Findings

Rowing is a growing sport and, over the past 20 years, there has been particularly large growth within the collegiate realm (Baker et al., 2020). Within this growth, the participation opportunities for women have dramatically grown, especially at the NCAA Division I level. Rowing became an NCAA sport in 1996-1997, and during the 2000-01 academic year the number of schools offering rowing at the varsity level increased from 96-136 (Rosner, 2001). The research representation of this population (collegiate female rowing athletes) does not match the growing level of participation. This research allows for a better understanding of the sport as it relates to a large and growing population of athletes. Using DXA provides a better understanding of how this sport impacts the health and performance of this population.

The outcomes of this research will help inform how training and racing affects the body composition of NCAA Division I female collegiate rowers. The results may be of particular interest for rowing team personnel (e.g., coaches, athletic trainers, physiotherapists, nutritionists). Understanding how body composition measures differ from a like-aged and sex matched control population will better inform the impact of extensive training. Outcomes may demonstrate positive health impacts that accompany rowing training. On the other hand, results may highlight or hint towards detrimental aspects of training. This may include potential long-term effects of NCAA Division I collegiate rowing training. Analyzing how body composition changes across a single rowing season, by boat racing category, and due to boat side may help inform coaches on their athletes' training programs and injury risk. This research may allow for improved injury prevention, injury risk reduction, and injury rehabilitation.

Strength and Limitations of Current Study

Strengths:

This research presents several strengths. One major strength is the sample size gathered for both the rowing athlete population and control population. Though initial numbers were reduced after scan selection, sample sizes used for analysis were large. Body composition for this study was done using DXA, which is widely considered the "gold standard" of body composition measures. DXA technology allows for easy repeatability. DXA provides a level of specificity and detailed analysis that is not achieved by many other body composition measures. The use of a DXA scanner and its accompanying software also allows for regional/segmental measures.

Limitations:

Because this was a retrospective analysis, there was little control over data collection. Individual and objective performance measures were not part of the original data collection. Without this type of performance measure, we are unable to analyze body composition relative to individual (objectively measured) performance. Another part of performing a retrospective analysis is the inability to gather other demographic information. One variable of particular interest would be years of experience. The uniqueness of collegiate rowing means there could be a variety of actual years of rowing specific experience. Although a large sample size was collected, scans were taken within a large date range (2006-2018). This large range of data collection introduces some confounding variables. One such variable is that during this time there was coaching turnover. With a change in head coach comes potential changes in training and racing that could affect body composition differently outside of the variables specifically examined. During this analysis, we did not have access to training data for the rowing participants. Having training data would have allowed us to control for training (frequency, duration, intensity) when running the analysis across season, boat categories, and between side.

Future Directions

More research is needed to better understand the body composition of female rowers. Linking objective performance measures (i.e. 2000m ergometer) to DXA measures will allow for better utilization of the information. Using individual performance measures alongside measuring body composition at seasonal timepoint may better define the role of body composition in performance gains.

Going forward it will be important to look closer at potential asymmetries in body composition within this population. The results of this research provide an indication of the lack of composition asymmetries. however, I believe it will be important to look closer at how years of rowing experience may play into the development of potential asymmetries.

CHAPTER 6: CONCLUSION

In summary, the results of this study demonstrate how the body composition of NCAA Division I collegiate female rowers differs from like-aged, same sex controls. A follow up examination of rowing athlete specific body composition showed a significant increase in LM from Fall season to Spring season, driven by a significant increase in arm LM from Fall season to Spring season. This study reported no other significant differences in regional body nor total-body composition measures relative to seasonal differences or boat race category. Finally, these findings show no significant body composition asymmetries based on oar side versus non-oar side distinction. Further research is needed to consider how years of rowing experience affects the analyses performed within this study.

Table 1. Demographics and Total Body DXA Results (Rowing and Controls)

	Rowing	**Control**	**P-value**
N	91	173	--
Age (yrs.)	20.22 (1.06)	20.46 (1.32)	--
Height (cm)	174.24 (5.77)	164.12 (6.48)	<0.001
Weight (kg)	75.19 (8.17)	62.63 (7.77)	<0.001
Total % Fat	0.27 (0.04)	0.31 (0.05)	<0.001
Lean Mass (kg)	51.97 (3.969)	41.12 (5.00)	<0.001
Fat Mass (kg)	20.74 (5.26)	19.34 (4.93)	0.037
BMC (kg)	2.82 (0.26)	2.37 (0.29)	<0.001
BMD (g/cm^2)	1.24 (0.09)	1.14 (0.09)	<0.001

Continuous variables presented as mean ± standard deviation (SD).
Abbreviations: VAT = visceral adipose tissue, BMC = bone mineral content, BMD = bone mineral density.
P-value represent two sample t-test between rowing and control within each variable.

Table 2. Total Body and Regional DXA Results Across Seasons.

	Fall	**Winter**	**Spring**
Weight (kg)	77.8 (8.13)	78.21 (8.09)	78.08 (7.92)
Total % Fat	29 (0.04)	29 (0.04)	29 (0.04)
Lean Mass (kg)			
Total	52.1 (3.50)^{A}	52.6 (3.56)^{AB}	52.8 (3.77)^{B}
Arm	5.55 (0.45)^{A}	5.73 (0.45)^{B}	5.84 (0.55)^{B}
Leg	18.3 (1.91)	18.3 (1.87)	18.4 (2.05)
Trunk	25.1 (1.68)	25.4 (1.64)	25.5 (1.71)
Fat Mass (kg)			
Total	23.25 (5.07)	23.14 (5.13)	22.83 (4.82)
Arm	2.55 (0.56)	2.57 (0.55)	2.58 (0.58)
Leg	9.68 (2.23)	9.50 (2.24)	9.49 (2.14)
Trunk	10.2 (2.76)	10.2 (2.77)	9.91 (2.57)
BMC (kg)			
Total	2.82 (0.25)	2.82 (0.24)	2.83 (0.24)
Arm	0.36 (0.03)	0.37 (0.04)	0.372 (0.036)
Leg	1.07 (0.11)	1.06 (0.11)	1.06 (0.11)
Trunk	0.86 (0.09)	0.86 (0.09)	0.86 (0.09)
VAT (g)	129.63 (144.43)	142.39 (127.59)	125.89 (126.97)

Continuous variable presented as mean ± standard deviation (SD).
Abbreviations: VAT = visceral adipose tissue, BMC = bone mineral content.
For each row, if a season does not share a letter, it is significantly different at and adjusted ($p<0.05$).

Table 3. Bone Mineral Density Results Across Seasons.

	Fall	**Winter**	**Spring**
BMD (g/cm^2)			
Total	1.22 (0.08)	1.22 (0.08)	1.23 (0.08)
Arm	0.80 (0.07)	0.80 (0.07)	0.81 (0.09)
Leg	1.31 (0.10)	1.30 (0.10)	1.31 (0.09)
Trunk	1.07 (0.08)	1.07 (0.08)	1.07 (0.08)

Continuous variable presented as mean ± standard deviation (SD).

Abbreviations: BMC = bone mineral content.

For each row, if a season does not share a letter, it is significantly different at and adjusted ($p<0.05$).

Table 4. Total Body and Regional DXA Results Across Boat Race Categories.

	1V8 (N=31)	**2V8 (N=24)**	**1V4 (N=10)**	**NS (N= 26)**
Height (cm)	175.87 (5.66)	173.79 (4.34)	172.72 (5.49)	173.29 (6.86)
Weight (kg)	75.21 (7.9)	76.27 (7.45)	71.59 (7.83)	75.55 (9.29)
Lean Mass (kg)				
Total	53.00 (3.33)	52.68 (3.96)	49.91 (3.30)	50.87 (4.51)
Arm	5.99 (0.55)	5.80 (0.56)	5.42 (0.44)	5.68 (0.78)
Leg	18.14 (1.78)	18.35 (2.10)	17.17 (1.72)	17.44 (1.78)
Trunk	25.76 (1.40)	25.45 (1.87)	24.25 (1.51)	24.65 (2.52)
Fat Mass (kg)				
Total	19.67 (5.31)	21.04 (4.40)	19.33 (5.24)	22.29 (5.77)
Arm	2.21 (0.62)	2.39 (0.61)	2.10 (0.54)	2.49 (0.66)
Leg	8.39 (2.29)	8.69 (2.02)	8.34 (1.78)	9.06 (2.31)
Trunk	8.25 (2.63)	9.12 (2.26)	8.08 (3.06)	9.91 (3.14)
BMC (kg)				
Total	2.87 (0.30)	2.86 (0.28)	2.75 (0.18)	2.75 (0.24)
Arm	0.38 (0.04)	0.37 (0.04)	0.35 (0.04)	0.35 (0.04)
Leg	1.08 (0.14)	1.07 (0.11)	1.04 (0.09)	1.03 (0.11)
Trunk	0.87 (0.10)	0.87 (0.10)	0.83 (0.06)	0.84 (0.10)
VAT (g)	99.37 (143.28)	78.25 (66.01)	104.46 (75.11)	132.51 (171.83)

Continuous variable presented as mean ± standard deviation (SD).

Abbreviations: 1V8 = First Varsity Eight, 2V8 = Second Varsity Eight, 1V4 = First Varsity Four, NS = Non-Scoring, BMC = bone mineral content, VAT = visceral adipose tissue.

Table 5. Bone Mineral Density Results Across Boat Race Categories.

	1V8 (N=31)	**2V8 (N=24)**	**1V4 (N=10)**	**NS (N= 26)**
BMD (g/cm^2)				
Total	1.24 (0.09)	1.25 (0.09)	1.24 (0.07)	1.22 (0.08)
Arm	0.80 (0.09)	0.83 (0.09)	0.84 (0.13)	0.80 (0.11)
Leg	1.33 (0.12)	1.32 (0.10)	1.30 (0.07)	1.29 (0.09)
Trunk	1.08 (0.09)	1.10 (0.11)	1.07 (0.06)	1.06 (0.09)

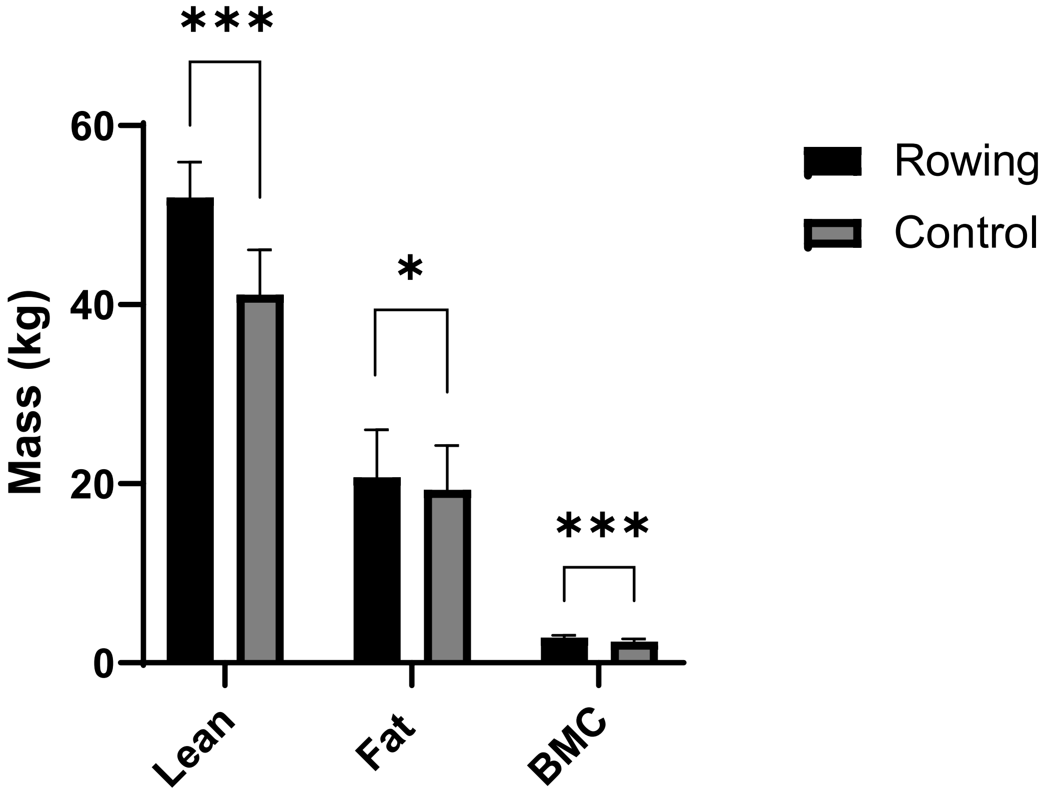
Continuous variable presented as mean ± standard deviation (SD).
Abbreviations: 1V8 = First Varsity Eight, 2V8 = Second Varsity Eight, 1V4 = First Varsity Four, NS = Non-Scoring, BMD = bone mineral density.

Table 6. Oar Side versus Non-Oar Side Regional DXA Results.

	Oar Side	**Non-Oar Side**	**P-value**
Arms:			
Lean Mass (kg)	2.90 (0.30)	2.89 (0.33)	0.759
Fat Mass (kg)	1.17 (0.31)	1.16 (0.32)	0.146
BMC (kg)	0.185 (0.02)	0.18 (0.02)	0.164
BMD (g/cm^2)	0.81 (0.09)	0.81 (0.10)	0.857
Legs:			
Lean Mass (kg)	9.01 (1.01)	8.95 (0.99)	0.147
Fat Mass (kg)	4.36 (1.11)	4.32 (1.07)	0.098
BMC (g)	0.53 (0.07)	0.53 (0.06)	0.362
BMD (g/cm^2)	1.32 (0.11)	1.32 (0.11)	0.341
Trunk:			
Lean Mass (kg)	12.59 (1.03)	12.61 (1.07)	0.812
Fat Mass (kg)	4.43 (1.40)	4.45 (1.40)	0.586
BMC (g)	0.430 (0.05)	0.430 (0.06)	0.903
BMD (g/cm^2)	1.09 (0.09)	1.08 (0.10)	0.794

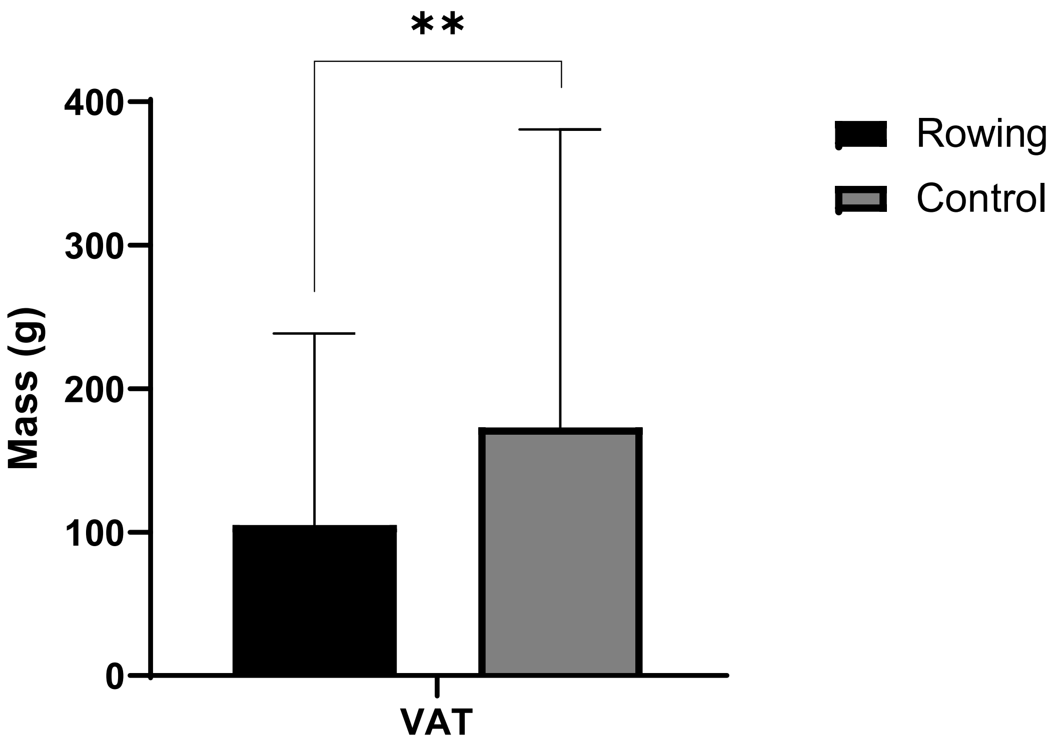
Continuous variables presented as mean ± standard deviation (SD).
Abbreviations: BMC = bone mineral content, BMD = bone mineral density, VAT = visceral adipose tissue.
P-values represent paired t-test between inside and outside.

Figure 1. Total Body Tissue Difference between Rowing and Controls



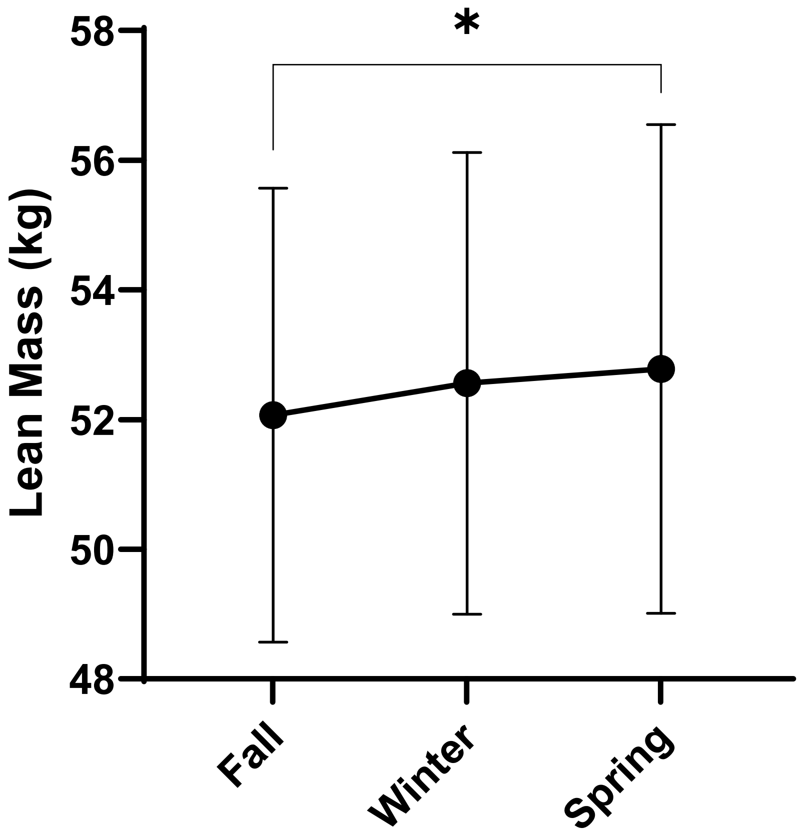
Bar plots represent mean tissue amount for each population with standard deviation (SD) bars. Abbreviations: BMC = Bone Mineral Content, * = Significance level of $p<0.05$, *** = Significance level of $p<0.001$.

Figure 2. Visceral Adipose Tissue Difference between Rowing and Controls



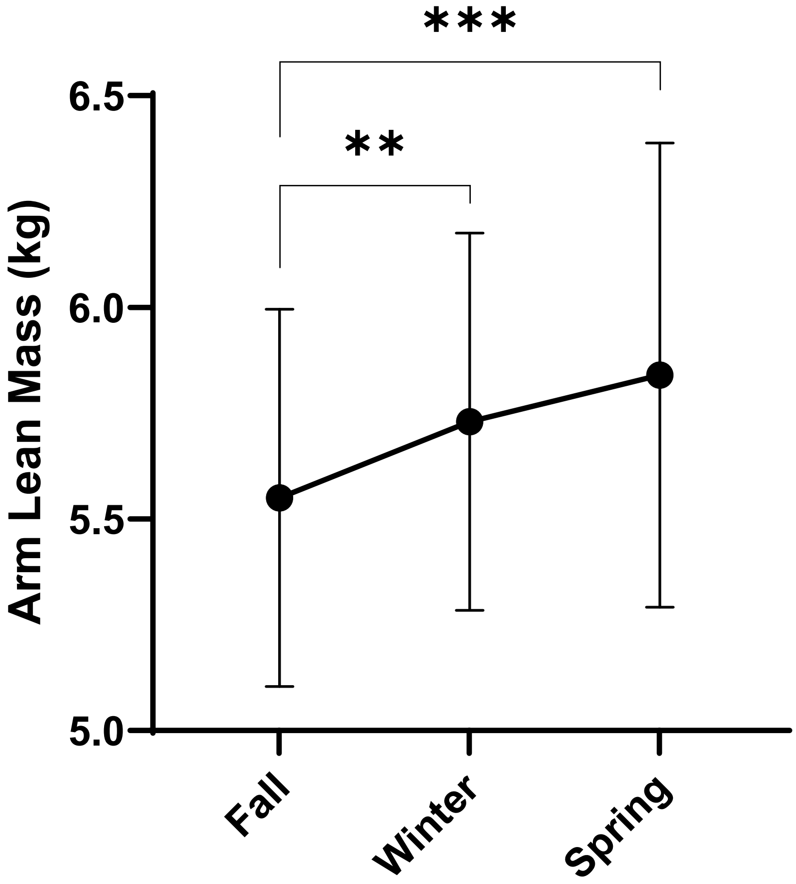
Bar plots represent mean VAT mass with standard deviation (SD) bars. Abbreviations: VAT = Visceral Adipose Tissue, ** = Significance level of p<0.01.

Figure 3. Total Body Lean Mass Changes Across Seasons



Total body lean mass changes across a subsequent season, the line represents change in total lean tissue mass (kg). Each point represents mean lean mass at that sub-season with SD bars. * = Significance level of $p<0.05$.

Figure 4. Arm Lean Mass Changes Across Seasons



Arm lean mass changes across a subsequent season, the line represents change in arm lean tissue mass (kg). Each point represents mean lean mass at that sub-season with SD bars. ** = Significance level of $p<0.01$, *** = Significance level of $p<0.001$.

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