Quantitative Texture and Blob Analyses on Patellar Tendon Sonographic Images of Collegiate Basketball Athletes

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(ABSTRACT)

Patellar Tendinopathy (PT), commonly called “Jumper’s Knee”, is a condition resulting from repetitive loading of the patellar tendon that presents as anterior knee pain, which is commonly seen in basketball players due to the maneuvers in the sport. Diagnosis of PT often involves a clinical exam followed by ultrasound images for confirmation of the diagnosis to look for key factors of PT. Clinical assessment of ultrasound images of tendons is subjective and requires a high level of experience for reliable interpretation. Thus, there is a need for objective, quantitative methods to assess tendon abnormalities associated with pathology. Ultrasound image texture analysis has emerged as a reliable technique to augment the utility of conventional US imaging, and has recently been shown to distinguish healthy from abnormal tendon and myofascial tissues. The objective of the present study was to conduct image texture analysis to evaluate patellar tendons of collegiate basketball athletes over two seasons.

Under an IRB-approved protocol with informed consent, a total of 33 Division 1 collegiate basketball athletes (16 male, 17 female, age 19.9 +/- 1.4 years) underwent clinical evaluation and ultrasound imaging. Four imaging sessions were collected over the course of two years (pre- and post-season). Participants were imaged using a GE LOGIQ S8 (General Electric, USA) ultrasound machine equipped with ML6-15 linear probe. At each imaging session, power Doppler images were collected in the longitudinal and transverse axis, at the proximal, central, and distal regions of the patellar tendon of both knees.

Image texture analysis was performed using a custom MATLAB (Mathworks, USA) program to obtain first order (mean, median, variance, skewness, kurtosis, entropy), second order (contrast, energy, and homogeneity), and blob analysis (blob count, BC, and blob area, BA, for 5%, 25%, 50%,

75%, and 95% thresholding values) texture parameters in each image, based upon borders manually drawn by a single researcher. Statistical analysis was conducted to compare imaging sessions (JMP Pro 16, SAS). P-values <0.05 were considered statistically significant.

Quantitative texture parameters are able to distinguish characteristics in patellar tendon ultrasound images to distinguish between anatomic region, gender, dominance and pre- to post- season. The 25% and 75% thresholding percentiles effectively showed characteristics of collagen fibers in the patellar tendon. The abnormal diagnosis does not greatly effect texture parameters, which needs to be investigated with more incorporation of grading criteria distinctions and a larger sample size.

Quantitative Texture and Blob Analyses on Patellar Tendon Sonographic Images of Collegiate Basketball Athletes

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(GENERAL ABSTRACT)

Patellar Tendinopathy (PT) is a knee injury that commonly occurs in basketball players. The recovery for PT is often long and the player can still have knee pain when returning to the sport. Diagnosis of PT requires a high level of expertise to consider the patients history, conduct a physical exam and take ultrasound images to look for factors that indicate patellar tendon is damaged. The difficulty of diagnosing PT calls for an objective method to allow for accuracy in assessing patellar tendons. In order to create a more objective measure of ultrasound images, quantitative texture parameters are explored to understand what the brightness values of each pixel and the proximity of pixels together can convey about the image. The objective of this study is to understand what characteristics of the subject (anatomic region, knee dominance, gender, and time point) texture parameters are able to distinguish in patellar tendon ultrasound images.

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1 Introduction

Patellar Tendinopathy (PT) is a common overuse injury resulting from repetitive loading of the patellar tendon and presents as anterior knee pain [6]. The condition is commonly called "Jumper's Knee" as it is common in basketball players from the power required by the patellar tendon for the jumping, landing, cutting, and pivoting maneuvers in the sport [7]. The patellar tendon is a continuation of the quadriceps muscle and tendon, which is extended in jumping, that goes across that patella. The proposed mechanism for PT is micro-tearing due to the repetitive movement of sports, which shows in the inferior pole of the patella where the patellar tendon inserts [8]. In early stages of PT, adequate rest and eccentric strengthening exercises are able to heal the tendon and the pain to subside, but PT is more difficult to manage as the disease becomes more advanced [9]. In a study on male collegiate basketball players, about 33% of players present with PT and were unable to return to the sport for more than six months [10]. Coincidingly, about 53% of athletes with jumper's knee retired from their sport due to their knee pain [11]. Women are more susceptible to injury due to their tendons responding less to mechanical loading and less mechanical strength [12]. Patellar tendon force in the dominant limb is significantly higher than the non dominant limb when performing stop-jump landing, which could potential cause more loading in the dominant limb [13], but structural changes in the patellar tendon have not been detected due to this difference in loading using ultrasound images [14].

Ultrasonography (US) is an accurate, quick and inexpensive imaging modality that is frequently used for confirming the clinical diagnosis of PT [15] [16]. Normal patellar tendons show distinct, parallel aligned, slightly wavy collegen fibers in the longitudinal view [17]. Ultrasound images show key factors of PT: darker (hypoechoic) lesions, disruption of the collagen fibers, tendon thickening (compared to normal state), marginal blurring, and neovascuralirization, examples seen in Figure 1 [16] [18] [19]. The clinical grading criteria used in research does not correlate with the presentation of the disease and the severity of symptoms that the clinician determines. The interpretation of ultrasound results for tendon structure (r = 0.379-0.837) and neovascularization (r = 0.767-0.992) is seen to have moderate reliability between operators, using the spearman correlation coefficient

[20]. Also, intra-observer reliability for tendon structure (k = 0.537-0.873) and neovascuralization (k = 0.639-0.864) shows moderately strong correlation, using the kappa correlation coefficient [20]. An objective method of evaluating ultrasound images is needed to improve reliability of analyzing the patellar tendon.

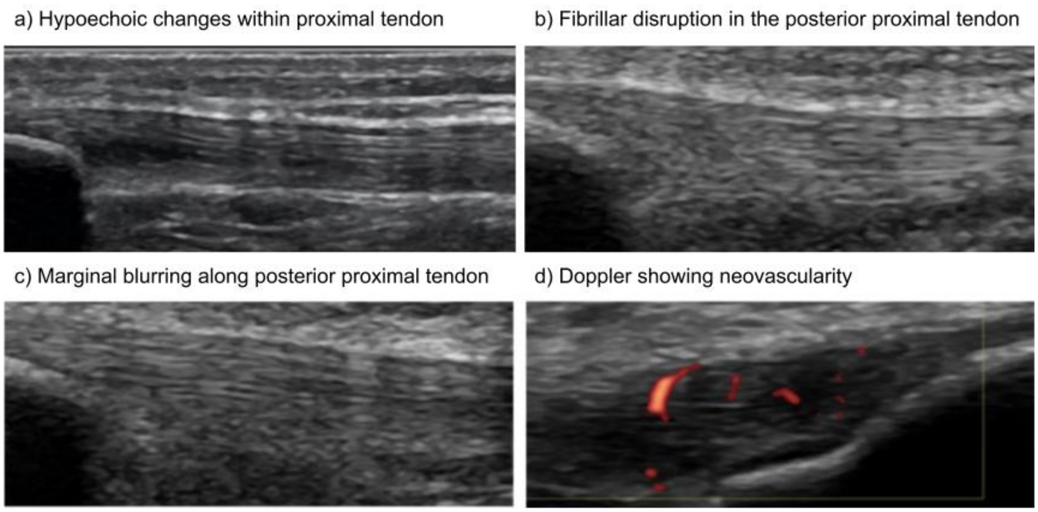

Figure 1: Examples of key factors in ultrasound images of PT. Longitudinal Greyscale-US (a, b, c) and Power Doppler (d) [1]

The impact and prevalence of this condition in basketball allows for more exploration to be vital for better preventative and rehabilitation measures. The interpretation of ultrasound images for an accurate diagnoses of PT requires considerable experience. Quantitative ultrasound analysis could provide an objective evaluation of patellar tendons to aid in the accuracy of PT diagnosis to help with earlier interventions.

Quantitative ultrasound analysis can be used to evaluate muscle tissues using the brightness of the pixel values, called the echogenicity (0 (black) to 255 (white)), and shown to give reliable measurements for identifying structures in the biceps and supraspinatus tendons [5]. Using three scanning sites in two directions, the quantitative analysis of ultrasound images using first order grey scale statistics has been evaluated on the supraspinatus tendon, showing the sensistivity of the parameters to detect tissue composition [21]. Regions of interest (ROI) are used to extract the echogenicities of the specific structure in focus from the image. First order statistics (mean, median, variance, skewness, kurtosis, and entropy) are computed using a grey scale histogram distribution for the ROI, descriptions included in Table 1 [4]. Second order statistics (contrast, homogeneity, and energy) are calculated using a co-occurrence matrix, which uses specific grey scale values, predefined distance, and predefined angle to define a spatial relationship to determine the occurrence of the arrangement of pixels for the ROI, descriptions included in Table 1.

Table 1 Description and formulas for 1st and 2nd Order Statistics. A(x,y) is the greyscale matrix in the ROI. p(i,j) is the grey level co-occurrence matrix comparing the probability i and j intensity values being adjacent. [4].

		Formula	Description
1st Order Statistics	Mean	$\mu = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} A(x,y)$	Average pixel value.
	Median		Middle pixel value.
	Variance	$\sigma^2 = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}\{A(x,y)-\mu\}^2$	Dispersion of pixel values around the mean.
	Skewness	$S_k = \frac{1}{MN\,\sigma^3}\sum_{x=1}^{M}\sum_{y=1}^{N}\{A(x,y)-\mu\}^3$	Asymmetry in the distribution of the pixel values. Zero indicates a symmetrical distribution, a positive coefficient indicates skewed to the left, and a negative coefficient indicates skewed to the right.
	Kurtosis	$K_t = \frac{1}{MN\,\sigma^4}\sum_{x=1}^{M}\sum_{y=1}^{N}\{A(x,y)-\mu\}^4$	Flatness of the pixels around the mean. A lower kurtosis values indicates a flatter appearance and a higher value indicates a concentration around the mean.
	Entropy	$E = -\sum_{i=0}^{255}\sum_{j=0}^{255} p(i,j)\log_2 p(i,j)$	Disorder within the ROI. Considers the number and proportions of the grey scale levels.
2nd Order Statistics	Contrast	$I_{con} = \sum_{i=0}^{255}\sum_{j=1}^{255} \lvert i-j\rvert^2\, p(i,j)$	Pixel intensity differences be-tween a pixel and its neighbor. Less contrast with less local variation. More contrast with large amounts of rapid variation.
	Homogeneity	$I_{hmg} = \sum_{i=0}^{255}\sum_{j=0}^{255} \frac{1}{1+(i-j)^2}\, p(i,j)$	Similarity in the image with grey scale levels and small transitions in grey scale
	Energy	$I_{eng} = \sum_{i=0}^{255}\sum_{j=0}^{255} p(i,j)^2$	Measures the consistency of patterns in the image. Larger energy shows a patterned constantly and steadily throughout the image. Lower energy shows a random image with little pattern.

Blob analysis is a higher order quantitative measure used on medical images to separate the pixels into regions of similar pixel values. Blob analysis has been able to be used to distinguish differences in pain interventions for myofascial pain and a healthy group in the trapezius muscle using blob count and blob size changes [22]. Specifically, after treatment for myofascial pain mean blob size decreased on both the right and left sides, and blob count decreased on the left side [22]. The use of blob analysis in PT might be well suited to see the disruption of collagen fibers and hypoechoic regions in the ultrasound image through the grouping of pixels (blobs) in a binary image. This could quantify the spatial relationship of pixels in the ultrasound image that 1st and 2nd order texture parameters are unable to identify. Blob analysis has been used in the supraspinatus and vastus lateralis muscle using the thresholding values of the 25% - 75% quartiles from a healthy control group to look at the contractile and non-contractile diversity [2]. In this study, more and larger blobs were seen to be in a unhealthy shoulder patient compared to the healthy group, and the blob count and size differed between each of the imaging locations [2]. Another study used the methods of Nielson et al. to study myofascial pain in the trapezius with thresholding of pixels between the 95th percentile and 99th percentile [23]. In this study, blob size increased and blob count decreased in the unhealthy group compared to the healthy group [23]. Thresholding is an important factor to consider as it determines how the image is segmented to show the different structures in the tissue image. These studies are the basis of choosing the thresholding levels of 5%, 25%, 50%, 75%, and 95% to study the patellar tendon in the current investigation.

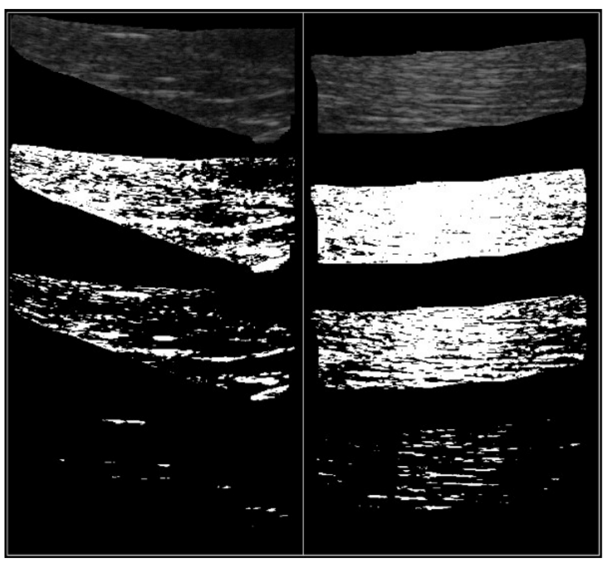

Figure 2: Ultrasound ROI for medial supraspinatus (left) and vastus lateralis (right). The 25%, 50% and 75% thresholding percentile binary images for blob analysis in Nielson et al. [2]

The overall purpose of this study is to evaluate the utility of blob analysis in patellar tendons in a population of participants prone to PT.

Aim 1: Investigate how texture parameters vary with anatomic region (proximal, central, and distal), gender, leg dominance, and longitudinally (pre- and post- season). This aim will allow us to observe the structural changes in the patellar tendon through texture parameters with factors known to effect PT. The 1st order statistics (mean, median, variance, skewness, kurtosis, and entropy), 2nd order statistics (contrast, homogeneity, and energy), and blob analysis (blob count and mean blob area) will be used to analyze the images. **We hypothesize that texture parameters will vary significantly with each of these four factors.**

Aim 2: Investigate the sensitivity of blob analysis to different thresholding percentiles. The use of blob analysis has not been investigated in the patellar tendon. So, understanding how blob analysis parameters differ with thresholding values allow for a preliminary validation of the methods. Thresholding values of <5%, <25%, <50%, >50%, >75% and >95% will be used to calculate blob count and mean blob area for each image. **We hypothesize that different thresholding percentiles will show differences in blob count and mean blob area.**

Aim 3: Investigate how texture parameters change in abnormal and normally diagnosed ultrasound images of the patellar tendon. This aim is focused on the utility of texture parameters for clinical diagnosis of PT. The images were classified as abnormal or normal based on tendon echogenicity, marginal blurring, tendon collagen linearity, neovascularity, tendon thickness, and tendon cross sectional area, which are parameters that indicate PT. **We hypothesize that texture parameters will differ between images defined as abnormal versus normal.**

2 Methodology

2.1 Ultrasound Image Collection and Segmentation

Under an IRB-approved protocol with informed consent, 33 members of a collegiate Division I basketball team (16 male, 17 female, age 19.9 +/- 1.4 years) underwent clinical evaluation and ultrasound imaging four times over the course of two years (November 2017, April 2018, October

2018, and April 2019). Each of the athletes were not imaged in all four of the imaging sessions. Participants were imaged using a GE LOGIQ S8 (General Electric, USA) ultrasound machine equipped with ML6-15 (4-15 MHz, 50mm) linear probe at the beginning and end of each season. Images were taken while the participant is sitting supine with a knee flexion of approximately 30 degrees using a wedge pillow. The participants laid in this position for 5 minutes in order for the elastic modulus of the muscle and tendon to be at rest. At each imaging session, power Doppler images were collected in the longitudinal and transverse axis, at the proximal, central, and distal regions of the patellar tendon of both knees resulting in 7 views (Proximal Central Longitudinal, Proximal Transverse 1, Proximal Transverse 2, Central Longitudinal, Central Transverse, Distal Longitudinal, and Distal Transverse), shown in Figure 3

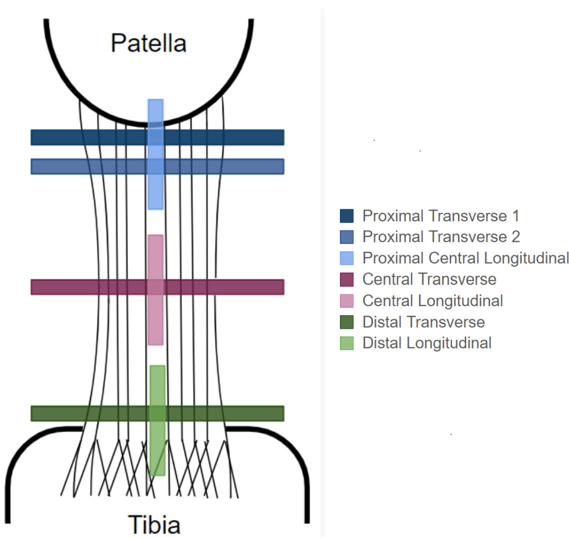

Figure 3: Imaging Session Patellar Tendon Imaging Views

Using a custom MATLAB (Mathorks, USA) program, included in Appendix B, the ROI for all of the ultrasound images was sectioned using the polygon tool to manually extract the patellar tendon echogenicity values for analysis. All color pixels in the power Doppler image are excluded from the analysis. The ROI's were segmented by one investigator (SC) with guidance from clinicians and a medical student. The echogenicity values within the ROI were used for the analysis, as described in Table 2.

Table 2 Subject and Image Summary for each Imaging Session

	November 2017	April 2018	October 2018	April 2019	
Number of Subjects	9	20	21	13	
Number of Images	125	280	293	175	873

2.2 1st and 2nd Order Statistics

Image texture analysis was performed using a custom MATLAB program to obtain first order (mean, median, variance, skewness, kurtosis, entropy) and second order (contrast, energy, and homogeneity) texture parameters of the patellar tendon in each image, based upon the ROI's. A histogram of the pixel intensity values, seen in Figure 4, is used to calculate 1st order statistics. The co-occurence matrix was calculated using pixel distance of 5, a relative orientation angle of 180 degrees (perpendicular), and binned into 8 levels for the matrix, which was based on the images [24]. An example of how grey level co-occurrence matrices are calculated is seen in Figure 5.

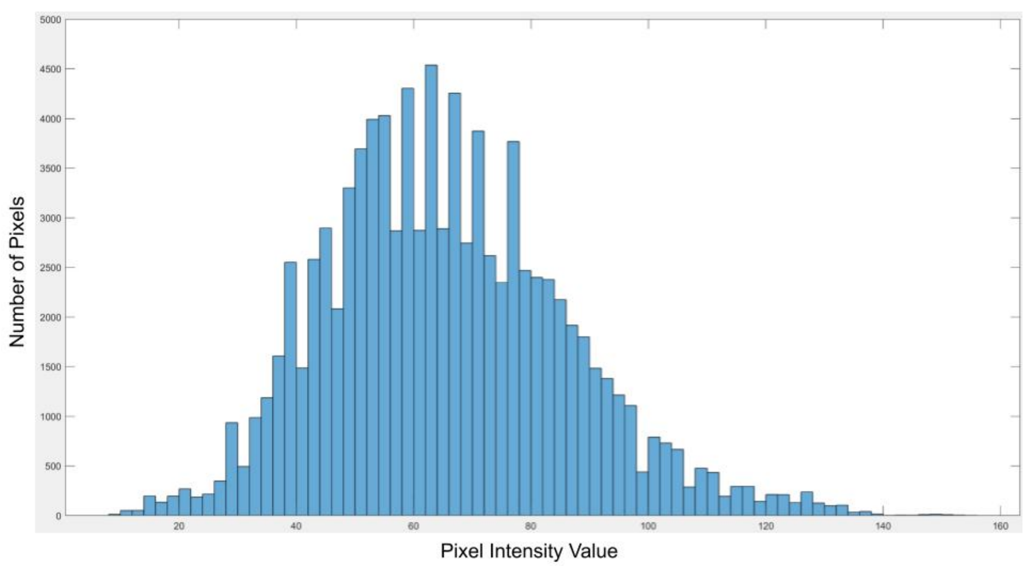

Figure 4: Histogram Example of a Distal Longitudinal Image Post Season

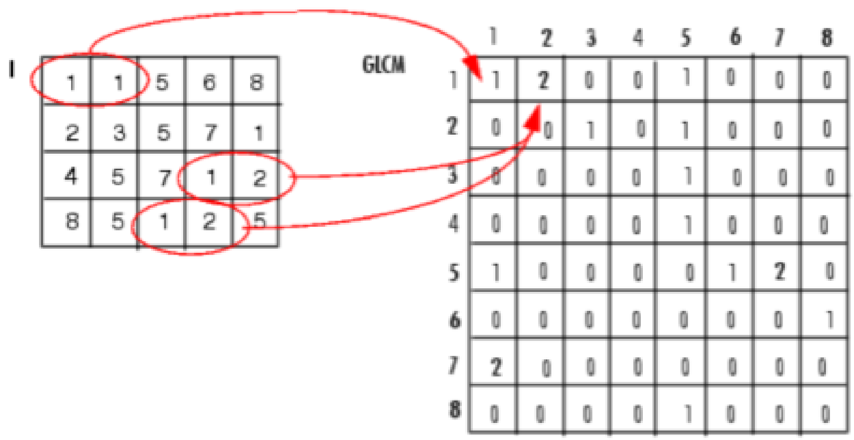

Figure 5: Grey Level Co-Occurrence Matrix Example [3]

2.3 Blob Analysis

In accordance with Neilson et al. (2006), all images were filtered using a 3 x 3 median filter in order to reduce pixel noise. Using 5 different thresholding levels (lowest 5%, lowest 25%, lowest 50%, highest 50%, highest 25% and highest 5%) binary images were created by assigning pixel values to either 0 or 1. Blob count (BC) and mean blob area (BA) (mm^2) were calculated in the specified region of interest.

$$s = \frac{1}{n}\sum_{j=1}^{n} p_j \tag{1}$$

where p_j is the number of pixels in blob **j** in the image and **n** is the number of blobs [2].

2.4 Abnormality Classification

From a previous study, longitudinal images from the women's basketball team have been classified by our clinician co-authors as abnormal or normal based on tendon echogenicity, marginal blurring, tendon collagen linearity, neovascularity, tendon thickness, and tendon cross sectional area [1]. If the image is identified to have any of the grading criteria above zero in Table 3, then it was declared abnormal.

Table 3 Grading Criteria and measurement methods for abnormal and normal declaration [1]

Grading Criteria	
Tendon Echogenicity (4-Grade Ohberg Scale)	Grade 0 - Normal Grade 1 - Focal hypoechoic ($< 50\%$) Grade 2 - Diffuse hypoechoic ($> 50\%$) Grade 3 - Focal mixed hypoechoic / hyperechoic ($< 50\%$) Grade 4 - Diffused mixed hypoechoic / hyperechoic ($> 50\%$)
Marginal Blurring	Yes or No
Tendon Collagen Linearity (Looking at fibrillar disruption)	Grade 0 - None Grade 1 - Focal ($< 50\%$) in width image Grade 2 - Diffuse ($> 50\%$) in width image
Neovascularity (4-Grade Ohberg Scale)	Grade 0 - no vessels Grade 1 - 1 or more vessel(s) (anterior or posterior to tendon) Grade 2 - 1 or 2 vessels (throughout vessels) Grade 3 - 3 vessels (throughout vessels) Grade 4 - 4 or more vessels (throughout vessels)
Tendon Thickness (Measured Anterior to Posterior)	Normal Thickness Abnormal Thickness
Tendon Cross Sectional Area (Tracing Measurement Software)	Normal Cross Sectional Area Abnormal Cross Sectional Area

2.5 Statistical Analysis

Statistical analyses were conducted using JMP (JMP Pro 16, SAS) mixed effects models. Variance within the subjects in each testing group was considered in each of the statistical analysis. For testing the anatomic region, images were divided into the proximal, central, and distal regions for all images including the longitudinal and transverse views, seen in Figure 3. Each of the seven testing groups are analyzed using a repeated measures mixed effects model statistical analysis to understand what texture parameters differed between the three regions imaged. The limb dominance comparison used a mixed effects model to understand whether texture parameters differed between the subjects dominant limb and non-dominant limb that they self reported during their imaging session. The seven testing groups are analyzed using a mixed effects model to understand whether texture parameters were increased or decreased in the limbs. The seven testing groups are used for the anatomic region and dominance analyses while the other factors of gender and time point are fixed. The gender comparison uses a three testing groups of the session where females and males were both imaged. A mixed effects model with gender defined as an in-between variable is used to understand how texture parameter differ between male and female. In order to compare time point pre- to post- season, three testing groups (2 female and 1 male) are use in a statistical analysis to understand how texture parameters differ pre- to post- season. were used to compare the differences in texture parameters.

A repeated measures post HOC tukey test is used to in order to understand where the differences are for each of the thresholding percentiles with BC and BA. One testing group (Session 3 Females) is used for the statistical analysis in order to have a controlled group for analyzing.

A mixed effects model with an in-between variable is used to understand the texture parameters that compare images graded clinically as abnormal and normal. One testing group (Session 3 Females) is used for the statistical analysis in order to have a controlled group for analyzing. The analysis groups are defined in Table 4.

Table 4 Testing groups for statistical analysis. (S1F = Session 1 Females)

	Factor	Testing Group(s)	Total Number of Testing Groups	Statistical Analysis
Aim 1	Anatomic Region	S1F, S2F, S2M, S3F, S3M, S4F, S4M	7	Repeated Measures Mixed Effects Model
	Dominance	S1F, S2F, S2M, S3F, S3M, S4F, S4M	7	Mixed Effects Model
	Gender	S2F&S2M, S3F&S3M, S4F&S4M	3	In-Between subjects, Mixed Effects Model
	Time Point	S1F to S2F, S3F to S3M, S4F to S4M	3	In-Between subjects, Mixed Effects Model
Aim 2	Thresholding Percentiles Sensitivity	S3F	1	Repeated Measures Mixed Effects Model, Tukey Post HOC Test
Aim 3	Abnormality	S3F	1	In-Between subjects, Mixed Effects Model

P-values < 0.05 were considered statistically significant.

3 Results

3.1 Aim 1: Comparison of Anatomic Region, Gender, Leg Dominance, and Time point

For the anatomic region comparison analysis, the seven testing groups were separated into their dominant and non-dominant limbs. A p-value below 0.05 indicates the defined texture parameter exhibits a significant difference amoung the proximal, central, and distal region, as seen in Table 5. Overall, the anatomic regions have significant differences in all the texture parameters of the testing groups for both the dominant and non-dominant sides. The dominant limb showed a total of 64 significant difference and the non-dominant limb showed a total of 70 significant difference for all of the seven testing groups.

Table 5 Anatomic Region Analysis Summary. Indicates how many of the seven testing groups showed significant differences. BC = Blob Count. BA = Blob Area.

Parameter	Dominant	Non-Dominant
Mean	7 (100%)	7 (100%)
Median	7 (100%)	7 (100%)
Variance	1 (14.3%)	4 (57.1%)
Skewness	1 (14.3%)	1 (14.3%)
Kurtosis	1 (14.3%)	0 (0%)
Entropy	3 (42.9%)	1 (14.3%)
Contrast	7 (100%)	7 (100%)
Energy	0 (0%)	5 (71.4%)
Homogeneity	7 (100%)	6 (85.7%)
BC < 5%	4 (57.1%)	3 (42.9%)
BC < 25%	2 (28.6%)	3 (42.9%)
BC < 50%	1 (14.3%)	0 (0%)
BC > 50%	2 (28.6%)	1 (28.6%)
BC > 75%	3 (42.9%)	4 (57.1%)
BC > 95%	6 (85.7%)	5 (71.4%)
Avg BA < 5%	1 (14.3%)	3 (42.9%)
Avg BA < 25%	1 (14.3%)	3 (42.9%)
Avg BA < 50%	3 (42.9%)	0 (0%)
Avg BA > 50%	1 (14.3%)	3 (42.9%)
Avg BA > 75%	3 (42.9%)	4 (57.1%)
Avg BA > 95%	3 (42.9%)	3 (42.9%)

For the gender comparison analysis, the three testing groups were separated into their dominant and non-dominant limbs for analysis, seen in Table 4. A p-value below 0.05 indicates the defined texture parameter differs between male and female subjects, as seen in Table 6 and 7. A total of 45 significant differences for the dominant limb while 35 significant differences were noted for the non-dominant limb.

Table 6 Dominant Leg Gender Comparison. X = Male is significantly less than Female. * = Male is significantly greater than Female. 1 = Session 2 Females and Males, 2 = Session 3 Females and Males, and 3 = Session 4 Females and Males.

	Proximal									**Central**						**Distal**					
	Long			**Trans 1**			**Trans 2**			**Long**			**Trans**			**Long**			**Trans**		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	X			X									X			X			X		
Median	X			X									X			X			X		
Variance												*									
Skewness								X													
Kurtosis																	*				
Entropy	*			*			*	*								*				*	
Contrast																					
Energy																					
Homogeneity																					
BC < 5%																	*				*
BC < 25%							*	*													
BC < 50%								*			*							*			
BC > 50%							*									*	*			*	
BC > 75%																*	*				*
BC > 95%				*				*													
Avg BA < 5%										X											
Avg BA < 25%	*															*					
Avg BA < 50%	*			*													X				
Avg BA > 50%					*						X								*		
Avg BA > 75%																					
Avg BA > 95%													*								

Table 7 Non Dominant Leg Gender Comparison. X = Male is significantly less than Female. * = Male is significantly greater than Female. 1 = Session 2 Females and Males, 2 = Session 3 Females and Males, and 3 = Session 4 Females and Males.

	Proximal									Central						Distal					
	Long			Trans 1			Trans 2			Long			Trans			Long			Trans		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	X	X					X														
Median	X	X					X												*		
Variance				*																	
Skewness																					
Kurtosis															*	*					
Entropy							*						*								
Contrast																					
Energy				X											*						
Homogeneity																					
BC < 5%														*	*						
BC < 25%								*						*							
BC < 50%						*		*					*								
BC > 50%																					
BC > 75%														*							
BC > 95%								*					*		*			*			
Avg BA < 5%						*	*						*								
Avg BA < 50%													*								
Avg BA < 50%										*											
Avg BA > 50%										*											
Avg BA > 75%				*									*				X				
Avg BA > 95%																					

For the leg dominance comparison analysis, the seven testing groups were analyzed to understand the difference in texture parameters between their dominant and non-dominant sides. The seven testing groups can be seen in Table 4. A p-value below 0.05 indicates the defined texture parameter is significantly different for dominant and non-dominant side, as seen in Table 8. A total of 49 parameters exhibited significant differences for all testing groups.

Table 8 Dominance Comparison Summary. Decrease = Parameter is significantly less than that of the dominant leg. Increase = Parameter is significantly greater than the dominant leg

	Proximal						Central				Distal			
	Long		Trans 1		Trans 2		Long		Trans		Long		Trans	
Parameter	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**
Mean	1 (14.3%)												1 (14.3%)	
Median						1 (14.3%)						1 (14.3%)		
Variance								1 (14.3%)						
Skewness						1 (14.3%)					1 (14.3%)			
Kurtosis				1 (14.3%)							1 (14.3%)		1 (14.3%)	1 (14.3%)
Entropy			1 (14.3%)						1 (14.3%)					
Contrast														1 (14.3%)
Energy				1 (14.3%)	1 (14.3%)	1 (14.3%)			1 (14.3%)					1 (14.3%)
Homogeneity							1 (14.3%)		1 (14.3%)					
BC < 5%									1 (14.3%)			1 (14.3%)		
BC < 25%											1 (14.3%)			
BC < 50%				1 (14.3%)	1 (14.3%)			2 (28.6%)			1 (14.3%)			
BC > 50%					1 (14.3%)				1 (14.3%)		1 (14.3%)			
BC > 75%		1 (14.3%)												
BC > 95%										1 (14.3%)				1 (14.3%)
Avg BA < 5%							1 (14.3%)				1 (14.3%)			
Avg BA < 25%								1 (14.3%)				1 (14.3%)		
Avg BA < 50%			1 (14.3%)	1 (14.3%)			2 (28.6%)							1 (14.3%)
Avg BA > 50%						1 (14.3%)		1 (14.3%)		2 (28.6%)		1 (14.3%)		
Avg BA > 75%								1 (14.3%)			1 (14.3%)			
Avg BA > 95%														1 (14.3%)

For the longitudinal comparison, the three testing groups were compared pre- and post- season for their dominant and non-dominant sides for each anatomic region. A p-value below 0.05 indicates the defined texture parameter is different between the athletes pre-season and post-season, seen in Table 9 and Table 10. Eighty texture parameters in the dominant leg and eighty texture parameters in the non-dominant leg show significant differences

Table 9 Dominant Leg Time Point Comparison. X = Parameter is significantly less than that of Pre-season. * = Parameter is significantly greater than that of Pre-season

	Proximal									**Central**						**Distal**					
	Long			**Trans 1**			**Trans 2**			**Long**			**Trans**			**Long**			**Trans**		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	X			X			X			X			X			X					
Median	X			X			X			X			X			X					
Variance	X			X			X		*	X			X		*	X			X		
Skewness							*														
Kurtosis							*														
Entropy	X	X		X			X			X	X		X			X					
Contrast				X			X			X											
Energy	*			*			*			*						*			*		
Homogeneity				*			*														
BC < 5%				X								X				X					
BC < 25%				X			X					X				X					
BC < 50%	X			X			X			X			X			X	X	X			
BC > 50%				X			X			X		X	X			X	*				
BC > 75%	X			X			X									X					
BC > 95%	X			X			X			X						X					
Avg BA < 5%															*						
Avg BA < 25%																					
Avg BA < 50%					*					X							*				
Avg BA > 50%										X							X				
Avg BA > 75%		X																			
Avg BA > 95%																					

Table 10 Non Dominant Time Point Comparison. X = Parameter is significantly less than that of Pre-season. * = Parameter is significantly greater than that of Pre-season

	Proximal									**Central**						**Distal**					
	Long			**Trans 1**			**Trans 2**			**Long**			**Trans**			**Long**			**Trans**		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	X			X			X			X			X			X			X		
Median	X			X			X			X			X			X			X		
Variance	X	X		X			X			X			X			X	*		X		
Skewness				*	*																*
Kurtosis				*									*								
Entropy	X	X					X			X	X		X			X			X		
Contrast	X			X			X			X			X			X					
Energy	*			*			*			*			*			*	X				
Homogeneity				*			*			*			*								
BC < 5%					*																
BC < 25%							X				X	X				X		X	X		
BC < 50%	X						X			X			X						X		
BC > 50%	X									X						X			X		
BC > 75%												X				X					
BC > 95%	X									X	X		X			X	X				
Avg BA < 5%																					
Avg BA < 25%																					
Avg BA < 50%										X											
Avg BA > 50%																					
Avg BA > 75%																					
Avg BA > 95%	*	X																			

3.2 Aim 2: Blob Analysis Thresholding Percentile Sensitivity

The thresholding percentiles for each image view show differences between BC and BA, shown in Tables 11 - 17. The BC and BA were able to show trends for each of the imaging views of the patellar tendon, such as the <5% and >95%, <25% and >75%, and <50% and >50% to be similar to each other.

Table 11 Thresholding Percentile Tukey Statistical Analysis for Proximal Central Longitudinal Images. Least Sqaures Mean (LSM) represents the measn for the group adjusted for the model. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey				BA - LSM	BA - Tukey			
<5	31.33			C	D	140.28				D
<25	44.67	A	B			436.47			C	
<50	31.94			C	D	1188.14	A			
>50	37.44		B	C		1003.72		B		
>75	45.78	A				354.67			C	
>95	28.17				D	132.26				D

Table 12 Thresholding Percentile Tukey Statistical Analysis for Proximal Transverse 1 Images. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey			BA - LSM	BA - Tukey			
<5	18.28			C	134.54			C	D
<25	28.33		B		469.29		B		
<50	24.11		B	C	923.51	A			
>50	27.28		B		791.85	A			
>75	39.78	A			274.38			C	
>95	29.78		B		69.33				D

Table 13 Thresholding Percentile Tukey Statistical Analysis for Proximal Transverse 2 Images. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey				BA - LSM	BA - Tukey				
<5	21.5			C	D	114.44				D	E
<25	30.94		B			367.53			C		
<50	19.56				D	1094.95	A				
>50	28.61		B			773.86		B			
>75	42.5	A				236.84			C	D	
>95	26.67		B	C		74.57					E

Table 14 Thresholding Percentile Tukey Statistical Analysis for Central Longitudinal Images. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey Test				BA - LSM	BA - Tukey				
<5	41.00		B	C		113.29				D	E
<25	49.83	A				348.78			C		
<50	32.00				D	1358.26	A				
>50	45.11	A	B			887.74		B			
>75	49.56	A				332.36			C		
>95	35.33			C	D	117.42				D	E

Table 15 Thresholding Percentile Tukey Statistical Analysis for Central Transverse Images. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey			BA - LSM	BA - Tukey				
<5	22.78			C	123.26				D	E
<25	32.83		B		357.6			C		
<50	22.11			C	1022.202	A				
>50	29.28		B		747.41		B			
>75	42.83	A			242.49			C	D	
>95	30.17		B		69.08					E

Table 16 Thresholding Percentile Tukey Statistical Analysis for Distal Longitudinal Images. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey			BA - LSM	BA - Tukey		
<5	26.22			C	178.38			C
<25	39.67	A			478.68		B	
<50	35.56	A	B		1104.17	A		
>50	31.06		B	C	1175.30	A		
>75	40.06	A			447.67		B	
>95	26.67		B	C	136.46			C

Table 17 Thresholding Percentile Tukey Statistical Analysis for Distal Transverse Images. A parameter with the same letter indicates no statistical difference detected.

	BC - LSM	BC - Tukey			BA - LSM	BA - Tukey				
<5	20.11			C	137.60				D	E
<25	27.94		B		471.06			C		
<50	19.56			C	1214.75	A				
>50	24.78		B	C	927.96		B			
>75	36.28	A			307.12			C	D	
>95	24.00		B	C	89.27					E

3.3 Aim 3: Abnormality Comparison Analysis

The number of abnormal and normal images for each image view is included in Table 18. A total of 3 significant difference were noted when comparing images by clinical label, seen in Table 19. The distal longitudinal view could not be analyzed on the non-dominant leg due to all the images being declared abnormal. Three significant differences are calculated for the abnormality statistical analysis.

Table 18 Number of Abnormal and Normal Images for the Longitudinal Images

	Dominant			**Non-Dominant**		
	Proximal	**Central**	**Distal**	**Proximal**	**Central**	**Distal**
Abnormal	5	4	7	6	3	8
Normal	3	4	1	2	5	0

Table 19 Abnormality Comparison for Longitudinally Images. Numeric values represent p-values.

	Dominant			**Non-Dominant**	
	Proximal	**Central**	**Distal**	**Proximal**	**Central**
Mean	0.8078	0.8694	0.8264	0.338	0.0933
Median	0.8089	0.8654	0.7794	0.3404	0.1068
Variance	0.3189	0.077	0.3386	0.7486	0.178
Skewness	0.1033	0.9342	0.7252	0.1895	0.3521
Kurtosis	0.2658	0.5757	0.3703	0.2553	0.3242
Entropy	0.9632	0.5738	0.1886	0.808	0.7911
Contrast	0.643	0.8101	0.6893	0.7322	0.0434
Energy	0.2457	0.406	0.4876	0.7484	0.0651
Homogeneity	0.402	0.8787	0.9312	0.7269	0.004
BC < 5%	0.3512	0.2496	0.6141	0.3443	0.6796
BC < 25%	0.465	0.3559	0.7834	0.5359	
BC < 50%	0.6244	0.1335	0.1572	0.396	0.8866
BC > 50%	0.4879	0.1848	0.8447	0.892	0.9193
BC > 75%	0.7731	0.3559	0.6708	0.4123	
BC > 95%	0.5223	1	0.3823	0.6759	0.84
Avg BA < 5%	0.3809	0.509	0.7686	0.4187	0.4838
Avg BA < 25%	0.4257	0.9689	0.3182	0.5902	0.539
Avg BA < 50%	0.0681	0.267	0.4953	0.3861	0.2197
Avg BA > 50%	0.4618	0.2462	0.3228	0.9418	0.9589
Avg BA > 75%	0.47	0.0876	0.5593	0.0324	0.9225
Avg BA > 95%	0.4977	0.8062	0.7318	0.767	0.7954

4 Summary, Conclusions, Discussion and Recommendations

4.1 Discussion

For a healthy tendon, ultrasound images should show symmetrical and bright aligned collagen fibers spanning longitudinally. For the 1st and second order statistics, the expectations correspond with these assumptions for the ultrasound image, as seen in Table 20.

Table 20 Healthy tendon texture parameter indications [5]

Variable	Expectation	Reasoning
Mean/Median	Larger	Brighter
Variance	Larger	Wider histogram
Skewness	Smaller	Less skewed. Symmetrical brightness
Kurtosis	Smaller	Flatter apperance
Entropy	Larger	More heterogenous
Contrast	Larger	More rapid variation in pixel values
Energy	Smaller	More consistent patterns
Homogeneity	Smaller	Spatial texture increases

The anatomic region comparison showed significant differences among 43.5% of the texture parameters in the dominant limb and significant difference among 47.6% of the texture parameters in the non-dominant limb of the texture parameter between the proximal, central, and distal views for all of the twenty-one parameter and seven testing groups. The mean, median, contrast, energy, and BC ($> 95\%$) are the texture parameters that showed statistically differences in at least six of the seven testing groups for the dominant and non-dominant sides. The proximal, central, and distal regions of the patellar tendon have seen difference in cross sectional area and advanced glycation end-products, which corresponds with increased cross-linking, changes in the most proximal and most distal section of the patellar tendon in adults who perform long term strength training [25].

PT is known to present in the inferior pole of the patella, which is in the proximal tendon region. These results indicate heterogeneity in texture parameters by anatomic region. On the basis of the results, it texture analysis of the patellar tendon should be conducted separately by anatomic region.

The gender comparison showed statistically significant changes in forty-five of the four hundred forty-one (10.2%) texture parameters in the dominant limb and thirty-five of the four hundred forty-one (7.9%) texture parameters in the non-dominant limb. The mean and median are seen to decrease in five of all of the twenty-one (23.8%) testing groups for all of the seven imaging views for the dominant side and three (14.3%) for the non-dominant side. This could indicate that male patellar tendons are less bright than female patellar tendons. Even though the echogenicity is seen to be brighter, the entropy is larger in males compared to females in six of the twenty-one (28.6%) total testing groups for the dominant side and larger in two of the twenty-one (9.5%) total testing groups for the non-dominant side. This is corresponds to the male patellar tendon being less bright and the differences between fibers are more heterogeneous. The blob count shows significant increases in sixteen (76.2%) in the testing groups for the dominant limb and twelve (57.1%) in the non-dominant limb, which could indicate more contrast in the male patellar tendon. An example of blob analysis between male and female can be seen in Figure 6. These seen difference in the quantitative texture parameters indicate that gender should be a parameter in consideration in analyses.

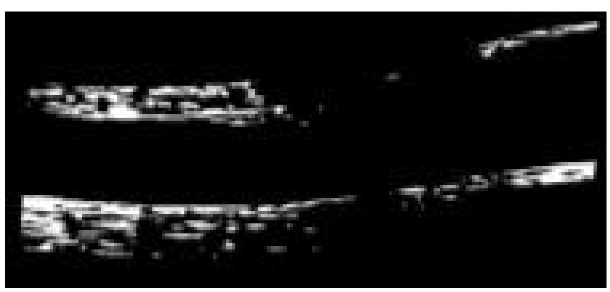

Figure 6: Distal Longitudinal view for Female (Top) and Male (Bottom) for Blobs with > 75% Thresholding Percentile in Testing group 1

Interestingly, only forty-nine out of one thousand twenty-nine (4.76%) differences are detected between the dominant and non-dominant legs for all seven testing groups and for all the texture parameters. In a healthy control group, no significant difference were detected between the dominant and non-dominant when looking at patellar tendon morphology and elastic properties [26]. The athletes in this study self reported their leg dominance. In a separate study looking into the correlation between self reported leg dominance and observed leg dominance, the one-legged jump had a 47.6% correlation for men and 70%. For one-legged jumping, self reported leg dominance and observed leg dominance were correlated in 47.6% of men and 70% of women [27]. The texture parameters not having the ability to distinguish between dominant and non-dominant could be due to tendon morphological changes not being detected and the use of self-reporting for leg dominance. For future analyses, the dominant and non-dominant sides may not need to be separated as texture parameters are not distinguishing consistent differences.

Significant differences can be seen in eighty out of four hundred forty-one (18.1%) texture parameters in the dominant leg and eighty out of four hundred forty-one (18.1%) texture parameters in the non-dominant leg for the pre- to post- season comparison. Sixty-five of the texture parameter differences are seen in testing group 1 (Session 1 Females) of the longitudinal comparison for both the dominant and non-dominant legs. Numerous number of the texture parameters show a more diseased state in the post-season imaging sessions compared to pre-season values, seen in Table 21. The rigorous season is indicated in the texture parameters, which allows for the recommendation of quantitative texture analysis to be used in the patellar tendon. More significant changes can be seen in the BC compared to the BA for both the dominant (BC-31 and BA-7) and non-dominant (BC-24 and BA-3) leg. Thirty of the thirty-one (96.8%) significant changes in the blob count decrease post-season and twenty-three of the twenty-four decrease on the non-dominant limb. The decrease in blob count could indicate that the changes in echogenicity values not distinguishing between collagen fibers. This could indicate blob count as a more sensitive statistic for detecting changes pre to post season.

Table 21 Number of texture parameters and expected change indicating a more diseased state post-season. Assumptions stated in Table 20,

Variable	Dominant	Non-Dominant	Expected change pre to post season
Mean	6	7	Decrease
Median	6	7	Decrease
Variance	7	8	Decrease
Skewness	1	3	Increase
Kurtosis	1	2	Increase
Entropy	8	8	Decrease
Contrast	3	6	Decrease
Energy	6	6	Increase
Homogeneity	2	4	Increase

In order to explore the concept of blob analysis in patellar tendons, one imaging session group was used to understand the changes in BC and BA in each of the thresholding percentiles. In each of the imaging views, the general trend for BA shows <5% and >95%, <25% and >75%, and <50% and >50% to be similar to each other from smallest to largest. This indicates that as we include more echogenicities to be grouped together that the mean blob area is increasing.

For the BC, the least square means show <25% and >75% to be the largest out of the lower percentile and larger percentiles, respectively. In the example in Figure 7, the <25% and >75% thresholding percentiles show more of the collagen fiber separation compared to the <50% and >50% thresholding percentile, which blends the collagen echogenicities into larger blobs. The <25% threshold percentile shows the darker regions between the collagen fibers and the >75% threshold percentile shows the light region of the collagen fibers.

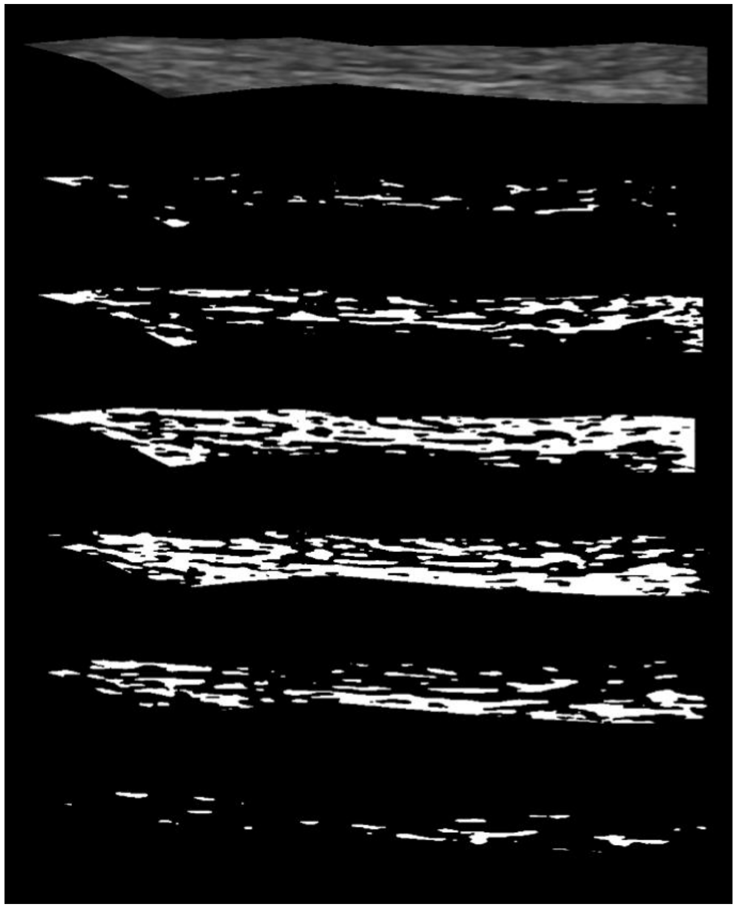

Figure 7: Blobs Example for Proximal Central Longitudinal Region. ROI (Top), $<5\%$, $<25\%$, $<50\%$, $>50\%$, $>75\%$, and $>95\%$ (Bottom)

Overall, the texture parameters were not able to distinguish differences between clinically graded images. The grading scale for abnormal classification includes factors that might not effect texture parameters, such as tendon thickening and cross sectional area. Focusing on how each grading factors effects texture parameters could be beneficial to understanding the utility of texture parameters in supplementing the PT diagnosis. The testing group includes eight subjects longitudinal views with abnormality classifications that were moderately skewed to an abnormal diagnosis rather than normal diagnosis. This small sample size could not be a representative population and a larger sample might be needed to draw more conclusions on the grading criteria.

4.2 Limitations and Recommendations

In the four imaging sessions collected, subjects were not consistent throughout the pre- to post-season and no male athletes images were collected in the first imaging session. In order to make more accurate predictions and get a better sense of the development of PT, another study could incorporate looking at athletes through their college career. Possibly, incorporating more imaging sessions to understand the phases of PT and its development.

The abnormality diagnoses collected were for females in the longitudinal view for proximal, central, and distal. Correlations between texture parameters and abnormal versus normal diagnosis could be explored with a larger sample size that could include a better representation of the population. Also, dividing the grading criteria into the separate categories to understand the correlation to each parameter would be interesting and could give more insight.

4.3 Summary

The use of quantitative texture and blob analyses in the patellar tendon is a feasible practice to distinguish characteristics of an ultrasound image. Texture parameters were able to detect differences in the three anatomic regions (Dominant Limb - 43.5% and Non-Dominant Limb - 47.6%) and gender (Dominant Limb - 30.6% and Non-Dominant Limb - 23.8%) of the athlete. The detection of dominance was only seen in 4.65% of parameters for all seven testing groups. More exploration in an athletes limb dominance is needed to provide a full evaluation of texture parameter differences. The time point comparison pre- to post- season showed consistency with texture parameters showing a more diseased state in post-season. Blob analysis effectively showed differences on blob count and mean blob area with different thresholding percentiles to understand the grouping of pixels within the patellar tendon. The results suggest that 25% and 75% thresholding percentiles could detect the most changes in the patellar tendon. This study gives justification for the use of blob analyses in patellar tendon ultrasound images.

References

[1] C. Cheung, "A machine learning approach for the objective sonographic assessment of patellar tendinopathy in collegiate basketball athletes," Master's thesis, Virginia Polytechnic Institute and State University, 2021.

[2] P. K. Nielsen, B. R. Jensen, T. Darvann, K. Jørgensen, and M. Bakke, "Quantitative ultrasound tissue characterization in shoulder and thigh muscles–a new approach," *BMC musculoskeletal disorders*, vol. 7, no. 1, pp. 1–11, 2006.

[3] MATLAB, "Create a gray-level co-occurrence matrix."

[4] M.-J. Nadeau, A. Desrochers, M. Lamontagne, C. Larivière, and D. H. Gagnon, "Quantitative ultrasound imaging of achilles tendon integrity in symptomatic and asymptomatic individuals: reliability and minimal detectable change," *Journal of foot and ankle research*, vol. 9, no. 1, pp. 1–17, 2016.

[5] J. L. Collinger, D. Gagnon, J. Jacobson, B. G. Impink, and M. L. Boninger, "Reliability of quantitative ultrasound measures of the biceps and supraspinatus tendons," *Academic radiology*, vol. 16, no. 11, pp. 1424–1432, 2009.

[6] A. Schwartz, J. N. Watson, and M. R. Hutchinson, "Patellar tendinopathy," *Sports health*, vol. 7, no. 5, pp. 415–420, 2015.

[7] P. Malliaras, J. Cook, C. Purdam, and E. Rio, "Patellar tendinopathy: clinical diagnosis, load management, and advice for challenging case presentations," *journal of orthopaedic & sports physical therapy*, vol. 45, no. 11, pp. 887–898, 2015.

[8] J. A. Santana, A. Mabrouk, and S. Al, "Jumpers knee," 2018.

[9] A. D. MILNE, N. A. EVANS, and W. D. STANISH, "Detecting and managing jumper's knee," *The Journal of Musculoskeletal Medicine*, vol. 18, no. 5, pp. 261–261, 2001.

[10] J. Cook, K. Khan, P. Harcourt, M. Grant, D. Young, and S. Bonar, "A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. the victorian institute of sport tendon study group.," *British journal of sports medicine*, vol. 31, no. 4, pp. 332–336, 1997.

[11] J. A. Kettunen, M. Kvist, E. Alanen, and U. M. Kujala, "Long-term prognosis for jumper's knee in male athletes: prospective follow-up study," *The American journal of sports medicine*, vol. 30, no. 5, pp. 689–692, 2002.

[12] S. P. Magnusson, M. Hansen, H. Langberg, B. Miller, B. Haraldsson, E. Kjoeller Westh, S. Koskinen, P. Aagaard, and M. Kjær, "The adaptability of tendon to loading differs in men and women," *International journal of experimental pathology*, vol. 88, no. 4, pp. 237–240, 2007.

[13] S. Edwards, J. R. Steele, J. L. Cook, C. R. Purdam, and D. E. McGhee, "Lower limb movement symmetry cannot be assumed when investigating the stop-jump landing," *Medicine and science in sports and exercise*, vol. 44, no. 6, pp. 1123–1130, 2012.

[14] J. C. Benítez-Martínez, F. Valera-Garrido, P. Martínez-Ramírez, J. Ríos-Díaz, M. E. del Baño-Aledo, and F. Medina-Mirapeix, "Lower limb dominance, morphology, and sonographic abnormalities of the patellar tendon in elite basketball players: a cross-sectional study," *Journal of Athletic Training*, vol. 54, no. 12, pp. 1280–1286, 2019.

[15] S. J. Warden, Z. S. Kiss, F. A. Malara, A. B. Ooi, J. L. Cook, and K. M. Crossley, "Comparative accuracy of magnetic resonance imaging and ultrasonography in confirming clinically diagnosed patellar tendinopathy," *The American journal of sports medicine*, vol. 35, no. 3, pp. 427–436, 2007.

[16] S. J. Warden and P. Brukner, "Patellar tendinopathy," *Clinics in sports medicine*, vol. 22, no. 4, pp. 743–759, 2003.

[17] K. M. Meiburger, M. Salvi, M. Giacchino, U. R. Acharya, M. A. Minetto, C. Caresio, and F. Molinari, "Quantitative analysis of patellar tendon abnormality in asymptomatic profes-

sional "pallapugno" players: A texture-based ultrasound approach," *Applied Sciences*, vol. 8, no. 5, 2018.

[18] J. H. Weinreb, C. Sheth, J. Apostolakos, M.-B. McCarthy, B. Barden, M. P. Cote, and A. D. Mazzocca, "Tendon structure, disease, and imaging," *Muscles, ligaments and tendons journal*, vol. 4, no. 1, p. 66, 2014.

[19] G. Bode, T. Hammer, N. Karvouniaris, M. J. Feucht, L. Konstantinidis, N. P. Südkamp, and A. Hirschmüller, "Patellar tendinopathy in young elite soccer–clinical and sonographical analysis of a german elite soccer academy," *BMC musculoskeletal disorders*, vol. 18, pp. 1–7, 2017.

[20] K. Sunding, M. Fahlström, S. Werner, M. Forssblad, and L. Willberg, "Evaluation of achilles and patellar tendinopathy with greyscale ultrasound and colour doppler: using a four-grade scale," *Knee Surgery, Sports Traumatology, Arthroscopy*, vol. 24, pp. 1988–1996, 2016.

[21] P. K. Nielsen, B. R. Jensen, T. Darvann, K. Jørgensen, and M. Bakke, "Quantitative ultrasound image analysis of the supraspinatus muscle," *Clinical Biomechanics*, vol. 15, pp. S13–S16, 2000.

[22] M. Sancar, Ö. Kenis-Coskun, O. H. Gündüz, and D. Kumbhare, "Quantitative ultrasound texture feature changes with conservative treatment of the trapezius muscle in female patients with myofascial pain syndrome," *American Journal of Physical Medicine & Rehabilitation*, vol. 100, no. 11, pp. 1054–1061, 2021.

[23] D. Kumbhare, S. Shaw, L. Grosman-Rimon, and M. D. Noseworthy, "Quantitative ultrasound assessment of myofascial pain syndrome affecting the trapezius: a reliability study," *Journal of Ultrasound in Medicine*, vol. 36, no. 12, pp. 2559–2568, 2017.

[24] Z. Kozar, G. Cao, A. Kozar, D. Woodson, and V. Wang, "Quantitative analysis of sonographic images of patellar tendons in collegiate women's basketball players using grayscale and shear wave elastography techniques," 2019.

[25] C. S. Eriksen, R. B. Svensson, A. T. Gylling, C. Couppé, S. P. Magnusson, and M. Kjaer, "Load magnitude affects patellar tendon mechanical properties but not collagen or collagen cross-linking after long-term strength training in older adults," *BMC geriatrics*, vol. 19, pp. 1–15, 2019.

[26] Z. J. Zhang, G. Y.-f. Ng, W. C. Lee, and S. N. Fu, "Changes in morphological and elastic properties of patellar tendon in athletes with unilateral patellar tendinopathy and their relationships with pain and functional disability," *PloS one*, vol. 9, no. 10, p. e108337, 2014.

[27] N. van Melick, B. M. Meddeler, T. J. Hoogeboom, M. W. Nijhuis-van der Sanden, and R. E. van Cingel, "How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults," *PloS one*, vol. 12, no. 12, p. e0189876, 2017.

A Additional Results

A.1 Aim 1

Table A1 Anatomic Region Comparison P-Values. 1 = Session 1 Females. 2 = Session 2 Females. 3 = Session 2 and Males. 4 = Session 3 Females. 5 = Session 3 Males. 6 = Session 4 Females. 7 = Session 4 Males

	Dominant							**Non-Dominant**						
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Mean	0.0001	0.0057	0.0001	0.0001	0.0001	0.0001	0.0094	0.0001	0.0004	0.0006	0.0001	0.0001	0.0001	0.0194
Median	0.0001	0.0031	0.0001	0.0001	0.0001	0.0001	0.0115	0.0001	0.0003	0.0004	0.0001	0.0001	0.0001	0.0305
Variance	0.6144	0.856	0.2318	0.7626	0.117	0.3539	0.0088	0.0472	0.2028	0.3235	0.0032	0.0006	0.8854	0.0405
Skewness	0.1348	0.7143	0.0497	0.6862	0.2308	0.8446	0.4259	0.1196	0.7631	0.0145	0.8164	0.6797	0.4366	0.8315
Kurtosis	0.2235	0.9278	0.0058	0.5074	0.682	0.7239	0.8584	0.6623	0.0657	0.0578	0.9903	0.8809	0.0989	0.8482
Entropy	0.1795	0.1478	0.5684	0.1868	0.0435	0.019	0.0453	0.1196	0.3665	0.1841	0.2871	0.0109	0.0697	0.1879
Contrast	0.0036	0.0031	0.0004	0.0005	0.0001	0.0003	0.0058	0.0001	0.0024	0.0001	0.0001	0.0001	0.0023	0.0256
Energy	0.1125	0.2579	0.0523	0.9209	0.2751	0.1187	0.1719	0.0006	0.7809	0.0002	0.0012	0.0045	0.8753	0.0113
Homogeneity	0.0015	0.0008	0.0002	0.0001	0.0001	0.0005	0.0364	0.0001	0.0012	0.0001	0.0001	0.0001	0.0005	0.0563
BC < 5%	0.1994	0.0087	0.0058	0.0026	0.0008	0.1839	0.4561	0.1538	0.001	0.1518	0.0855	0.0001	0.32	0.0051
BC < 25%	0.8368	0.1191	0.2364	0.0495	0.0444	0.1868	0.2649	0.495	0.0377	0.1182	0.0988	0.0026	0.0028	0.1162
BC < 50%	0.0722	0.6171	0.204	0.6763	0.0152	0.1531	0.4758	0.0903	0.1168	0.4539	0.4238	0.2007	0.4681	0.5251
BC > 50%	0.1764	0.1785	0.0592	0.0002	0.0154	0.4436	0.1678	0.0879	0.1593	0.2756	0.2138	0.0145	0.1046	0.2244
BC > 75%	0.1056	0.0324	0.0952	0.0154	0.1452	0.0082	0.1012	0.4763	0.007	0.1238	0.0193	0.0022	0.0016	0.4406
BC > 95%	0.0275	0.0015	0.0028	0.0328	0.0442	0.3283	0.0117	0.1702	0.0088	0.002	0.003	0.0001	0.0029	0.3497
Avg BA < 5%	0.0866	0.2203	0.16	0.1126	0.0478	0.05	0.4178	0.3155	0.0049	0.2834	0.2827	0.0124	0.03	0.0905
Avg BA < 25%	0.4878	0.9446	0.1241	0.3425	0.0806	0.0027	0.8477	0.8916	0.0083	0.5598	0.0007	0.1147	0.0001	0.1554
Avg BA < 50%	0.009	0.3343	0.3452	0.034	0.2658	0.0091	0.099	0.81	0.2472	0.7338	0.2564	0.3724	0.7184	0.437
Avg BA > 50%	0.6061	0.2123	0.405	0.0067	0.7738	0.1554	0.5169	0.0281	0.0687	0.289	0.0497	0.9111	0.0098	0.7504
Avg BA > 75%	0.1336	0.026	0.4487	0.0517	0.009	0.0001	0.2302	0.0402	0.0004	0.9623	0.0012	0.1724	0.0001	0.5235
Avg BA > 95%	0.0674	0.2684	0.0247	0.1209	0.0132	0.0342	0.8905	0.0056	0.0789	0.0117	0.15	0.3417	0.0005	0.6702

Table A2 Gender Comparison P-Values for Dominant Leg. Red filled represents a confounded variable a p-value could not be calculated. 1 = Session 2 Females and Males. 2 = Session 3 Females and Males. 3 = Session 4 Female and Males

	Proximal									Central						Distal					
	LONG			TRANS 1			TRANS 2			LONG			TRANS			LONG			TRANS		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	0.0033	0.3486	0.8137	0.036	0.2281	0.7481	0.1893	0.3118	0.8592	0.2909	0.2797	0.289	0.028	0.5473	0.6624	0.0081	0.3283	0.7472	0.0179	0.6559	0.7072
Median	0.0024	0.3764	0.8278	0.0334	0.1927	0.7092	0.1826	0.3878	0.7919	0.2499	0.2809	0.2904	0.0238	0.6286	0.6509	0.0116	0.3373	0.663	0.01	0.6127	0.7136
Variance	0.3267	0.5239	0.4257	0.1975	0.2105	0.7911	0.9502	0.6109	0.0718	0.2874	0.6983	0.0342	0.4592	0.5278	0.1819	0.7893	0.1576	0.8457	0.341	0.2444	0.208
Skewness	0.8208	0.2984	0.8305	0.2145	0.3574	0.5088	0.6685	0.0408	0.6427	0.2717	0.8616	0.7083	0.198	0.9099	0.6226	0.2124	0.244	0.0738	0.1393	0.6437	0.9143
Kurtosis	0.696	0.1931	0.8136	0.2985	0.0877	0.5624	0.7335	0.1337	0.8418	0.5467	0.9366	0.7832	0.0552	0.1791	0.9776	0.0783	0.0473	0.061	0.231	0.832	0.2464
Entropy	0.0015	0.9291	0.5928	0.0044	0.1395	0.8305	0.0043	0.0259	0.3171	0.0908	0.0829	0.7706	0.0697	0.4036	0.2556	0.0216	0.0605	0.3745	0.2584	0.0261	0.1005
Contrast	0.8671	0.5798	0.8262	0.7154	0.7392	0.7413	0.8835	0.5373	0.3274	0.2514	0.9494	0.0672	0.3007	0.8656	0.2428	0.4612	0.5166	0.3626	0.7066	0.9175	0.8969
Energy	0.6753	0.6331	0.719	0.723	0.6168	0.7505	0.7727	0.3771	0.1427	0.547	0.7062	0.1886	0.156	0.4878	0.3954	0.883	0.0794	0.4681	0.521	0.6626	0.8776
Homogeneity	0.7943	0.8894	0.9216	0.9053	0.7722	0.8926	0.9924	0.3559	0.4747	0.3489	0.7823	0.1616	0.1404	0.5801	0.4745	0.4512	0.5044	0.3806	0.3833	0.6094	0.8825
BC < 5%	0.7165	0.7923	0.5312	0.2153	0.8128	0.3351	0.0718	0.6539	0.314	0.3312	0.1944	0.095	0.7469	0.5391	0.688	0.5764	0.0259	0.9467	0.6491	0.2156	0.0184
BC < 25%	0.9912	0.7926	0.8528	0.5006	0.1595	0.8832	0.023	0.0399	0.9238	0.61	0.2585	0.9147	0.3361	0.1211	0.3211	0.448	0.0589	0.739	0.7516	0.3949	0.1707
BC < 50%	0.2741	0.9484	0.5728	0.0546	0.0598	0.5123	0.1061	0.0075	0.2941	0.2251	0.0053	0.2542	0.376	0.051	1	0.3898	0.4244	0.8093	0.2377	0.2723	0.5373
BC > 50%	0.2297	0.9719	0.9709	0.0813	0.3871	0.5729	0.0031	0.6469	0.3515	0.4146	0.1577	0.9438	0.059	0.479	0.1372	0.0241	0.0016	0.7464	0.3252	0.0275	0.249
BC > 75%	0.8923	0.1437	0.9851	0.2013	0.8575	0.67	0.0683	0.611	0.9387	0.3574	0.2585	0.4758	0.364	0.3305	0.1915	0.0189	0.0356	0.5304	0.7776	0.3853	0.0307
BC > 95%	0.0905	0.5629	0.5977	0.02	0.6522	0.6189	0.0742	0.003	0.9163	0.5761	0.3788	0.9867	0.6593	0.4032	0.4632	0.3574	0.2503	0.0393	0.8905	0.5998	0.1367
Avg BA < 5%	0.068	0.9248	0.591	0.1247	0.2139	0.1874	0.8339	0.1306	0.112	0.8207	0.9539	0.157	0.9759	0.5277	0.275	0.7095	0.166	0.704	0.2408	0.392	0.2457
Avg BA < 25%	0.001	0.5635	0.9013	0.0631	0.4304	0.5838	0.491	0.6649	0.7111	0.0181	0.13	0.5759	0.5434	0.4339	0.5921	0.039	0.7862	0.6901	0.4129	0.8456	0.7503
Avg BA < 50%	0.4469	0.7871	0.8764	0.7372	0.0044	0.6624	0.3392	0.7196	0.8047	0.5323	0.0331	0.1099	0.3094	0.4133	0.2641	0.1724	0.1161	0.8698	0.0234	0.4218	0.9144
Avg BA > 50%	0.0013	0.7517	0.5684	0.0012	0.411	0.7349	0.7657	0.1012	0.0563	0.1812	0.3819	0.7468	0.3592	0.1033	0.7982	0.6168	0.024	0.3707	0.9741	0.4641	0.7012
Avg BA > 75%	0.1193	0.2535	0.1552	0.0597	0.1666	0.993	0.8377	0.0567	0.4525	0.2305	0.8324	0.2639	0.6238	0.6422	0.6234	0.6175	0.4901	0.8041	0.4043	0.751	0.1029
Avg BA > 95%	0.6178	0.602	0.7515	0.1789	0.2019	0.0557	0.501	0.406	0.2697	0.362	0.8831	0.717	0.0489	0.9648	0.9135	0.6513	0.6814	0.2267	0.2458	0.2418	0.7486

Table A3 Gender Comparison P-Values for Non-Dominant Leg. Red filled represents a confounded variable a p-value could not be calculated. 1 = Session 2 Females and Males. 2 = Session 3 Females and Males. 3 = Session 4 Females and Males

	Proximal									Central						Distal					
	LONG			TRANS 1			TRANS 2			LONG			TRANS			LONG			TRANS		
Parameter	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Mean	0.0027	0.0088	0.8333	0.1087	0.0544	0.1642	0.0386	0.3332	0.2628	0.6871	0.0732	0.484	0.2423	0.5793	0.3466	0.2313	0.5837	0.2077	0.0676	0.7307	0.5485
Median	0.002	0.0097	0.8187	0.0993	0.0678	0.1933	0.0362	0.3779	0.2694	0.6611	0.0728	0.5126	0.2599	0.5693	0.3806	0.2056	0.5204	0.2542	0.0478	0.7963	0.5085
Variance	0.4691	0.7939	0.3853	0.0051	0.8563	0.4951	0.691	0.531	0.723	0.18	0.4619	0.8868	0.1203	0.378	0.205	0.9647	0.3139	0.0779	0.6694	0.4674	0.2904
Skewness	0.9583	0.5658	0.7495	0.3768	0.6951	0.7653	0.7861	0.8975	0.2253	0.9073	0.8653	0.5114	0.6032	0.159	0.1797	0.0517	0.5066	0.6755	0.2368	0.314	0.2011
Kurtosis	0.6006	0.7902	0.6939	0.4585	0.5979	0.2692	0.9416	0.6736	0.2925	0.9117	0.9128	0.4942	0.9333	0.214	0.029	0.0175	0.3674	0.819	0.1381	0.9979	0.0602
Entropy	0.1491	0.661	0.6836	0.0908	0.6993	0.1964	0.0108	0.0905	0.9885	0.0809	0.4818	0.6407	0.0025	0.081	0.1999	0.0519	0.8164	0.9838	0.7133	0.9356	0.872
Contrast	0.6595	0.2421	0.5634	0.7702	0.5877	0.9802	0.7537	0.2549	0.764	0.0516	0.4275	0.6192	0.5694	0.1671	0.7523	0.9451	0.6556	0.4717	0.6142	0.2844	0.7118
Energy	0.6925	0.9262	0.4044	0.0438	0.4016	0.9666	0.7223	0.6209	0.5296	0.2803	0.3452	0.8935	0.2092	0.6002	0.0357	0.2883	0.3917	0.0553	0.2433	0.3753	0.7103
Homogeneity	0.554	0.3804	0.512	0.7886	0.3497	0.5849	0.5326	0.3123	0.8922	0.1624	0.4355	0.9386	0.7814	0.2286	0.806	0.8461	0.9183	0.4926	0.2966	0.4389	0.8507
BC < 5%	0.6681	0.7051	0.1247	0.8131	0.8857	0.334	0.9086	0.2851	0.7203	0.3632	0.5625	0.3787	0.9931	0.008	0.0056	0.1921	0.1933	0.3198	0.5162	0.5256	0.8467
BC < 25%	0.9882	0.1443	0.5524	0.8582	0.7482	0.0908	0.1703	0.0433	0.468	0.3657	Issue	0.8781	0.3063	0.031	0.1618	0.1002	0.0897	0.6929	0.6707	0.695	0.6736
BC < 50%	0.316	0.4836	0.9213	0.181	0.4617	0.0101	0.0742	0.0112	0.1328	0.5477	0.7423	0.258	0.0125	0.2746	0.1602	0.6767	0.808	0.2177	0.5799	0.4627	0.4542
BC > 50%	0.328	0.7397	0.377	0.5444	0.6875	0.8729	0.237	0.3949	0.9566	0.6444	1	0.4072	0.2559	0.0625	0.2116	0.1739	0.4009	0.4069	0.2923	0.7474	0.3286
BC > 75%	0.3261	0.1219	0.7958	0.1049	0.4025	0.7795	0.3119	0.269	0.3153	Issue	Issue	0.3557	0.2691	0.0269	0.1456	0.0556	0.0521	0.4024	0.9362	0.7097	0.9843
BC > 95%	0.4562	0.6812	0.6145	0.3089	0.7375	0.6873	0.1125	0.0395	0.9535	0.8477	0.4171	0.1873	0.0132	0.0805	0.0334	0.283	0.6646	0.0135	0.4991	0.4958	0.4673
Avg BA < 5%	0.224	0.7051	0.2751	0.3222	0.3475	0.016	0.0289	0.9665	0.554	0.7415	0.5227	0.5887	0.0058	0.0759	0.2061	0.8509	0.2804	0.1725	0.9786	0.5186	0.4196
Avg BA < 25%	0.6986	0.3277	0.8543	0.067	0.9143	0.6346	0.1238	0.3058	0.4718	0.5205	0.2231	0.8194	0.0048	0.4154	0.9127	0.3216	0.1591	0.546	0.7162	0.8718	0.5501
Avg BA < 50%	0.9894	0.4464	0.5566	0.4417	0.8463	0.6287	0.4612	0.5819	0.3252	0.034	0.5865	0.0912	0.1963	0.2505	0.7302	0.4066	0.6818	0.316	0.8759	0.3953	0.6501
Avg BA > 50%	0.3844	0.956	0.6616	0.1513	0.3429	0.1075	0.1423	0.7471	0.9623	0.025	0.5924	0.5923	0.2328	0.9077	0.9842	0.6053	0.3304	0.546	0.298	0.3736	0.3706
Avg BA > 75%	0.6995	0.2746	0.8355	0.0003	0.6553	0.4128	0.3024	0.6608	0.3428	0.143	0.866	0.2532	0.021	0.8555	0.5365	0.1787	0.0117	0.3986	0.7357	0.8481	0.7516
Avg BA > 95%	0.5468	0.9575	0.9817	0.4952	0.3815	0.4309	0.5684	0.6406	0.697	0.2584	0.4845	0.4088	0.7286	0.4113	0.4982	0.4225	0.6141	0.0706	0.1278	0.4202	0.8788

Table A4 Dominance Comparison P-Values. Red filled represents a confounded variable a p-value could not be calculated. 1 = Session 1 Females. 2 = Session 2 Females. 3 = Session 2 and Males. 4 = Session 3 Females. 5 = Session 3 Males. 6 = Session 4 Females. 7 = Session 4 Males

	Proximal																				
	LONG							TRANS 1							TRANS 2						
Parameter	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Mean	0.8475	0.5532	0.9013	0.1829	0.4271	0.6332	0.0078	0.8045	0.2328	0.6992	0.3672	0.8070	0.7680	0.1710	0.2667	0.0538	0.5031	0.9818	0.6510	0.4586	0.3293
Median	0.7905	0.6026	0.9613	0.1522	0.3515	0.5780	0.0942	0.8069	0.2168	0.7343	0.4012	0.9826	0.5331	0.1838	0.3946	0.0403	0.4745	1.0000	0.5932	0.4105	0.3169
Variance	0.3744	0.4971	0.2044	0.7000	0.1569	0.6032	0.5990	0.3082	0.6615	0.4447	0.3109	0.6202	0.8149	0.4730	0.4823	0.4908	0.3898	0.0521	0.1690	0.4423	0.4221
Skewness	0.5667	0.6744	0.8280	0.9699	0.4680	0.3088	0.5346	0.5118	0.1252	0.6691	0.8627	0.5237	0.2535	0.6931	0.5210	0.7594	0.7341	0.5938	0.2093	0.2142	0.0237
Kurtosis	0.6397	0.6369	0.7411	0.1524	0.3302	0.4666	0.7571	0.3651	0.0266	0.7936	0.2502	0.7795	0.7468	0.6987	0.3029	0.9303	0.5890	0.6980	0.2158	0.5094	0.3459
Entropy	0.5423	0.1054	0.5555	0.5386	0.8582	0.5506	0.6127	0.0335	0.0841	0.8168	0.8671	0.2658	0.9893	0.3106	0.2018	0.8453	0.6370	0.7171	0.8463	0.3337	0.9129
Contrast	0.6931	0.7880	0.5447	0.3416	0.4029	0.8586	0.0897	0.8359	0.5673	0.6901	0.3121	0.9742	0.9372	0.8959	0.7579	0.1855	0.2659	0.5294	0.6820	0.9740	0.6072
Energy	0.9050	0.7057	0.3072	0.6788	0.2422	0.7740	0.2981	0.9865	0.0093	0.6719	0.6644	0.3928	0.5247	0.6831	0.9094	0.0369	0.5356	0.9906	0.8254	0.7534	0.0458
Homogeneity	0.5733	0.7022	0.5704	0.5745	0.8062	0.8551	0.2905	0.6994	0.3917	0.5946	0.5302	0.5024	0.7125	0.7630	0.9844	0.1081	0.3677	0.2618	0.4704	0.9154	0.6200
BC < 5%	0.4105	0.7693	0.4831	0.7704	0.5485	0.9485	0.2083	0.0811	0.9472	0.1579	0.3990	0.9510	0.2188	0.5026	0.7410	0.6214	0.4470	0.0959	0.3670	0.7566	0.7586
BC < 25%		0.9589	0.9509	0.3117	0.3381	0.3650	0.7338	0.5081	0.2017	0.7713	0.7699	0.3117	0.4082	0.4134	0.8449	0.3519	0.8785	0.4643	0.9776	0.9995	0.6027
BC < 50%	0.5839	0.6991	0.7103	0.6191	0.6858	0.6195	0.9622	0.1443	0.5348	0.6240	0.2941	0.0496	0.5947	0.1663	0.0411	0.3837	0.7223	0.3307	0.8335	0.9948	0.1835
BC > 50%	0.2032	0.2465	0.1922	0.8920	0.7401	0.8545	0.6919	0.3937	0.4348	0.6759	0.4185	0.6842	0.6337	1.0000	0.3694	0.3289	0.7133	0.0104	0.3735	0.8574	0.5101
BC > 75%		0.0218	0.6093	0.2557	0.1060	0.5916	0.8485	0.3334	0.1480	0.0639	0.5178	0.5559	0.9065	0.6501	0.1110	0.3389	0.6840	0.1204	0.3806	0.6997	0.6562
BC > 95%	0.2283	0.0631	0.2898	0.9409	0.2672	0.1003	0.5799	0.5741	0.4140	0.9502	0.9533	0.4761	0.4217	0.8408	0.5379	0.6706	0.8267	0.9375	0.7055	0.1965	0.2697
Avg BA < 5%	0.2262	0.9839	0.6970	0.8546	0.4497	0.5490	0.2236	0.7803	0.1304	0.3921	0.9176	0.3397	0.3678	0.9428	0.6956	0.5277	0.9485	0.2183	0.3957	0.2836	0.6810
Avg BA < 25%	0.5419	0.1928	0.6734	0.3760	0.2863	0.7864	0.8335	0.3055	0.6654	0.7497	0.5442	0.7532	0.4250	0.7342	0.4327	0.1900	0.4351	0.1825	0.8831	0.7015	0.6807
Avg BA < 50%	0.3894	0.0773	0.1998	0.8317	0.8814	0.6731	0.7840	0.1995	0.2423	0.2783	0.2923	0.7228	0.7455	0.3463	0.6279	0.3600	0.7115	0.0206	0.0690	0.2407	0.7170
Avg BA > 50%	0.1385	0.4009	0.7819	0.9249	0.4132	0.7852	0.6352	0.9216	0.8313	0.7853	0.0078	0.0261	0.3984	0.7931	0.5341	0.2834	0.6391	0.6901	0.7868	0.3703	0.7270
Avg BA > 75%	0.6678	0.9015	0.1519	0.2733	0.1670	0.2386	0.7781	0.3118	0.2818	0.2766	0.2924	0.4336	0.4122	0.1547	0.7888	0.1103	0.4810	0.0702	0.4542	0.9563	0.7289
Avg BA > 95%	0.5138	0.2541	0.5166	0.6138	0.2270	0.1043	0.5458	0.1855	0.4688	0.9955	0.3240	0.6184	0.0610	0.6433	0.7507	0.6967	0.5753	0.7277	0.4201	0.3812	0.6089

	Central													
	LONG							TRANS						
Parameter	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Mean	0.3748	0.8861	0.6875	0.9605	0.2732	0.2267	0.1100	0.1312	0.2786	0.1001	0.4692	0.3929	0.6824	0.1425
Median	0.3680	0.8596	0.6809	0.9158	0.3257	0.2189	0.1304	0.1388	0.3341	0.0985	0.5462	0.3904	0.8315	0.0581
Variance	0.0175	0.6800	0.7695	0.9866	0.6138	0.0703	0.2613	0.5948	0.5989	0.0519	0.3687	0.5407	0.2609	0.2335
Skewness	0.9540	0.5493	0.6336	0.7863	0.8746	0.7882	0.6265	0.1791	0.8725	0.1496	0.1664	0.7802	0.8599	0.3529
Kurtosis	0.5503	0.6734	0.3293	0.4525	0.7148	0.5649	0.9772	0.0578	0.7384	0.2537	0.5913	0.5880	0.5376	0.3864
Entropy	0.6064	0.3732	0.5010	0.2523	0.9382	0.5635	0.6805	0.8352	0.9203	0.1007	0.0301	0.3231	0.6661	0.6867
Contrast	0.0582	0.3049	0.8741	0.6556	0.6214	0.6155	0.3831	0.1288	0.8816	0.0579	0.3349	0.3921	0.6399	0.1030
Energy	0.0783	0.8774	0.7938	0.8589	0.6186	0.3085	0.3827	0.1913	0.9962	0.0055	0.9776	0.9760	0.1864	0.2442
Homogeneity	0.0339	0.4389	0.7937	0.7512	0.7634	0.4388	0.4622	0.1168	0.9584	0.0473	0.1746	0.5535	0.3005	0.2856
BC < 5%	0.8834	0.5485	0.8668	0.7298	0.4956	0.1073	0.0730	0.2177	0.8258	0.5339	0.0125	0.5326	0.8267	0.1721
BC < 25%		0.6400	0.3466	0.3466		0.6218	0.4226	0.7330	0.9856	0.8857	0.2597	0.9137	0.7283	0.8006
BC < 50%	0.2110	0.0019	0.0279	0.1256	0.3357	0.3533	0.4226	0.9666	0.5299	0.1437	0.9133	0.8260	0.3141	0.6327
BC > 50%	0.3466	0.9894	0.5905	0.4946	0.0546	0.5164	0.2419	0.9646	0.9541	0.9204	0.0015	0.7410	0.2347	0.7520
BC > 75%		0.3043		0.3466		0.6079	0.4226	0.6994	0.4988	0.7960	0.5228	0.3260	0.7783	
BC > 95%	0.7361	0.3357	0.5666	0.4279	0.3992	0.2188	0.4012	0.4256	0.4090	0.0300	0.9666	0.1072	0.2832	0.6161
Avg BA < 5%	0.4988	0.7901	0.6843	0.6016	0.8741	0.2025	0.0058	0.1986	0.5988	0.1560	0.0833	0.7680	0.8810	0.1908
Avg BA < 25%	0.6774	0.0098	0.8896	0.3941	0.1981	0.5648	0.6831	0.9023	0.3843	0.3120	0.7826	0.9729	0.6067	0.9301
Avg BA < 50%	0.7764	0.3322	0.3090	0.0446	0.1721	0.3817	0.7261	0.9784	0.5580	0.0241	0.0279	0.5603	0.6121	0.8070
Avg BA > 50%	0.9275	0.0036	0.0097	0.0608	0.3237	0.1476	0.7190	0.5302	0.3377	0.9882	0.3489	0.1601	0.2294	0.6163
Avg BA > 75%	0.7675	0.7311	0.8196	0.4434	0.6087	0.4891	0.0396	0.7996	0.4759	0.6945	0.6938	0.7862	0.4808	0.2341
Avg BA > 95%	0.8396	0.9949	0.7473	0.4971	0.1625	0.5405	0.3709	0.2816	0.3596	0.2099	0.4191	0.9551	0.3547	0.8214

	Distal													
	LONG							TRANS						
Parameter	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Mean	0.7474	0.5400	0.3718	0.2910	0.6285	0.3677	0.1075	0.1863	0.8377	0.7005	0.1705	0.0440	0.6292	0.8110
Median	0.5715	0.7127	0.3379	0.4478	0.6877	0.3211	0.1480	0.1877	0.8209	0.6674	0.1727	0.0681	0.7179	0.7784
Variance	0.1592	0.7722	0.4923	0.0624	0.2782	0.0344	0.6771	0.6852	0.1398	0.9402	0.8001	0.6470	0.4774	0.0642
Skewness	0.7111	0.6503	0.6466	0.7381	0.4743	0.2596	0.5854	0.8261	0.9461	0.7336	0.8968	0.0680	0.4579	0.1045
Kurtosis	0.2802	0.7799	0.7217	0.8974	0.2231	0.0402	0.4116	0.5029	0.6653	0.5305	0.9636	0.5813	0.2932	0.4917
Entropy	0.5430	0.6536	0.6916	0.9497	0.0063	0.4776	0.4027	0.1607	0.0367	0.8103	0.3431	0.3542	0.6450	0.0395
Contrast	0.7097	0.2985	0.7897	0.1981	0.8497	0.1086	0.1287	0.9482	0.2670	0.8121	0.0660	0.4450	0.8708	0.9584
Energy	0.4617	0.9342	0.4560	0.0828	0.5305	0.0847	0.3699	0.6547	0.1863	0.9561	0.0022	0.4748	0.8584	0.9938
Homogeneity	0.8749	0.4995	0.7115	0.2894	0.7866	0.1870	0.3364	0.8163	0.4667	0.8962	0.0345	0.3137	0.7926	0.9345
BC < 5%	0.1740	0.5684	0.0297	0.9281	0.1915	0.4629	0.5616	0.3139	0.6033	0.3964	0.8135	0.0552	0.7862	0.2520
BC < 25%	1.0000	0.3920	0.8635	0.6198	0.3183	0.0610	0.0234	0.4897	0.7062	0.8753	0.5245	0.3413	0.5367	0.4243
BC < 50%	0.0894	0.2307	0.0602	0.1637	0.0021	0.4943	0.2078	0.0739	0.2980	0.3164	0.8821	0.8437	0.7002	0.2539
BC > 50%	0.1806	0.7807	0.8933	0.2273	0.0945	0.0197	0.4670	0.7589	0.9827	0.8149	0.7680	0.1012	0.5722	0.7947
BC > 75%	0.5588	0.2255	0.3642	0.9822	0.3942	0.6790	0.9704	0.3760	0.9723	0.6297	0.7986	0.2965	0.7996	0.2390
BC > 95%	0.7563	0.2753	0.2402	0.9098	0.2125	0.3078	0.1074	0.0304	0.6309	0.8099	0.9594	0.9554	0.1463	0.4886
Avg BA < 5%	0.4292	0.6109	0.0257	0.8126	0.5343	0.4439	0.1559	0.1529	0.5041	0.3010	0.2356	0.1914	0.2243	0.5755
Avg BA < 25%	0.1802	0.0299	0.3626	0.6942	0.3656	0.0545	0.4717	0.7297	0.1950	0.9399	0.9862	0.7071	0.3433	0.8533
Avg BA < 50%	0.5578	0.7931	0.9329	0.0809	0.8902	0.0313	0.8548	0.4860	0.2084	0.9812	0.5538	0.4030	0.4811	0.6383
Avg BA > 50%	0.3104	0.3401	0.1577	0.1407	0.3883	0.3131	0.0616	0.1603	0.0354	0.1515	0.5721	0.2562	0.8772	0.6443
Avg BA > 75%	0.5376	0.2066	0.1370	0.9051	0.0315	0.6851	0.7106	0.5640	0.5042	0.6812	0.6086	0.9503	0.7026	0.3050
Avg BA > 95%	0.6673	0.5922	0.2286	0.6526	0.4523	0.9240	0.4291	0.2610	0.7395	0.4503	0.4768	0.1888	0.0306	0.6582

Table A5 Timepoint Comparison P-Values for Dominant Leg. Red filled represents a confounded variable a p-value could not be calculated. 1 = Session 1 and 2 Females. 2 = Session 3 and 4 Females. 3 = Session 3 and 4 Males

	Proximal									Central						Distal					
	LONG			TRANS 1			TRANS 2			LONG			TRANS			LONG			TRANS		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	0.0415	0.7663	0.2731	0.0068	0.1474	0.1846	0.0007	0.7285	0.3420	0.0021	0.2506	0.2720	0.0250	0.5978	0.6348	0.0196	0.3278	0.7608	0.4152	0.8672	0.8061
Median	0.0392	0.7491	0.2885	0.0084	0.1627	0.1953	0.0009	0.7559	0.3528	0.0033	0.2227	0.3111	0.0335	0.7009	0.6144	0.0316	0.2898	0.7273	0.5447	0.8764	0.8619
Variance	0.0209	0.1207	0.8784	0.0001	0.1777	0.8522	0.0001	0.5928	0.0384	0.0001	0.1116	0.1254	0.0126	0.4657	0.0102	0.0051	0.0750	0.8322	0.0016	0.4500	0.1145
Skewness	0.4948	0.3643	0.9725	0.5454	0.7778	0.8460	0.0074	0.9253	0.5816	0.3908	0.5353	0.8830	0.9125	0.6597	0.2575	0.7390	0.1661	0.1520	0.4672	0.5002	0.4799
Kurtosis	0.3123	0.3914	0.7344	0.4150	0.2389	0.5422	0.0172	0.5529	0.8892	0.0898	0.6160	0.9563	0.6454	0.5983	0.5981	0.3185	0.0846	0.1263	0.4264	0.3168	0.7645
Entropy	0.0003	0.0389	0.2744	0.0002	0.8766	0.6233	0.0333	0.5194	0.8993	0.0013	0.0477	0.1019	0.0266	0.9422	0.4390	0.0343	0.4224	0.2659	0.0605	0.0671	0.2655
Contrast	0.1002	0.7622	0.8381	0.0259	0.0897	0.3636	0.0091	0.6493	0.2459	0.0486	0.2983	0.0777	0.3945	0.7659	0.2251	0.0971	0.2372	0.5673	0.8467	0.8657	0.9211
Energy	0.0317	0.6816	0.7717	0.0006	0.5180	0.8612	0.0001	0.9619	0.0818	0.0028	0.1398	0.3975	0.2007	0.6276	0.2504	0.0039	0.1196	0.4305	0.0323	0.3716	0.7716
Homogeneity	0.1635	0.7131	0.7757	0.0466	0.2603	0.4301	0.0199	0.7380	0.3916	0.1156	0.2602	0.2292	0.8026	0.5201	0.4455	0.0998	0.3579	0.3923	0.7490	0.6240	0.8809
BC < 5%	0.2264	0.8815	0.4593	0.0010	1.0000	0.6700	0.2750	0.2285	0.5700	0.1692	0.9154	0.0039	0.5247	0.1015	0.0884	0.0084	0.6854	0.1613	0.8038	0.9608	0.4980
BC < 25%	0.0781	0.4186	0.4597	0.0155	0.1604	0.8613	0.0173	0.2415	0.7008	0.3574	0.0536	0.0401	0.2989	0.5731	0.9669	0.0223	0.8311	0.3939	0.4730	0.7212	0.2040
BC < 50%	0.0038	0.1257	0.4483	0.0021	0.1173	0.3996	0.0012	0.3400	0.8387	0.0001	0.6973	0.3740	0.0217	0.4897	0.6665	0.0146	0.0250	0.0207	0.7453	0.4431	0.7650
BC > 50%	0.0970	0.5512	0.6372	0.0030	0.7319	0.7433	0.0001	0.8707	0.2899	0.0301	0.2404	0.0489	0.0054	0.0093	0.7057	0.0098	0.0497	0.6636	0.0766	0.2022	0.6377
BC > 75%	0.0259	0.8951	0.2409	0.0375	0.9225	0.5016	0.0132	1.0000	0.8164	0.3574	0.3659		0.4377	0.9752	0.2855	0.0025	0.8451	0.1955	0.6623	0.8443	0.1548
BC > 95%	0.0003	0.2033	0.4073	0.0004	0.9761	0.4537	0.0179	0.5873	0.0882	0.0053	0.2410	0.1326	0.3456	0.8009	1.0000	0.0086	0.3344	0.4044	0.5490	0.3448	0.0665
Avg BA < 5%	0.6136	0.1253	0.1485	0.6808	0.9024	0.6471	0.7507	0.7363	0.9228	0.8415	0.3298	0.2996	0.9453	0.1563	0.0004	0.2006	0.3726	0.3172	0.0779	0.0737	0.5790
Avg BA < 25%	0.8771	0.1583	0.3534	0.3552	0.2701	0.8172	0.9510	0.9544	0.7735	0.7225	0.7728	0.5146	0.6328	0.5214	0.4809	0.9996	0.3073	0.3836	0.2845	0.8203	0.7449
Avg BA < 50%	0.1133	0.4793	0.4893	0.3143	0.0257	0.1970	0.4136	0.7222	0.9113	0.0046	0.0700	0.3699	0.8551	0.4224	0.2144	0.9342	0.0260	0.0511	0.0788	0.5614	0.9621
Avg BA > 50%	0.4748	0.1531	0.4922	0.1290	0.8361	0.3965	0.7382	0.5944	0.1610	0.0354	0.5261	0.4869	0.4236	0.0570	0.7539	0.8023	0.0034	0.6779	0.9560	0.9729	0.4364
Avg BA > 75%	0.3261	0.0189	0.9844	0.4266	0.7671	0.3236	0.9108	0.5262	0.7720	0.5431	0.4344	0.0849	0.7606	0.6625	0.5806	0.4820	0.8853	0.9776	0.7399	0.3888	0.1928
Avg BA > 95%	0.1146	0.6048	0.6545	0.6875	0.5941	0.9969	0.8474	0.8639	0.0719	0.6952	0.7473	0.8409	0.1588	0.7092	0.5982	0.3269	0.3521	0.0603	0.2585	0.8754	0.4153

Table A6 Timepoint Comparison P-Values for Non-Dominant Leg. Red filled represents a confounded variable a p-value could not be calculated. 1 = Session 1 and 2 Females. 2 = Session 3 and 4 Females. 3 = Session 3 and 4 Males

	Proximal									Central						Distal					
	LONG			TRANS 1			TRANS 2			LONG			TRANS			LONG			TRANS		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	0.0018	0.8440	0.1574	0.0002	0.4606	0.9150	0.0001	0.4016	0.8934	0.0001	0.7198	0.7428	0.0001	0.6520	0.8368	0.0254	0.6990	0.4194	0.0275	0.3758	0.8703
Median	0.0051	0.8973	0.1549	0.0002	0.6378	0.8341	0.0001	0.3499	0.8901	0.0001	0.6186	0.7649	0.0001	0.7807	0.7739	0.0190	0.8340	0.4521	0.0420	0.3380	0.9349
Variance	0.0011	0.0119	0.6078	0.0001	0.5436	0.3416	0.0001	0.7357	0.5540	0.0001	0.9696	0.7653	0.0001	0.6179	0.7053	0.0001	0.0204	0.8896	0.0025	0.0527	0.8586
Skewness	0.9071	0.8884	0.4654	0.0349	0.0423	0.3389	0.9592	0.3122	0.7410	0.8266	0.3219	0.8434	0.0699	0.2516	0.1872	0.4754	0.3626	0.7968	0.3854	0.3802	0.0363
Kurtosis	0.3659	0.3010	0.7610	0.0029	0.8341	0.3565	0.3284	0.3400	0.9505	0.7273	0.4308	0.8692	0.0400	0.9404	0.0866	0.7555	0.9896	0.4573	0.6585	0.1592	0.4332
Entropy	0.0248	0.0327	0.1407	0.5331	0.9705	0.3096	0.0124	0.2408	0.7947	0.0087	0.0277	0.2014	0.0015	0.1991	0.8046	0.0047	0.1825	0.4922	0.0242	0.3942	0.7531
Contrast	0.0283	0.7585	0.1741	0.0005	0.1851	0.4597	0.0124	0.2742	0.7745	0.0002	0.3589	0.6671	0.0024	0.2630	0.9346	0.0132	0.1655	0.9099	0.7509	0.3468	0.6786
Energy	0.0015	0.3381	0.6777	0.0001	0.3547	0.4084	0.0002	0.6460	0.4997	0.0010	0.6674	0.9694	0.0001	0.2285	0.9316	0.0070	0.0240	0.6896	0.0649	0.1076	0.9877
Homogeneity	0.0948	0.9305	0.0940	0.0009	0.1081	0.6758	0.0176	0.1804	0.7356	0.0036	0.4749	0.9053	0.0064	0.1146	0.9639	0.3497	0.2153	0.9469	0.3597	0.4420	0.7742
BC < 5%	0.0581	0.9434	0.3852	0.2130	0.0445	0.8462	0.8438	0.0882	0.8590	0.1863	0.1725	0.6688	0.0108	0.4901	0.4485	0.0687	0.8980	0.8276	0.0556	0.8901	0.4664
BC < 25%	0.1769	0.0847	0.5870	0.8233	0.7583	0.1445	0.0467	0.1614	0.2758	0.3657	0.0295	0.0401	0.4396	0.3568	0.7510	0.0122	0.1077	0.0220	0.0230	0.8021	0.7094
BC < 50%	0.0142	0.1518	0.6892	0.1829	0.2448	0.4660	0.0108	0.6866	0.8213	0.0051	0.0881	0.8502	0.0011	0.8066	0.4871	0.1645	0.1387	0.6135	0.0054	0.3827	0.4617
BC > 50%	0.0003	0.5465	0.1604	0.1390	0.9973	0.6922	0.0617	0.2093	0.7900	0.0042	0.2028	0.9373	0.0760	0.1667	0.4424	0.0156	0.4885	0.9187	0.0149	0.6298	0.2919
BC > 75%	0.3657	0.1214	0.9886	0.7815	0.6461	0.8887	0.8022	0.0556	0.8329		0.0564	0.0401	0.2572	0.4353	0.4374	0.0476	0.6926	0.4980	0.2200	0.7539	0.9791
BC > 95%	0.0007	0.9113	0.9772	0.0539	0.3799	0.8672	0.0650	0.1157	0.7296	0.0016	0.0061	0.2299	0.0322	0.2262	0.7901	0.0042	0.0044	0.7858	0.0770	0.8785	0.7277
Avg BA < 5%	0.5898	0.2066	0.7510	0.2521	0.0526	0.9294	0.2218	0.7454	0.5716	0.5427	0.7846	0.6110	0.6915	0.5912	0.8097	0.7351	0.6090	0.4107	0.8544	0.9647	0.3771
Avg BA < 25%	0.0819	0.3140	0.3822	0.9687	0.6088	0.3621	0.9790	0.5785	0.2792	0.0702	0.4016	0.9418	0.2315	0.8072	0.5751	0.0511	0.5813	0.2095	0.7456	0.4406	0.7777
Avg BA < 50%	0.2740	0.7545	0.3135	0.2995	0.1465	0.8421	0.0717	0.4096	0.8560	0.4790	0.5345	0.4023	0.3084	0.2032	0.8394	0.4670	0.5388	0.2664	0.2583	0.9731	0.1884
Avg BA > 50%	0.1399	0.0710	0.6292	0.8261	0.9287	0.4291	0.9112	0.4298	0.4385	0.0434	0.6810	0.0765	0.0945	0.5542	0.7233	0.1861	0.7255	0.9552	0.5831	0.8708	0.4278
Avg BA > 75%	0.0790	0.3317	0.4548	0.3483	0.6559	0.4956	0.1606	0.3869	0.5429	0.1422	0.6961	0.7205	0.3416	0.5220	0.8663	0.5452	0.5082	0.8191	0.4698	0.4302	0.7160
Avg BA > 95%	0.0347	0.0337	0.1429	0.0588	0.1079	0.1798	0.8147	0.4446	0.7861	0.7139	0.2243	0.9611	0.9246	0.0670	0.8540	0.4301	0.0532	0.7480	0.4893	0.2195	0.2799

B Code

B.1 1st, 2nd and Blob Analyses Code

```
% Blob Analysis Code - Patellar Tendon
% Author: Sarah Crimmins
% This code calculates 1st, 2nd and blob analyses statistics for a
    DICOM
% images in one file folder. Displays each of the blob percentile
    binary
% images

% Initializing Variables
close all; imtool close all; clc;
files = seriesDetails.Filenames{1}; % reads the information about
    the DICOM image
i = 1;

% Declare subject
subject = 'sub1_right_';

% While loop to run through all of the images in the folder
while i <= length(files)

    % Reading the DICOM Image File
    file = files(i);
    info = dicominfo(file);
    tag = info.Private_7fe1_1001.Item_1.Private_7fe1_1073.Item_1.
        Private_7fe1_1075.Item_8.Private_7fe1_1057;
```

```
   % Looking at Power Doppler images only
  if startsWith(tag, 'PWDP')
      [im, ~, ~] = dicomread(file);
      [~, ~, ~, n] = size(im);

      for j = 1:n

          % Showing image
          figure
          imshow(im)

          % Initialization for drawing the Region of Interest
          makeBox = @(region) double([region.RegionLocationMinX0+1
          region.RegionLocationMinY0+1
          region.RegionLocationMaxX1-region.RegionLocationMinX0
          region.RegionLocationMaxY1-region.RegionLocationMinY0]);

          figure
          imshow(im)

          % Drawing the Region of Interest (ROI)
          roi = drawpolygon('FaceAlpha', 0, 'LineWidth', 1, '
              MarkerSize', 0.5);
          roiVertices = roi.Position; close;
          roi = drawpolygon('Position', roiVertices, 'Color', 'g')
              ;
          mask = roi.createMask;
```

```

            % Creating a mask with only the ROI
            maskPixels = uint8(mask).*im;
            maskPixels_double_color = double(maskPixels);
            maskPixels_double_color(maskPixels_double_color == 0) = NaN;

            % Taking away the colored pixels
           idx = abs(maskPixels_double_color(:,:,1)-maskPixels_double_color(:,:,2)) >=2 | abs(maskPixels_double_color(:,:,2)-maskPixels_double_color(:,:,3)) >=2;

           number_of_color_pixels = sum(idx, 'all') % calculating how many total color pixels

           maskPixels_double = maskPixels_double_color;

            for x = 1:(size(maskPixels_double_color,1))
                for y = 1:(size(maskPixels_double_color,2))
                    if idx(x,y) == 1
                        maskPixels_double(x,y,:) = NaN;
                    end
                end
            end

            % Showing new image
            figure
```

```
        imshow(maskPixels_double)

        maskPixels_double =  maskPixels_double(1:size(maskPixels_double,1),1:size(maskPixels_double,2));
        figure
        imshow(maskPixels_double,[0 255])
        maskPixels_filt = medfilt3(maskPixels_double); % filtering

        % 1st and 2nd
        [first_order_GS_stats, first_order_GS_data] = calcFirstOrderStatsGS(maskPixels_filt);
        first_order_GS_stats
        second_order_GS_stats = calcSecondOrderStats(maskPixels_filt./255)

        % Calculating the Percentile of the Image
        percentile5 = prctile(maskPixels_filt,5,"all")
        percentile25 = prctile(maskPixels_filt,25,"all")
        percentile50 = prctile(maskPixels_filt,50,"all")
        percentile75 = prctile(maskPixels_filt,75,"all")
        percentile95 = prctile(maskPixels_filt,95,"all")

        % Calcualting the binary image
        BW_5_flip = not(imbinarize(maskPixels_filt, percentile5)).*maskPixels_filt;
        BW_5 = imbinarize(BW_5_flip);
```

```
            BW_25_flip = not(imbinarize(maskPixels_filt,
                percentile25)).*maskPixels_filt;
            BW_25 = imbinarize(BW_25_flip);
            BW_50_more = imbinarize(maskPixels_filt, percentile50);
            BW_50_less = imbinarize(not(imbinarize(maskPixels_filt,
                percentile50)).*maskPixels_filt);
            BW_75 = imbinarize(maskPixels_filt, percentile75);
            BW_95 = imbinarize(maskPixels_filt, percentile95);

            % Displaying Blobs
            figure
            imshow(BW_5)
            title('5 Percent')

            figure
            imshow(BW_25)
            title('25 Percent')

            figure
            imshow(BW_50_more)
            title('50 Percent')

            figure
            imshow(BW_50_less)
            title('50 Percent Flip')

            figure
            imshow(BW_75)
```

```
        title('75 Percent')

        figure
        imshow(BW_95)
        title('95 Percent')

        % Blob Calculations (Blob count and Blob Area) using
            MATLAB
        % blob analysis
       Hblob = vision.BlobAnalysis('AreaOutputPort',true);
       [area_5, centroid_5] = Hblob(BW_5);
       [area_25, centroid_25] = Hblob(BW_25);
       [area_50, centroid_50] = Hblob(BW_50_more);
       [area_50_flip, centroid_50_flip] = Hblob(BW_50_less);
       [area_75, centroid_75] = Hblob(BW_75);
       [area_95, centroid_95] = Hblob(BW_95);

       number_blobs_5 = length(area_5)
       number_blobs_25 = length(area_25)
       number_blobs_50 = length(area_50)
       number_blobs_50_flip = length(area_50_flip)
       number_blobs_75 = length(area_75)
       number_blobs_95 = length(area_95)

       mean_area_5 = mean(area_5)
       mean_area_25 = mean(area_25)
       mean_area_50 = mean(area_50)
       mean_area_50_flip = mean(area_50_flip)
```

```
            mean_area_75 = mean(area_75)
            mean_area_95 = mean(area_95)

            percentiles_blob = [percentile5, percentile25,
               percentile50, percentile75, percentile95]
            number_of_blobs = [number_blobs_5, number_blobs_25,
               number_blobs_50, number_blobs_50_flip, number_blobs_75
               , number_blobs_95];
            mean_area_blobs = [mean_area_5, mean_area_25,
               mean_area_50, mean_area_50_flip mean_area_75,
               mean_area_95];

            name_border = convertCharsToStrings(subject)+
               convertCharsToStrings(tag)+"_border";

            % Saving Options for Session
            save(fullfile("Baskeball Images by Month/2017_NOV/
               Nov_Data/",name_border), 'roi');
            %save(fullfile("Baskeball Images by Month/2018_APR/
               Apr_18_Data/", name_border), 'roi');
            %save(fullfile("Baskeball Images by Month/2018_OCT/
               Oct_18_Data/", name_border), 'roi');
            %save(fullfile("Baskeball Images by Month/2019_APR/
               Apr_19_Data/", name_border), 'roi');

            first_order_GS_stats_cell = cell2mat(struct2cell(
               first_order_GS_stats)).'
```

```
second_order_GS_stats_cell = cell2mat(struct2cell(second_order_GS_stats)).'

GS_stats_cell = {first_order_GS_stats_cell, second_order_GS_stats_cell}
save_var = {subject, tag, first_order_GS_stats_cell(1), first_order_GS_stats_cell(2), first_order_GS_stats_cell(3), first_order_GS_stats_cell(4),first_order_GS_stats_cell(5),first_order_GS_stats_cell(6), second_order_GS_stats_cell(1), second_order_GS_stats_cell(2), second_order_GS_stats_cell(3) , number_of_blobs(1), number_of_blobs(2), number_of_blobs(3), number_of_blobs(4), number_of_blobs(5), number_of_blobs(6), mean_area_blobs(1), mean_area_blobs(2), mean_area_blobs(3), mean_area_blobs(4), mean_area_blobs(5), mean_area_blobs(6), percentiles_blob(1), percentiles_blob(2),  percentiles_blob(3), percentiles_blob(4),  percentiles_blob(5), number_of_color_pixels}

tag_string = convertCharsToStrings(tag)
[success, message]  = xlsappend('Baskeball Images by Month\2017_NOV\Nov_Data\November_Data.xlsx',save_var,1)
```

```
            %[success, message]  = xlsappend('Basketball Images by
                Month\2018_APR\Apr_18_Data\April_18_Data.xlsx',
                save_var, 1)
            %[success, message]  = xlsappend('Basketball Images by
                Month\2018_OCT\Oct_18_Data\October_18_Data.xlsx',
                save_var, 1)
            %[success, message] = xlsappend('Basketball Images by
                Month/2019_APR/Apr_19_Data/April_2019_Data.xlsx',
                save_var,1)
        end

    end
    i = i+1;
end
```

B.2 1st Order Calculation Function

```
%Calculate First Order Stats Grey Scale
%Author: Zachary Kozar
%The entropy calculation needs to be fixed, it includes the regions
    where the SWE map is black or saturated

function [stats, data] = calcFirstOrderStatsGS(grayscaleImage)
    IMG = double(grayscaleImage);
    data = IMG(IMG ~= 0);
    data = IMG(~isnan(IMG));

    stats.Mean = mean(data);
```

```
    stats.Median = median(data);
    stats.Variance = var(data);
    stats.Skewness = skewness(data);
    stats.Kurtosis = kurtosis(data);

    tmp = im2double(grayscaleImage);
    tmp(tmp == 0) = NaN;
    stats.Entropy = entropy(tmp);
end
```

B.3 2nd Order Calculation Function

```
% Calculates Second Order Stats Grey Scale
% Author: Zachary Kozar
function stats = calcSecondOrderStats(grayscaleImage)
%     tmp = im2double(grayscaleImage);
%     tmp(tmp == 0) = NaN;

    matrix = graycomatrix(grayscaleImage, 'Offset', [-5 0], '
       NumLevels', 8);
    stats = graycoprops(matrix,{'contrast', 'energy', 'homogeneity'
       });
end
```