ORIGINAL ARTICLE

Sonographic Findings and Body Composition Analysis in Division I Female Volleyball Athletes: A Novel Pilot Study

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ABSTRACT

Background: Using ultrasound imaging, evaluate sonographic findings in the upper and lower extremities across the competitive season in Division I female collegiate volleyball athletes. Second, evaluate association between sonographic tendon thickness, cross-sectional area (CSA) measurements, and body composition variables.

Methods: Prospective observational study with repeated sonographic findings and body composition measurements in 16 female volleyball athletes at pre and postseason.

Results: Sonographic tendon and bony abnormalities were most prevalent in the knees and ankles pre and postseason. Chi-Square revealed significant differences across the competitive season in prevalence of left Achilles tendon pathology (x^2=3.5, P=.060), pathology in either Achilles tendon (x^2=4.1, P=.044), and tendon abnormalities in ≥4 body regions (x^2=6.6, P=.010). MANOVA revealed significant differences with large effect sizes across the competitive season in right Achilles tendon CSA (P=.020, x^2=.17), right plantar fascia thickness (P=.069, x^2=.11), combined right lower extremity measurements (P=.072, x^2=.11), combined left lower extremity measurements (P=.057, x^2=.12), combined bilateral lower extremity measurements (P=.054, x^2=.12), and combined bilateral upper extremity measurements (P=.070, x^2=.11). Significant moderate to large correlations found between Achilles tendon CSA and body composition variables at pre and postseason (ranging from -.51 to .79).

Conclusions: This pilot investigation provides novel data and insights into the effects of competitive season on sonographic findings in the upper and lower extremities in Division I female volleyball athletes and an association between sonographic tendon measurements and body composition variables. Findings suggest that monitoring tendon health across competitive seasons may be helpful in informing injury prevention and training programs for collegiate athletes.

Keywords: body composition; tendinopathy; ultrasonography; volleyball.

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INTRODUCTION

Nearly 30,000 women compete in collegiate volleyball in the United States, with just over 6,000 competing at the Division I level [1]. The most common body regions injured in volleyball athletes are the shoulder, knee, ankle, and foot, with reported incidence rates ranging from 2 to 11 injuries per 1,000 player hours, including acute and overuse injuries resulting from contact and noncontact mechanisms [2]. The most common soft tissue structures to be injured in volleyball athletes are the rotator cuff, patellar, and Achilles tendons [2-7].

High-resolution ultrasound imaging (USI) is a reliable [8], patient-friendly, cost-effective, dynamic point-of-care diagnostic tool allowing for rapid evaluation of various neuromusculoskeletal structures, including easy bilateral comparison [9,10]. Research has shown that sonographic evaluation of some tendon pathologies is more sensitive and accurate than MRI;[11-13], however, like other soft tissue imaging modalities, USI may detect tendon and bony abnormalities in asymptomatic athletes. The relationship between sonographic abnormalities and the development of musculoskeletal symptoms remains unclear, in part because of the prevalence of asymptomatic findings; [9,14] however, recent investigations have found a link between sonographic tendon abnormalities in athletes and the development of pain identifying focal hypoechoic tendon appearance, barrel-shaped tendon thickening, and neovascularization as factors most predictive of symptom development, particularly in the patellar and Achilles tendons and less predictive in the rotator cuff tendons [3-5,8,10,15,16]. Cushman et al.,[7] investigating a variety of Division I athletes (including 14 indoor volleyball players of unspecified sex), found a 4 to 6-fold increase in the development of pain in athletes with preseason sonographic abnormalities in the lower extremities. They found the highest prevalence of sonographic abnormalities in the patellar tendon of indoor volleyball athletes, which approached 60%. Despite these findings, uncertainty remains regarding the value of sonographic findings in screening for injury risk and future development of musculoskeletal pain and dysfunction. Caution should be exercised when using USI in isolation to identify athletes at an increased risk of injury; instead, interpreting sonographic findings – like other imaging modalities – within the context of an athlete's medical history, sporting demands, and clinical examination is considered best practice [9,15].

Although studies exist evaluating preseason sonographic findings in athletes and the development of musculoskeletal pain or injury,[3,7,16] the authors could find no studies evaluating sonographic tendon measurements or description of cortical changes at the various entheses across the competitive season (i.e., comparing pre and postseason examinations) in any athletic population. Additionally, the authors could find no studies evaluating the association between sonographic tendon measurements and body composition variables in any athletic population.

This investigation aimed to evaluate sonographic findings in the upper and lower extremities in Division I female collegiate volleyball athletes at pre and postseason using high-resolution USI. Secondarily, the association between sonographic tendon measurements and body composition variables was evaluated, including body segment-specific analysis. Notably, this investigation was conducted at the largest Historically Black College and University in the United States and presented novel data on female athletes, the majority of which identified as racial/ethnic minorities, which is a population largely underrepresented in the scientific literature [7].

MATERIALS AND METHODS

This was a prospective observational study with a repeated measures design. The primary outcome measures were sonographic tendon thickness and cross-sectional area (CSA). All recruitment and study-related procedures were approved by the Institutional Review Board at Winston-Salem State University (IRB-FY2023-79). Participants were NCAA Division I female volleyball athletes medically cleared for participation at a southeastern Historically Black College and University who provided written informed consent before initiation of data collection. Every effort was made to ensure the rights of all study participants were protected, including the handling of personal and health information provided by each athlete.

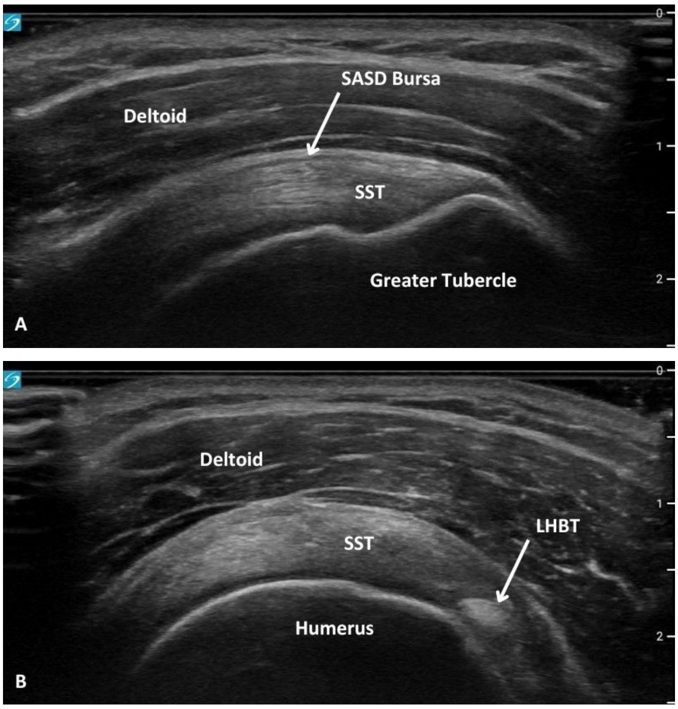
Study Procedures and Instrumentation

Athletes provided demographic information and completed a brief health history at baseline. Pre and postseason data collections included self-report questionnaires, body composition analysis, sonographic examination of the upper and lower extremities, and functional strength and power testing of the upper and lower extremities. Prior to body composition analysis, athletes completed electronic versions of the *Recovery-Stress Questionnaire for Athletes[17]* and the *Low Energy Availability in Females* questionnaire [18-20] using a secure anonymous link (Qualtrics^{XM}; https://www.qualtrics.com). Following at least 8 hours of fasting, athletes' height was measured using a wall-mounted stadiometer (Seca Model 217; Hanover, MD, USA), and their body composition was measured using multifrequency bioelectrical impedance (InBody770; Cerritos, CA, USA). Athletes then underwent sonographic examination of bilateral shoulders, knees, ankles, and feet using a 15-4 MHz linear array transducer (Sonosite PX; FUJIFILM Sonosite, Kennewick, WA, USA). Following a brief dynamic warm-up, functional strength and power tests were performed: closed kinetic chain upper extremity stability, broad jump, double broad jump, single leg hop for distance, single leg vertical jump for height, vertical jump, and 12-inch (30 cm) drop jump. All vertical and drop jumps were simultaneously video recorded in the frontal and sagittal planes for subsequent analysis (Kinovea, version 0.9.5; https://www.kinovea.org).

Sonographic Examination

All sonographic examinations were performed by the principal investigator (NJS), who is registered in Musculoskeletal® sonography by the Alliance for Physician Certification & Advancement and has over 7 years of experience performing and teaching neuromusculoskeletal USI. Shoulders were examined with the athlete seated and their hand placed on their ipsilateral posterior hip with their elbow pointing posteriorly to position their glenohumeral joint in extension and neutral rotation (i.e., modified Crass position) to obtain long and short-axis images of the supraspinatus tendon and enthesis [9] (Figure 1). Knees were examined with the athlete supine, and their knees flexed approximately 30° over a bolster to obtain long and short-axis images of the patellar tendon and enthesis [9,21] (Figure 2). Ankles and feet were examined with the athlete prone and their distal leg off the edge of the table relaxed in slight plantar flexion to obtain long and short-axis images of the Achilles tendon and enthesis (Figures 3A and 3B) and long-axis images of the plantar fascia and enthesis [9,22] (Figure 3C).

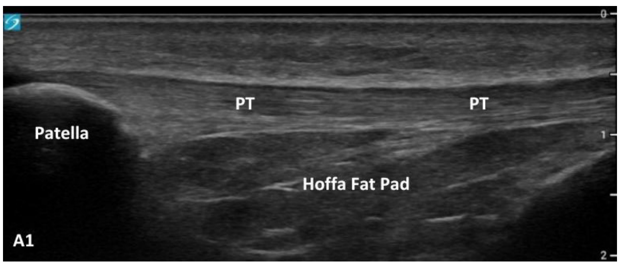
Figure 1: Ultrasound images of the supraspinatus tendon in long-axis view (A) and short-axis view (B)

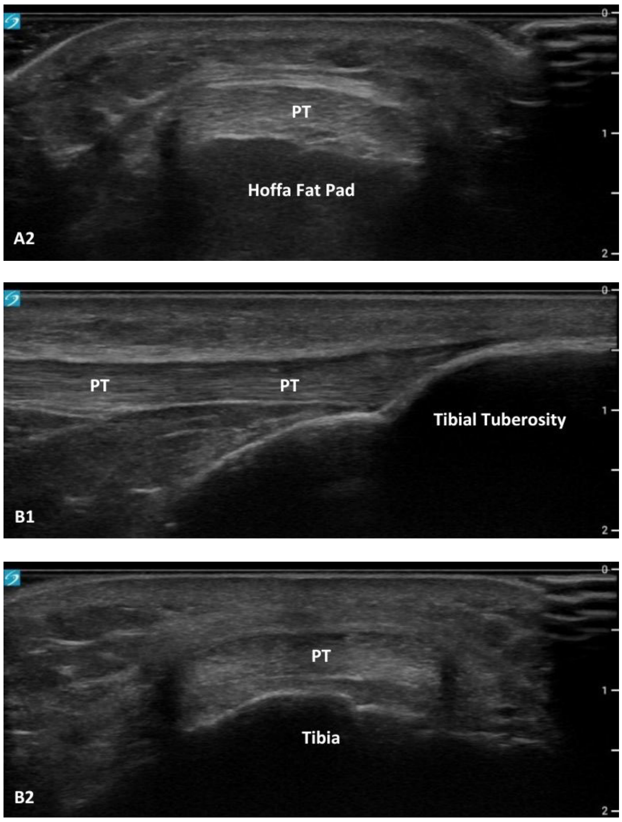


SASD, subacromial-subdeltoid bursa; SST, supraspinatus tendon; LHBT, long-head biceps tendon

Image Review and Analysis

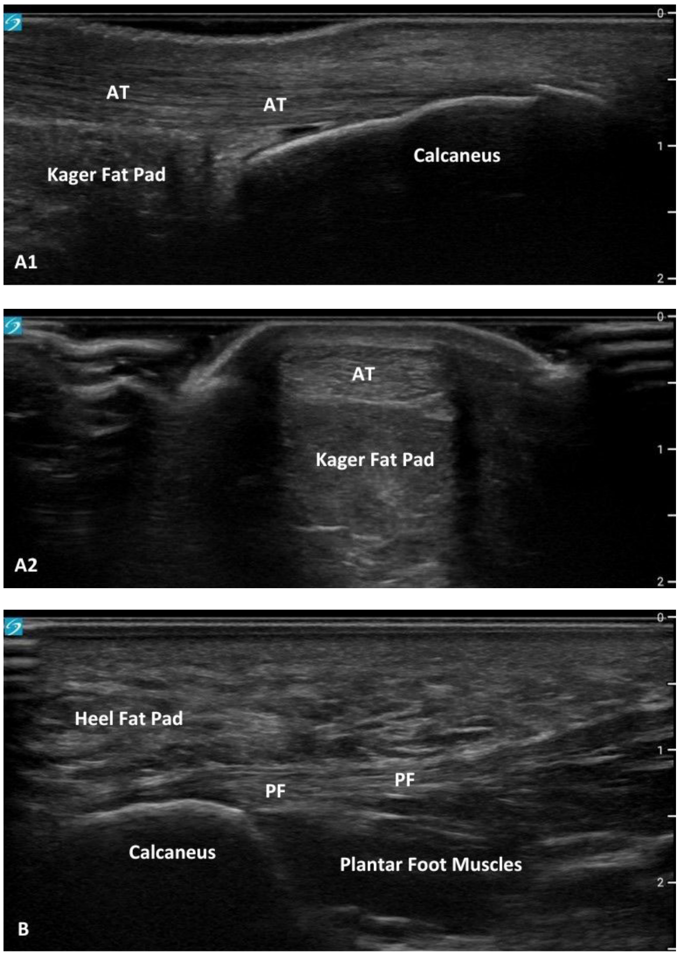
Figure 2: Ultrasound images of the proximal patellar tendon in long-axis view (A1) and short-axis view (A2) and the distal patellar tendon in long-axis view (B1) and short-axis view (B2)





PT, patellar tendon

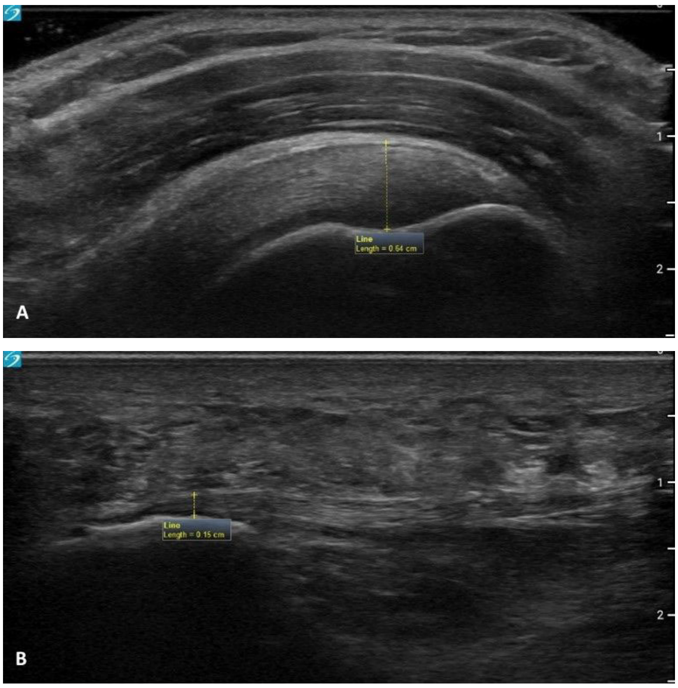
Figure 3: Ultrasound images of the Achilles tendon in long axis view (A1) and short axis view (A2) and the plantar fascia tendon in long axis view (B)



AT, Achilles tendon; PF, plantar fascia

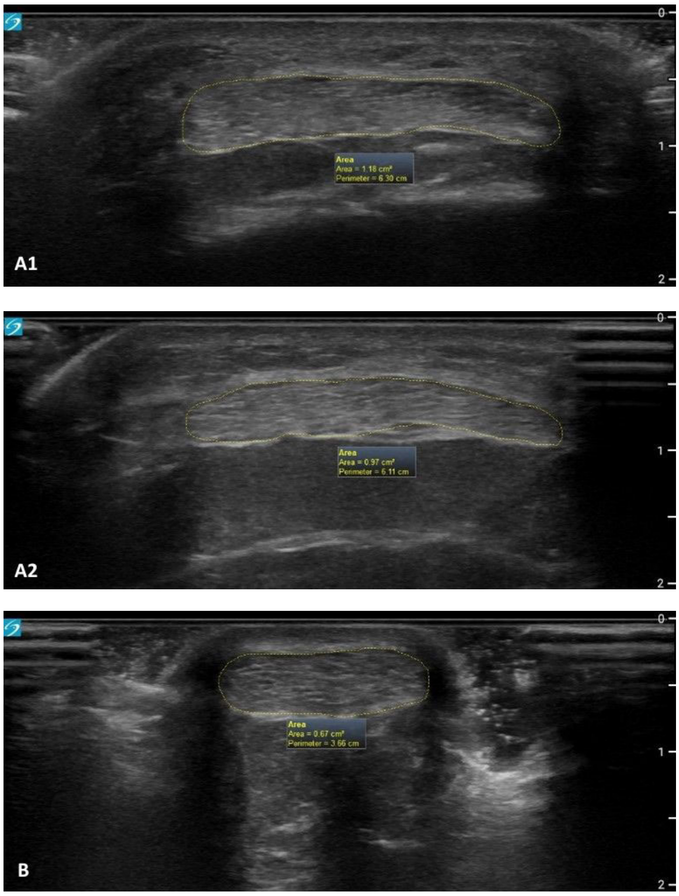
Saved images were exported for measurement and analysis using a DICOM viewer (*ShowCase Premiere* software version 6.1.3.11; Trillium Technology, Inc., Ann Arbor, MI, USA). Supraspinatus tendon thickness was measured at the medial aspect of the superior facet of the greater tubercle of the humerus (Figure 4A), and plantar fascia thickness was measured at the distal curvature of the plantar aspect of the calcaneus [22] (Figure 4B). Patellar tendon CSA was measured in the proximal region of the tendon immediately distal to the patella, and the distal region of the tendon just proximal to the tibial tuberosity (Figure 5A1 and 5A2) and Achilles tendon CSA was measured at a level intersecting the malleoli (Figure 5B). Consistent with prior studies, for statistical analysis, tendon thickness and CSA measurements were normalized to 1/3 of body mass [21]. Sonographic findings were described for each body region based on the tendon or bony abnormalities at the entheses. Tendon abnormalities were categorized according to tendinopathy (i.e., loss of fibrillar pattern, hypoechoic thickening) or intrasubstance tendon defect. Bony abnormalities were categorized according to the presence of osteophytes, enthesophytes, or cortical defects at the entheses. Examples of sonographic abnormalities in each body region examined are found in Figure 6. A final sonographic impression was determined for each athlete by summing the areas with observed pathology – tendon, bony, or any – to categorize "sonographic risk", which the authors defined as sonographic abnormalities observed in at least 4 of the 8 body regions examined.

Figure 4: Examples of sonographic measurements of thickness in the supraspinatus tendon (A) and plantar fascia tendon (B)



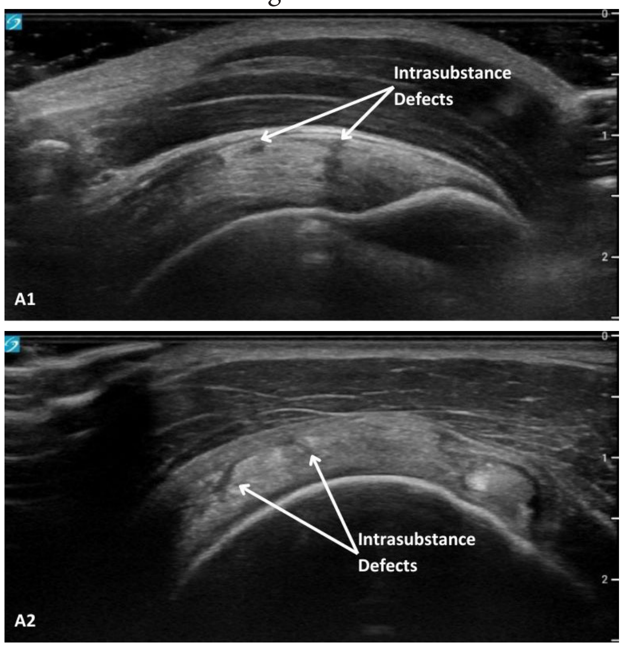
cm, centimeters

Figure 5: Examples of sonographic measurements of cross-sectional area in the proximal patellar tendon (A1), distal patellar tendon (A2), and Achilles tendon (B)



cm^2, centimeters squared; cm, centimeters

Figure 6: Examples of sonographic abnormalities in the supraspinatus tendon in long axis (A1) and short axis (A2) views, proximal patellar tendon (B1) and distal patellar tendon (B2) in long axis views, Achilles tendon (C) in long axis view, and plantar fascia tendon (D) in long axis view



Body Composition Analysis

The following measurements were included in each athlete's body composition analysis: height, body mass, fat mass, lean mass, fat-free mass, skeletal muscle mass, skeletal muscle index, percent body fat, visceral fat area, intracellular water, extracellular water, 50 kHz whole body phase angle, and basal metabolic rate. Body composition analysis included whole-body and body segment-specific upper and lower extremities and trunk measurements.

Data Analysis

SPSS© (IBM© Statistics, version 28.0.1.0; Armonk, NY, USA) was used for all data analysis. Descriptive statistics were used to summarize athlete characteristics at baseline. Chi-square analysis was used to compare the frequency and distribution of sonographic findings in each body region across the competitive season. MANOVA was used to evaluate changes in sonographic tendon thickness or CSA across the competitive season. A two-tailed alpha level of <.10 was chosen for dependent t-tests, MANOVA, and Chi-Square analyses to improve statistical power and reduce the probability of a type II error, given the small sample size of this pilot investigation. Bivariate correlations were used to evaluate associations between sonographic tendon measurements and body composition variables at pre and postseason.

RESULTS

Data were collected between August and November 2023 from 16 female volleyball athletes (Age = 19.9 ± 1.2 years; Height = 174.9 ± 8.4 cm; Body mass = 73.2 ± 9.4 kg; 88% right-handed) that contributed 32 shoulders, knees, ankles, and feet for preseason sonographic examination. The NCAA Division I volleyball season included 60 team practices and 100 competitive sets over 26 games. The average athlete participated in 62 sets (ranging from a high of 100 sets to a low of 1 set).

All 16 athletes participated in complete preseason data collection. One athlete did not participate in the postseason sonographic examination, and 2 athletes did not participate in the postseason body composition analysis. Ten athletes (63%) identified as a racial/ethnic minority. Four athletes (25%) reported experiencing pain in their lower extremities at the time of preseason data collection, although all were cleared for full athletic participation and completed preseason testing. Four athletes (27%) reported experiencing pain in their lower extremities at postseason data collection, with 1 of those athletes unable to complete the single leg jumping activities secondary to acute unilateral knee pain.

Sonographic Findings

Preseason sonographic examination revealed 8 athletes (50%) with abnormalities in the shoulder region (5 unilateral, 3 bilateral) involving intrasubstance supraspinatus tendon defects; 15 athletes (94%) with abnormalities in the knee region (8 unilateral, 8 bilateral) involving a mixture of patellar tendinopathies, intrasubstance patellar tendon defects, and cortical defects at the patellar or tibial entheses; 14 athletes (88%) with abnormalities in the ankle region (6 unilateral, 10 bilateral) involving predominately calcaneal enthesophytes with some Achilles tendinopathies; 1 athlete (6%) with an abnormality in the foot region (unilateral) involving cortical defects at the calcaneal enthesis.

Postseason sonographic examination revealed 10 athletes (67%) with abnormalities in the shoulder region (3 unilateral, 7 bilateral) involving predominately intrasubstance supraspinatus tendon defects with a single instance of enthesophyte at the humerus and a single instance of supraspinatus tendinopathy; 15 athletes (100%) with abnormalities in the knee region (5 unilateral, 10 bilateral) involving predominately patellar tendinopathies along with a mixture of intrasubstance patellar tendon defects and cortical defects at the patellar or tibial entheses; 12 athletes (80%) with abnormalities in the ankle region (7 unilateral, 5 bilateral) involving a mixture of calcaneal enthesophytes and Achilles tendinopathies; 1 athlete (7%) with an abnormality in the foot region (unilateral) involving plantar fasciosis.

Overall, the highest prevalence of tendon abnormalities was found in the knee region in the pre-and postseason. The highest prevalence of bony abnormalities was found in the ankle region at pre and postseason. Chi-Square analysis of sonographic abnormalities across the competitive season revealed significant differences in the prevalence of athletes with left Achilles tendon pathology, pathology in either Achilles tendon, and tendon abnormalities in at least 4 body regions (Table 1). No significant differences were found in the prevalence of bony abnormalities (Table 2) or any sonographic abnormalities (i.e., tendon and/or bony) across the competitive season (Table 3).

Table 1: Prevalence of *tendon* abnormalities across the competitive season

Body Regions	Preseason (n=16)	Postseason (n=15)	χ^2	P
Shoulders				
Right Supraspinatus Tendon	6 (38%)	8 (53%)	0.78	.376
Left Supraspinatus Tendon	5 (31%)	9 (60%)	2.58	.108
Knees				
Right Patellar Tendon	10 (63%)	12 (80%)	1.15	.283
Left Patellar Tendon	11 (69%)	13 (87%)	1.42	.233
Bilateral Knees	14 (88%)	15 (100%)	2.00	.157
Ankles				
Right Achilles Tendon	3 (19%)	6 (40%)	1.69	.193
Left Achilles Tendon	0 (0%)	3 (20%)	3.54	*.060**
Bilateral Ankles	3 (19%)	8 (53%)	4.05	*.044***
Feet				
Right Plantar Fascia	0 (0%)	1 (7%)	1.10	.294
Left Plantar Fascia	0 (0%)	0 (0%)	NA	NA
Bilateral Feet	0 (0%)	1 (7%)	1.10	.294
Body Regions Combined				
Bilateral Upper Extremities	8 (50%)	10 (67%)	0.88	.347
Right Lower Extremity	11 (69%)	12 (80%)	0.51	.474
Left Lower Extremity	11 (69%)	13 (87%)	1.42	.233
Bilateral Lower Extremities	14 (88%)	15 (100%)	2.00	.157
Sonographic "Risk"				
Abnormalities ≥4 Body Regions	1 (6%)	7 (47%)	6.61	*.010***

**P < .10*

***P < .05*

χ^2, Chi Square

Table 2: Prevalence of *bony* abnormalities across the competitive season

Body Regions	Preseason (n=16)	Postseason (n=15)	χ^2	P
Shoulders				
Right Greater Tubercle	0 (0%)	1 (3%)	1.10	.294
Left Greater Tubercle	0 (0%)	0 (0%)	NA	NA
Knees				
Right Patella or Tibial Tuberosity	2 (13%)	5 (33%)	1.92	.166
Left Patella or Tibial Tuberosity	5 (31%)	3 (20%)	0.51	.474
Bilateral Knees	7 (44%)	5 (33%)	0.35	.552
Ankles				
Right Calcaneal Tuberosity	12 (75%)	8 (53%)	1.59	.208
Left Calcaneal Tuberosity	12 (75%)	7 (47%)	2.62	.106
Bilateral Ankles	14 (88%)	10 (67%)	1.92	.166
Feet				
Right Plantar Fascia	0 (0%)	0 (0%)	NA	NA
Left Plantar Fascia	1 (6%)	0 (0%)	0.97	.325
Bilateral Feet	1 (6%)	0 (0%)	0.97	.325
Limbs Combined				
Bilateral Upper Extremities	0 (0%)	1 (7%)	1.10	.294
Right Lower Extremity	14 (88%)	10 (67%)	1.92	.166
Left Lower Extremity	12 (75%)	8 (53%)	1.59	.208
Bilateral Lower Extremities	15 (94%)	11 (73%)	2.39	.122
Sonographic "Risk"				
Abnormalities ≥4 Body Regions	0 (0%)	1 (7%)	1.10	.294

χ^2, Chi Square

Table 3: Prevalence of *any* sonographic abnormalities across the competitive season

Body Regions	Preseason (n=16)	Postseason (n=15)	χ^2	P
Shoulders				
Right	6 (38%)	9 (60%)	1.57	.210
Left	5 (31%)	9 (60%)	2.58	.108
Knees				
Right	11 (69%)	13 (87%)	1.42	.233
Left	12 (75%)	13 (87%)	0.68	.411
Bilateral Knees	15 (94%)	15 (100%)	0.97	.325
Ankles				
Right	13 (81%)	11 (73%)	0.28	.598
Left	12 (75%)	7 (47%)	2.62	.106
Bilateral Ankles	15 (94%)	13 (87%)	0.44	.505
Feet				
Right	0 (0%)	1 (7%)	1.10	.294
Left	1 (6%)	0 (0%)	0.97	.325
Bilateral Feet	1 (6%)	1 (7%)	0.00	.962
Limbs Combined				
Bilateral Upper Extremities	8 (50%)	10 (67%)	0.88	.347
Right Lower Extremity	15 (94%)	15 (100%)	0.97	.325
Left Lower Extremity	15 (94%)	14 (93%)	0.00	.962
Bilateral Lower Extremities	16 (100%)	15 (100%)	NA	NA
Sonographic "Risk"				
Abnormalities ≥4 Body Regions	9 (56%)	10 (67%)	0.35	.552

χ^2, Chi Square

Progression from a normal preseason to an abnormal postseason sonographic examination was found in 20 out of 120 measurements (17%) when considering all body regions combined, most of which involved tendon abnormalities. Alternatively, an improvement from an abnormal preseason to a normal postseason sonographic examination was found in 11 out of 120 measurements (9%) when considering all body regions combined, most of which involved bony abnormalities. The shoulder was the most common body region to show the progression from a normal preseason to an abnormal postseason sonographic examination, with 12 out of 30 measurements (40%). It was evenly split between the right and left sides. Alternatively, the ankle was the most common body region to show improvement from an abnormal preseason to a normal postseason sonographic examination, with 6 out of 30 measurements (20%). It was predominately on the left side, accounting for 5 of the 6 observed improvements.

Normalized tendon thickness and CSA values across the competitive volleyball season are summarized in Table 4. Comparison of the right and left limbs in each athlete revealed a significantly larger right supraspinatus tendon at pre (1.48 ± 1.37, $P < .001$) and postseason (1.33 ± 1.32, $P = .002$) with large (g = 0.73) and medium (g = 0.65) effect sizes, respectively. Additionally, a significantly larger left distal patellar tendon (1.36 ± 2.06, $P = .022$) and right

Achilles tendon (0.95 ± 1.38, P = .018) were found at the postseason with medium effect sizes (g = 0.36 and g = 0.47), respectively. No other significant interlimb tendon differences were found in pre or postseason.

MANOVA revealed significant differences across the competitive season in right Achilles tendon CSA and right plantar fascia thickness, respectively, with large and medium effect sizes. Significant differences were also found when combining CSA and thickness measurements in the right lower extremity, left lower extremity, bilateral lower extremities, and bilateral upper extremities all with medium effect sizes (Table 4). No interaction was found between tendon measurements and athletes playing ≥50% versus <50% of sets during the competitive season.

Table 4: Changes in normalized tendon thickness and cross-sectional area across the competitive season

Body Regions	Preseason (n=16)	Postseason (n=15)	P	η^2
Shoulders (mm/kg)				
Right Supraspinatus Tendon	14.6 ± 1.8	14.6 ± 1.9	.965	.000
Left Supraspinatus Tendon	13.1 ± 2.0	13.3 ± 1.9	.798	.002
Knees (mm²/kg)				
Right Proximal Patellar Tendon	20.4 ± 3.3	22.3 ± 4.0	.172	.063
Right Distal Patellar Tendon	19.9 ± 3.8	19.4 ± 3.2	.651	.007
Left Proximal Patellar Tendon	19.6 ± 3.7	21.1 ± 3.8	.275	.041
Left Distal Patellar Tendon	19.2 ± 3.6	20.8 ± 3.8	.243	.047
Ankles (mm²/kg)				
Right Achilles Tendon	12.6 ± 1.6	14.2 ± 1.9	*.020***	*.174*
Left Achilles Tendon	12.3 ± 1.5	13.3 ± 1.8	.109	.086
Feet (mm/kg)				
Right Plantar Fascia	4.1 ± 1.1	4.9 ± 1.0	*.069**	*.109*
Left Plantar Fascia	4.4 ± 1.1	4.9 ± .95	.205	.055
Body Regions Combined				
Bilateral Upper Extremities	27.7 ± 3.6	27.9 ± 3.6	.871	.001
Right Lower Extremity	36.9 ± 4.5	39.9 ± 4.4	*.072**	*.107*
Left Lower Extremity	36.1 ± 4.5	39.1 ± 3.9	*.057**	*.120*
Bilateral Lower Extremities	73.1 ± 8.6	79.1 ± 7.9	*.054**	*.123*
Bilateral Upper & Lower Extremities	100.8±9.6	107.1±9.1	*.070**	*.109*

**P < .10*

***P < .05*

η^2, partial eta squared; mm/kg, millimeters per kilogram of body mass; mm²/kg, millimeters squared per kilogram of body mass

Bivariate correlation coefficients for normalized tendon measurements and body composition variables are summarized in Table 5. Because perfect correlations (i.e., r = 1.0) were found between lean body mass and basal metabolic rate, lean body mass and total body water, and intracellular water and skeletal muscle mass, only lean body mass and intracellular water variables were included in the analysis. Fourteen large (r ≥ 0.7) and 13 medium (r ≥ 0.5 but < 0.7) significant correlations were found at preseason, most involving the Achilles tendon or combined body regions. Similarly, 8 large (r ≥ 0.70) and 3 medium (r ≥ 0.50 but < 0.70) significant correlations were found at the postseason, all involving the Achilles tendon.

Table 5: Significant associations (*P < .05*) between normalized tendon measurements and body composition analysis

Body Region vs Body Composition Variable	Preseason (n=16)	Postseason (n=13)
Shoulders (mm/kg)		
Right Supraspinatus Tendon vs Right Upper Extremity…		
-Extracellular/Total Water (%)	-.52 (-.03, -.81)	None
Knees (mm²/kg)		
Right Proximal Patellar Tendon vs Right Lower Extremity…		
-Intracellular Water (lbs)	None	-.55(-.00, -.85)
Left Proximal Patellar Tendon vs Left Lower Extremity…		
-Lean Mass (kg)	.65 (.23, .87)	None
-Intracellular Water (lbs)	.63 (.19, .86)	None
-Extracellular Water (lbs)	.68 (.28, .88)	None
Left Distal Patellar Tendon vs Left Lower Extremity…		
-Lean Mass (kg)	.58 (.11, .83)	None
-Intracellular Water (lbs)	.55 (.08, .82)	None
-Extracellular Water (lbs)	.63 (.19, .86)	None
Ankles (mm²/kg)		
Right Achilles Tendon vs Right Lower Extremity…		
-Lean Mass (kg)	.74 (.39, .91)	.72 (.28 .91)
-Lean Mass (%)	.67 (.27, .88)	.69 (.23, .90)
-Intracellular Water (lbs)	.75 (.41, .91)	.71 (.26, .91)
-Extracellular Water (lbs)	.72 (.35, .89)	.73 (.30, .91)
-Fat Mass (%)	None	-.57(-.02, -.85)
Left Achilles Tendon vs Left Lower Extremity…		
-Lean Mass (kg)	.65 (.22, .87)	.72 (.27, .91)
-Lean Mass (%)	.77 (.44, .92)	.79 (.43, .94)
-Intracellular Water (lbs)	.64 (.21, .86)	.72 (.28, .91)
-Extracellular Water (lbs)	.66 (.24, .87)	.69 (.23, .90)
-Fat Mass (%)	-.51 (-.02, -.80)	-.56(-.01, -.85)
Body Regions Combined		
Right Lower Extremity vs…		
-Right Lower Extremity Lean Mass (kg)	.51 (.01, .80)	None
-Right Lower Extremity Extracellular Water (lbs)	.53 (.05, .81)	None
Left Lower Extremity vs…		
-Left Lower Extremity Lean Mass (kg)	.72 (.35, .89)	None
-Left Lower Extremity Lean Mass (%)	.69 (.29, .88)	None
-Left Lower Extremity Intracellular Water (lbs)	.70 (.32, .89)	None
-Left Lower Extremity Extracellular Water (lbs)	.74 (.39, .91)	None
Bilateral Lower Extremity vs…		
-Bilateral Lower Extremity Lean Mass (kg)	.64 (.21, .86)	None
Bilateral Upper & Lower Extremities vs		
-Lean Body Mass (kg)	.64 (.20, .86)	None
-Intracellular Water Body (lbs)	.62 (.18, .85)	None
-Extracellular Water Body (lbs)	.65 (.23, .87)	None
-Skeletal Muscle Index Body (mm/kg²)	.56 (.08, .83)	None

Data presented as Correlation Coefficient (95% Confidence Interval)

mm/kg, millimeters per kilogram; mm²/kg, millimeters squared per kilogram; lbs, pounds; kg/mm², kilograms per meters squared

DISCUSSION

This study investigated sonographic findings in the upper and lower extremities in Division I female collegiate volleyball players across the competitive season, including associations between sonographic tendon measurements and body composition variables at pre and postseason.

These findings contribute novel data to further the understanding of the effects of training and competition on tendon health and provide insight into the potential use of high-resolution USI as a screening tool to help identify athletes at risk for developing pain or injury. Notably, this study evaluated female collegiate athletes, a majority of which identified as racial/ethnic minorities, providing data on an athletic population largely underrepresented in the scientific literature.

The results of this investigation reveal a generally high prevalence of patellar tendon abnormalities at pre and postseason, which is consistent with prior studies, including the recent work by Cushman et al. that evaluated a variety of Division I collegiate athletes and found the highest prevalence of patellar tendon abnormalities among indoor volleyball athletes.[7] This study found that sonographic abnormalities in the patellar tendon were the most common finding at pre and postseason; it also found that sonographic abnormalities in the Achilles tendon showed the largest increase from pre to postseason. Additionally, athletes in our study developed significantly larger right Achilles tendon CSA and right plantar facia thickness throughout the competitive season. This may be associated with jumping technique or approach/positioning for ball striking, as 14 out of 16 were right-handed. Overall, the number of athletes with sonographic tendon abnormalities in 4 or more body regions increased significantly from a single athlete at preseason to 7 athletes at the postseason, a potentially meaningful finding informing sport-specific training and recovery prescriptions throughout the competitive season to reduce the risk of injury and optimize athletic performance. This investigation was unique in including and tracking sonographic bony abnormalities at the various entheses evaluated, being most prevalent at the Achilles-calcaneal enthesis. Interestingly, most sonographic bony abnormalities observed during the preseason examination were resolved by postseason examination. No athletes had bony abnormalities in 4 or more body regions at preseason, and only one athlete was in the postseason.

This investigation was also unique in evaluating associations between sonographic tendon measurements and body composition variables. The strongest and most persistent correlations were pre- and postseason Achilles tendon measurements, which generally had large and significant relationships to body segment-specific lean mass and water content. While these findings suggest a relationship between Achilles tendon size and segmental muscle mass that may inform injury prevention and/or training programs, the significance of such findings remains unclear. Notably, among the several moderate and strong correlations found at preseason examination between body composition and shoulder, knee, and foot body regions – whether analyzed individually or combining extremities – all were absent at postseason examination, suggesting a disparate impact of the competitive season on tendon size and body composition.

These findings underscore the importance of monitoring sonographic tendon health in collegiate volleyball athletes across the competitive season, as abnormalities may develop and/or progress over time, potentially predisposing athletes to an increased risk of developing pain or injury [5,7,15,16]. Additionally, the observed interlimb differences in tendon size highlight the potential importance of including bilateral limb comparisons in the sonographic evaluation of an athlete to quantify ongoing changes in soft tissue morphology, which may reflect sport and/or athlete-specific adaptations to the physiological training load and demands of the competitive season [21,23,24]. This investigation's evaluation of sonographic tendon measurements and body composition variables provides potentially valuable insights into the relationship between tendon health and female athletes' physique. Future studies must clarify the relationship between body composition and sonographic tendon measurements to help elucidate underlying physiological mechanisms influencing or mediating changes in tendon health, injury risk, and performance optimization in collegiate athletes.

Limitations

First, this pilot investigation included a small sample size of female collegiate volleyball athletes, limiting our study's statistical power and the generalizability of our findings. Second, the novel method of describing and categorizing sonographic bony abnormalities may not be clinically meaningful and requires further investigation. Finally, the lack of a control group (e.g., non-jumping, non-hitting athletes) prevents comparison of sonographic findings across the competitive season in other athletic populations, limiting our findings' generalizability.

CONCLUSIONS

This pilot investigation provides novel data and insights into the effects of the competitive season on sonographic findings in the upper and lower extremities in Division I female volleyball athletes and the association between sonographic tendon measurements and body composition variables. These results inform the discussion about using USI as a screening tool to prevent injuries and optimize athletic performance and underscore the importance of regular monitoring of tendon health in athletes performing repetitive and forceful jumping and/or overhead hitting activities. Future longitudinal studies with larger sample sizes and comparison groups must elucidate the relationship between sonographic findings, body composition, athletic performance, and injury risk. Additionally, the potential for interventional approaches aimed at optimizing sport-specific tendon health and body composition with particular emphasis on mitigating injury risk and improving athletic performance should be explored to enhance the well-being and performance of all collegiate athletes.

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REFERENCES

[1] O'Rourke P. Scholarship Stats.com. 2024. https://scholarshipstats.com/volleyball

[2] Kilic O, Maas M, Verhagen E, Zwerver J, Gouttebarge V. Incidence, aetiology and prevention of musculoskeletal injuries in volleyball: A systematic review of the literature. *Eur J Sport Sci*. Jul 2017;17(6):765-793. doi:10.1080/17461391.2017.1306114

[3] Keefer Hutchison M, Patterson C, Cuddeford T, Dudley R, Sorenson E, Brumitt J. Low prevalence of patellar tendon abnormality and low incidence of patellar tendinopathy in female collegiate volleyball players. *Res Sports Med*. 2020;28(2):155-167. doi:10.1080/15438627.2019.1683559

[4] Sharif F, Ahmad A, Gilani SA, Bacha R, Hanif A. Substantiating the predictive role of ultrasound imaging in athletes with lower limb tendinopathy: a systematic review. *J Pak Med Assoc*. Mar 2023;73(3):575-588. doi:10.47391/JPMA.5187

[5] McAuliffe S, McCreesh K, Culloty F, Purtill H, O'Sullivan K. Can ultrasound imaging predict the development of Achilles and patellar tendinopathy? A systematic review and meta-analysis. *Br J Sports Med*. Dec 2016;50(24):1516-1523. doi:10.1136/bjsports-2016-096288

[6] Chan JJ, Chen KK, Sarker S, et al. Epidemiology of Achilles tendon injuries in collegiate level athletes in the United States. *Int Orthop*. Mar 2020;44(3):585-594. doi:10.1007/s00264-019-04471-2

[7] Cushman DM, Carefoot A, Corcoran B, et al. Prevalence of Sonographic Achilles Tendon, Patellar Tendon, and Plantar Fascia Abnormalities in Division I Collegiate Athletes From a Variety of Sports. *Clin J Sport Med*. Aug 4 2023;doi:10.1097/jsm.0000000000001183

[8] Ingwersen KG, Hjarbaek J, Eshoej H, Larsen CM, Vobbe J, Juul-Kristensen B. Ultrasound assessment for grading structural tendon changes in supraspinatus tendinopathy: an inter-rater reliability study. *BMJ Open*. May 24 2016;6(5):e011746. doi:10.1136/bmjopen-2016-011746

[9] Jacobson JA. *Fundamentals of musculoskeletal ultrasound*. Third edition. ed. Fundamentals of radiology series. Elsevier; 2018.

[10] Matthews W, Ellis R, Furness J, Hing W. Classification of Tendon Matrix Change Using Ultrasound Imaging: A Systematic Review and Meta-analysis. *Ultrasound Med Biol*. Oct 2018;44(10):2059-2080. doi:10.1016/j.ultrasmedbio.2018.05.022

[11] Khan KM, Forster BB, Robinson J, et al. Are ultrasound and magnetic resonance imaging of value in assessment of Achilles tendon disorders? A two year prospective study. *Br J Sports Med*. Apr 2003;37(2):149-53. doi:10.1136/bjsm.37.2.149

[12] Warden SJ, Kiss ZS, Malara FA, Ooi AB, Cook JL, Crossley KM. Comparative accuracy of magnetic resonance imaging and ultrasonography in confirming clinically diagnosed patellar tendinopathy. *Am J Sports Med*. Mar 2007;35(3):427-36. doi:10.1177/0363546506294858

[13] Westacott DJ, Minns JI, Foguet P. The diagnostic accuracy of magnetic resonance imaging and ultrasonography in gluteal tendon tears--a systematic review. *Hip Int*. 2011;21(6):637-45. doi:10.5301/HIP.2011.8759

[14] Lawrence RL, Moutzouros V, Bey MJ. Asymptomatic Rotator Cuff Tears. *JBJS Rev*. Jun 2019;7(6):e9. doi:10.2106/JBJS.RVW.18.00149

[15] Splittgerber LE, Ihm JM. Significance of Asymptomatic Tendon Pathology in Athletes. *Curr Sports Med Rep*. Jun 2019;18(6):192-200. doi:10.1249/JSR.0000000000000600

[16] Cushman DM, Petrin Z, Eby S, et al. Ultrasound evaluation of the patellar tendon and Achilles tendon and its association with future pain in distance runners. *Phys Sportsmed*. Nov 2021;49(4):410-419. doi:10.1080/00913847.2020.1847004

[17] Gnacinski SL, Meyer BB, Wahl CA. Psychometric Properties of the RESTQ-Sport-36 in a Collegiate Student-Athlete Population. *Front Psychol*. 2021;12:671919. doi:10.3389/fpsyg.2021.671919

[18] Melin A, Tornberg AB, Skouby S, et al. The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad. *Br J Sports Med*. Apr 2014;48(7):540-5. doi:10.1136/bjsports-2013-093240

[19] Sim A, Burns SF. Review: questionnaires as measures for low energy availability (LEA) and relative energy deficiency in sport (RED-S) in athletes. *J Eat Disord*. Mar 31 2021;9(1):41. doi:10.1186/s40337-021-00396-7

[20] Witkoś J, Błażejewski G, Gierach M. The Low Energy Availability in Females Questionnaire (LEAF-Q) as a Useful Tool to Identify Female Triathletes at Risk for Menstrual Disorders Related to Low Energy Availability. *Nutrients*. Jan 27 2023;15(3)doi:10.3390/nu15030650

[21] Rubio-Peirotén A, García-Pinillos F, Jaén-Carrillo D, Cartón-Llorente A, Roche-Seruendo LE. Is There a Relationship between the Morphology of Connective Tissue and Reactivity during a Drop Jump? Influence of Sex and Athletic Performance Level. *Int J Environ Res Public Health*. Feb 18 2021;18(4)doi:10.3390/ijerph18041969

[22] Salehi S, Shadmehr A, Olyaei G, Bashardoust Tajali S, Mir SM, Sobhani V. Ultrasonographic measurements of plantar fascia thickness and echogenicity in individuals with and without plantar fasciitis: Reliability and group differences. *Foot (Edinb)*. Dec 2021;49:101849. doi:10.1016/j.foot.2021.101849

[23] Wiesinger HP, Rieder F, Kösters A, Müller E, Seynnes OR. Are Sport-Specific Profiles of Tendon Stiffness

and Cross-Sectional Area Determined by Structural or Functional Integrity? *PLoS One*. 2016;11(6):e0158441. doi:10.1371/journal.pone.0158441

[24] Harput G, Toprak U, Colakoglu F, Temel E, Saylisoy S, Baltaci G. Effects of Plyometric Training on Sonographic Characteristics of Quadriceps Muscle and Patellar Tendon, Quadriceps Strength, and Jump Height in Adolescent Female Volleyball Players. *International Journal of Athletic Therapy and Training*. 01/01 2022;28:1-8. doi:10.1123/ijatt.2021-0100