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Beyond the Diagnosis: Using Patient Characteristics and Domains of Tendon Health to Identify Latent Subgroups of Achilles Tendinopathy

Treatment for Achilles tendinopathy has evolved over the past 2 decades, reflecting a maturing understanding of pathophysiology.[37,61,68] Exercise therapy is the current gold standard for treating Achilles tendinopathy; however, not all patients achieve full recovery.[4,19,34,39] Up to 4 in every 10 patients continue to report poor outcomes following 12 weeks of treatment.[5,19,27,44,50,54,65] Recovery remains poorly defined for tendinopathy, which impedes the ability to measure success in rehabilitation.[54] Symptom resolution, return to participation, and normalization of tendon structure are all important but individually may not ensure complete recovery for all patients.[25,60]

OBJECTIVE: To identify latent subgroups among patients with Achilles tendinopathy, describe patient characteristics and clinical attributes that defined each subgroup, and develop a clinical classification model for subgroup membership.

DESIGN: Cross-sectional study.

METHODS: One hundred forty-five participants (men, n = 73; mean ± SD age, 51 ± 14 years) with clinically diagnosed Achilles tendinopathy completed a baseline evaluation, including demographics and medical history, patient-reported outcome measures, a clinical exam, tendon structure measures via ultrasound imaging and continuous shear-wave elastography, and a functional test battery. Subgroups were identified using mixture modeling. We compared the subgroups using a 1-way analysis-of-variance or chi-square test and the Tukey post hoc test to identify defining attributes. We developed a clinical classification model using logistic regression and receiver operating characteristic curves.

RESULTS: Three latent subgroups were identified and named by their distinctive patient characteristics and clinical attributes. The activity-dominant subgroup (n = 67), on average, had the highest physical activity level, function, and quality of life; reported mild symptoms; and was the youngest. The psychosocial-dominant subgroup (n = 56), on average, had the worst symptoms, impaired function, heightened psychological factors, the poorest quality of life, minimal tendon structural alterations, and was obese and predominantly female. The structure-dominant subgroup (n = 22), on average, had the most tendon structural alterations, severe functional deficits, moderate symptoms and psychological factors, reduced quality of life, and was the oldest, obese, and predominantly male. The clinical classification model correctly classified 85% (123/145) of participants.

CONCLUSION: Three Achilles tendinopathy subgroups (activity dominant, psychosocial dominant, and structure dominant) differed in patient characteristics and clinical attributes. *J Orthop Sports Phys Ther 2021;51(9):440-448. Epub 1 Jun 2021. doi:10.2519/jospt.2021.10271*

KEY WORDS: *Achilles tendon pain, clinical classification, mixture modeling, tendinitis, tendon*

Individual differences between patients with Achilles tendinopathy are poorly understood due to insufficient reporting of patient characteristics.[46] Therefore, clinicians have limited evidence to inform their treatment plan or determine a patient's prognosis. Generic approaches to treating Achilles tendinopathy will dominate until clinicians and researchers understand individual differences and which factors influence treatment outcomes. If patients could be classified into distinct subgroups by their specific deficits and other related factors, then treatment could shift from a one-size-fits-all approach[54] to an individualized treatment strategy. To understand whether there are ways to improve treatment strategies for patient-specific recovery, it is important to evaluate whether all patients diagnosed with Achilles tendinopathy are affected in the same way or whether there are subgroups that might need additional or modified treatment strategies.

Mixture modeling is a method for classifying individuals into heterogeneous subgroups within a population

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when the groups are not known a priori.[43] This model-based approach focuses on relationships among individuals and identifies patterns among individuals, separating those who are less similar and grouping those who are more similar. Mixture modeling has helped derive targeted treatment approaches for disorders that are multifaceted in nature (eg, low back pain).[62] No previous study has applied mixture modeling to Achilles tendinopathy.

The purpose of our study was 3-fold: (1) to identify subgroups of patients with Achilles tendinopathy, (2) to describe which patient characteristics and clinical attributes define each subgroup, and (3) to develop a clinical classification model for identifying subgroup membership.

METHODS

A cross-sectional study was conducted within 2 larger longitudinal studies in patients with Achilles tendinopathy. Selection criteria were consistent with the parent studies, from which we analyzed baseline data.

Participants

Participants were asked to provide informed consent if they were at least 18 years of age and had a clinical diagnosis of Achilles tendinopathy (insertional or midportion). The clinical diagnosis was established by (1) pain on palpation at either the calcaneal insertion or the midportion of the Achilles tendon, (2) self-reported pain with loading, and (3) self-reported impaired function (eg, reduced ability to participate in activities of daily living/work/sport).[32,52] Exclusion criteria were previous Achilles tendon rupture, diagnosis of bursitis only, or another injury that limited participants' ability to complete the tests. All participants were recruited by referral from local physicians, at physical therapy clinics, and via advertisements. Data were collected between November 2014 and December 2019. Data extracted from both studies were approved by the Institutional Review Board at the University of Delaware (ID 1090153-18 and ID 1063764-12).

Variables

To be as inclusive as possible, we selected 14 variables that were (1) reported as outcome measures in previous tendinopathy studies, (2) clinically meaningful, (3) established as being associated with Achilles tendinopathy, and (4) collected in the parent studies (**FIGURE 1**). The variables represent 5 domains of tendon health[57] and promote a biopsychosocial appraisal of the patient suffering from tendinopathy.

Symptoms The Victorian Institute of Sport Assessment-Achilles[47] (VISA-A) and self-rated pain with hopping evaluated pain and symptoms. The VISA-A is a valid and reliable measure of symptom severity in patients with Achilles tendinopathy and is scored from 0 to 100, where a lower score indicates more pain and symptoms. Participants performed 2 trials of 25 single-leg hops. Self-rated pain with hopping was recorded using a numeric pain-rating scale[17] scored from 0 (no pain) to 10 (worst pain imaginable).

Lower Extremity Function Jump performance and calf muscle endurance were measured via a single-leg countermovement jump (CMJ), a drop CMJ, and a heel-rise endurance test, using the MuscleLab measurement system (Ergotest Innovation AS, Porsgrunn, Norway).[56] Participants needed to jump at least 1 cm for MuscleLab to register a trial. Participants received a zero for height if they were unable to jump at least 1 cm. Participants who declined to attempt a jump for any reason were assigned no value for that trial. Average jump heights for the CMJ and drop CMJ were calculated from up to 3 attempted trials per test. Total heel-rise work was measured in joules (heel-rise height by repetitions by body mass). Physical activity level during the past week was assessed using the Physical Activity Scale[24] (PAS). The PAS is measured on a scale from 1 to 6, where 1 indicates hardly any physical activity and greater than 5 indicates vigorous physical activity for several days per week.

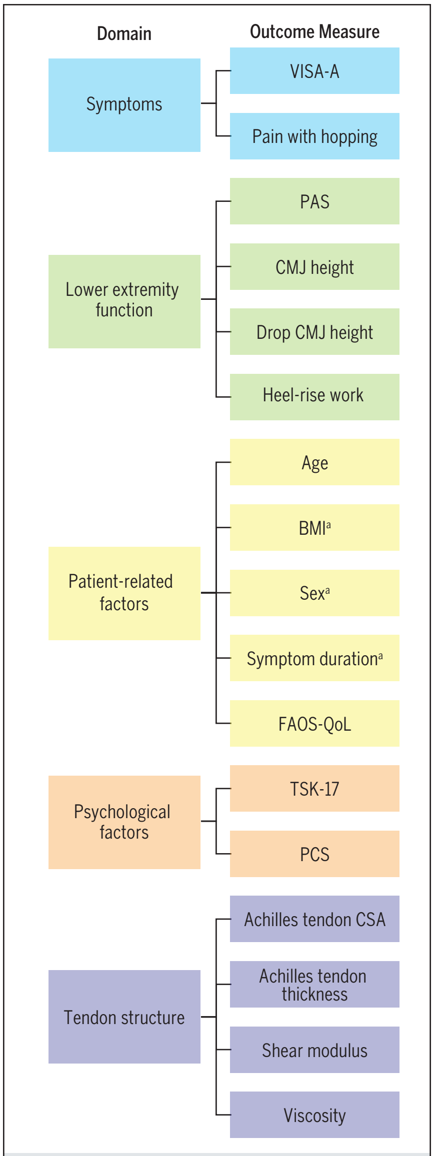

FIGURE 1. Domains and outcome measures of tendon health. [a]Not included in the mixture model. Abbreviations: BMI, body mass index; CMJ, countermovement jump; CSA, cross-sectional area; FAOS-QoL, Foot and Ankle Outcome Score foot and ankle–related quality of life subscale; PAS, Physical Activity Scale; PCS, Pain Catastrophizing Scale; TSK-17, 17-item Tampa Scale of Kinesiophobia; VISA-A, Victorian Institute of Sport Assessment-Achilles.

Patient-Related Factors Body mass index (BMI) was calculated from measured height and weight. Participant age and sex were collected and considered clinically relevant because tendon mechanical properties and morphology are different between sexes and change throughout the lifespan.[28,35] Quality of life was measured with the Foot and Ankle Outcome Score foot and ankle–related quality of life subscale[48] (FAOS-QoL) and considered to be a patient-related factor because it is "an individual's subjective evaluation of their overall well-being in the context of their own experiences."[9] A higher score (0-100) indicates a higher quality of life. Self-reported duration of symptoms (number of months) was collected because injury duration is proposed to affect nociception and affects quality of life.[18] Injury laterality (unilateral, bilateral) and location (insertional, midportion, both) were also recorded.

Psychological Factors The 17-item Tampa Scale of Kinesiophobia (TSK-17) measured fear of movement.[21,30,31] A higher TSK-17 score (17-68) indicates greater fear of movement, and a score of 37 or greater indicates high kinesiophobia.[21] The Pain Catastrophizing Scale[63] (PCS) measured pain catastrophizing. Participants reflect on past painful experiences and indicate the degree to which they experienced catastrophizing thoughts or feelings. A higher PCS score (0-52) indicates a higher degree of pain catastrophizing.

Tendon Structure and Mechanical Properties Achilles tendon structure was assessed using brightness-mode ultrasound imaging (frequency of 10 MHz and depth of 3.5 cm) on a LOGIQ *e* ultrasound scanner (General Electric Company, Boston, MA). All images were taken with the participant lying prone, with the feet hanging off the edge of the table. Measurements included tendon thickness and cross-sectional area (CSA) at the thickest portion, using previously described reliable procedures.[58,70]

Achilles tendon mechanical properties were measured using continuous shear-wave elastography, which has excellent reliability and validity.[13,14,64] This method is similar to commercial shear-wave elastography[16]; however, continuous shear-wave elastography uses an external actuator to generate shear waves and allows for extrapolation of 2 separate viscoelastic properties: shear modulus (ie, stiffness) and viscosity (rate-dependent stiffness) of the tendon.[13]

Statistical Analysis

Mixture modeling was used to identify the number of subgroups (best-fitting model), using the 14 variables described above (**FIGURE 1**). Measures for all analyses were taken from the most symptomatic limb (self-reported). The limb with the lower VISA-A[47] score was identified as "most symptomatic" for participants with bilateral symptoms. Mixture modeling was performed in Mplus (Version 8.3; Muthén & Muthén, Los Angeles, CA). Missing data were handled using Mplus and a robust maximum-likelihood estimator. A summary of missing data is presented in **APPENDIX A** (available at www.jospt.org).

Determining the number of subgroups depends on a number of factors in addition to fit statistics.[23,26,42] Fit statistics included Akaike's information criterion[3] (AIC), the Bayesian information criterion[51] (BIC), and the sample-adjusted BIC,[51] all of which have been considered to be the strongest indicators among the fit statistics of subgroup enumeration.[42] The best-fitting model should have the lowest AIC, BIC, and sample-adjusted BIC values.[26] The entropy criterion represents the ability of the model to provide well-separated subgroups; a higher value (0-1) indicates that the model has both strong separation between subgroups and strong cohesion within subgroups.[8] The Vuong-Lo-Mendell-Rubin (VLMR), sample-adjusted VLMR, and bootstrap likelihood ratio tests were used to compare statistical significance between the current model and one with 1 fewer subgroup (eg, 3 versus 2).[26] Finally, we ensured that each subgroup included greater than 5% of the sample[69] and used clinical expertise to interpret meaningful differences among subgroups.

Following subgroup enumeration, all variables were compared across subgroups, using analyses of variance for continuous variables, chi-square tests for categorical variables, and the Tukey post hoc test, with SPSS Version 26 (IBM Corporation, Armonk, NY). Sex, BMI, symptom duration, injury location, and injury laterality were used for post hoc comparisons across subgroups. All analyses were 2 sided, where $P<.05$ was considered statistically significant. All results are reported as mean ± SD unless otherwise stated. To help illustrate the group differences visually across domains, variables were rescaled to z scores and adjusted so that better performance is indicated by higher positive values (**FIGURES 2** and **3**).

The clinical classification model (**FIGURE 4**) was developed post hoc, using the results, to provide clinicians with a tool to classify patients via outcome measures that are accessible in clinical practice. Initially, a regression tree approach was attempted, using the variables included in the mixture model, but the results were unstable. Instead, a 2-step receiver operating characteristic (ROC) process was employed iteratively to differentiate between subgroups, using cut scores for each variable that jointly maximized sensitivity and specificity using Youden's index.[20] For each variable, individuals were scored as having met or not met the criteria.

RESULTS

The best-fitting model by information criteria (AIC, BIC, sample-adjusted BIC) identified 3 latent subgroups (**APPENDIX B**, available at www.jospt.org). The VLMR and sample-adjusted VLMR suggested 2 subgroups, although the 3-subgroup model was close to significantly better. The bootstrap version (bootstrap likelihood ratio) was uninformative, and entropy was good for all models. Ultimately, 3 subgroups were deemed most appropriate. The 3 patient subgroups were labeled activity dominant (n = 67), psychosocial dominant (n = 56), and structure dominant (n = 22) (**TABLE**), based on their respective distinguishing clinical features (**FIGURE 2**).

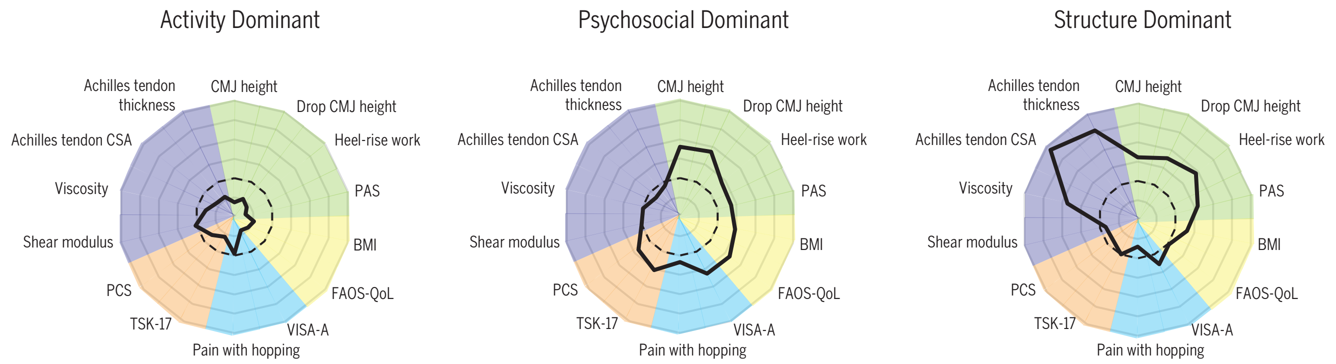

FIGURE 2. Comparison of subgroup performance on outcome measures, separated by tendon health domain. The dotted line represents the total sample. Variables were rescaled by standardizing and were adjusted so that less distance from the center represents lower deficit or better performance. Abbreviations: BMI, body mass index; CMJ, countermovement jump; CSA, cross-sectional area; FAOS-QoL, Foot and Ankle Outcome Score foot and ankle–related quality of life subscale; PAS, Physical Activity Scale; PCS, Pain Catastrophizing Scale; TSK-17, 17-item Tampa Scale of Kinesiophobia; VISA-A, Victorian Institute of Sport Assessment-Achilles.

Activity Dominant

On average, the activity-dominant subgroup reported the highest PAS, VISA-A, and FAOS-QoL scores, the lowest TSK-17 score and lowest BMI, and the youngest mean age (**TABLE**). The CMJ and drop CMJ values were significantly higher compared to other subgroups, and this subgroup produced nearly 2 and 5 times the heel-rise work compared to the psychosocial-dominant and structure-dominant subgroups, respectively (**TABLE**, **FIGURE 3**). Achilles tendon thickness was significantly less than that in the other subgroups, and CSA and viscosity were significantly better than those in the structure-dominant subgroup.

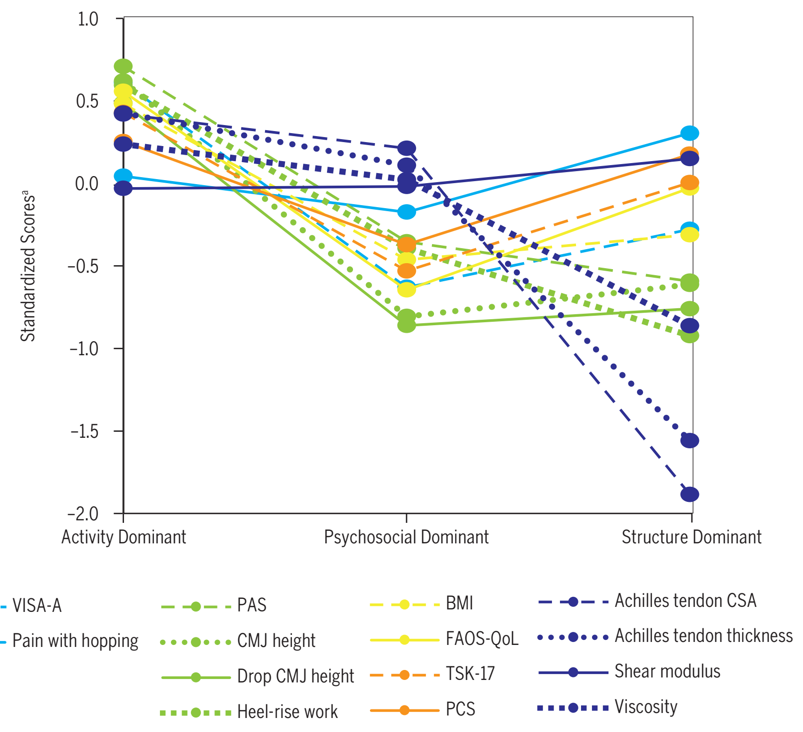

FIGURE 3. Comparison of similar and differing subgroup performances on outcome measures and respective tendon health domains. [a]Variables were rescaled by standardizing and were adjusted so that a higher standardized score indicates lower deficit or better performance. Abbreviations: BMI, body mass index; CMJ, countermovement jump; CSA, cross-sectional area; FAOS-QoL, Foot and Ankle Outcome Score foot and ankle–related quality of life subscale; PAS, Physical Activity Scale; PCS, Pain Catastrophizing Scale; TSK-17, 17-item Tampa Scale of Kinesiophobia; VISA-A, Victorian Institute of Sport Assessment-Achilles.

Psychosocial Dominant

On average, the psychosocial-dominant subgroup reported the greatest psychological response (TSK-17, PCS) and the lowest FAOS-QoL scores compared to the other subgroups (**TABLE**). This subgroup was older than the activity-dominant subgroup and performed significantly worse (although values were similar to those of the structure-dominant subgroup) on the following variables: VISA-A, PAS, CMJ height, and drop CMJ height (**FIGURES 2** and **3**). The psychosocial-dominant subgroup produced over 3 times more heel-rise work than did the structure-dominant subgroup, but significantly less than did the activity-dominant subgroup. Achilles tendon thickness, CSA, and viscosity measures were similar to those of the activity-dominant subgroup, but were significantly better than those of the structure-dominant subgroup. This subgroup was predominantly obese and 66% female.

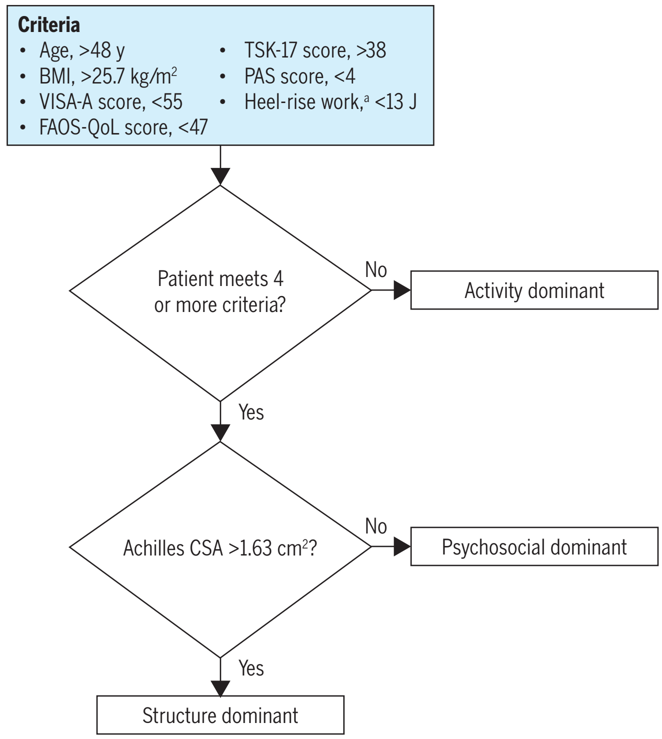

FIGURE 4. Clinical classification flow chart. [a]Formula for estimating heel-rise work (joules): [J = 59.44 × repetitions + (BMI × 5.87) – 7.3]. Abbreviations: BMI, body mass index; CSA, cross-sectional area; FAOS-QoL, Foot and Ankle Outcome Score foot and ankle–related quality of life subscale; PAS, Physical Activity Scale; TSK-17, 17-item Tampa Scale of Kinesiophobia; VISA-A, Victorian Institute of Sport Assessment-Achilles.

Structure Dominant

On average, the structure-dominant subgroup demonstrated the largest Achilles tendon thickness and CSA, the lowest viscosity, and produced the lowest heel-rise work (**TABLE, FIGURE 2**). This subgroup was the oldest, predominantly obese, and 77% male. The structure-dominant subgroup reported similar physical activity levels, but significantly higher quality of life, compared to the psychosocial-dominant subgroup.

Clinical Classification

Only variables with an ROC area under the curve cut point greater than 0.725 (BMI, TSK-17, age, PAS, FAOS-QoL, heel-rise work, and VISA-A) were retained in the final model (**FIGURE 4**). The presence of missing data (**APPENDIX A**) caused most combinations of potential predictors to have too few individuals in the structure-dominant subgroup using ROC curves. Alternatively, multinomial logistic regression suggested that a CSA greater than 1.63 cm^2 accurately classified 86% (18/21) of structure-dominant participants, while excluding everyone in the other 2 subgroups (**FIGURE 4**). Having 4 or more of the 7 criteria accurately classified individuals 85% of the time (105/123). Using both these rules accurately classified 85% (123/145) of participants (**FIGURE 4**).

DISCUSSION

We identified 3 subgroups—activity dominant, psychosocial dominant, and structure dominant—within a population of patients with Achilles tendinopathy using statistical modeling. The subgroups were identified by testing model fit using 14 variables commonly associated with tendinopathy, including clinical exam findings, patient-reported outcome measures, ultrasound imaging, patient-related factors, and lower extremity functional tests.

Our latent subgroups share parallels with the theoretical continuum model of tendon pathology, which proposed clinical heterogeneity among patients based on imaging, clinical findings, and histological evidence.[10] Our results support evaluating all domains of tendinopathy that may impact tendon and patient health.[66] While our findings cannot inform treatment recommendations, the distinguishing features of each subgroup reveal 3 differential patient profiles (**FIGURE 2**) that may explain the variability observed in both clinical practice and research outcomes.[12,33,49,50] Using the clinical classification model (**FIGURE 4**), clinicians can prospectively identify a patient's subgroup membership and recognize considerations for each subgroup and the potential obstacles to patient recovery.

The activity-dominant subgroup had the most members. These individuals demonstrated minimal performance impairments, suggesting a higher tendon load capacity than the other subgroups. This may be because they have less pathological tendons. Athletes with early-onset tendinopathy symptoms have demonstrated slight (25%) increases in tendon CSA, with unaltered tendon mechanical properties, compared to healthy controls. However, symptom duration was not a distinguishing factor among subgroups. Lower kinesiophobia may explain why activity-dominant participants reported a higher quality of life and high activity levels, or vice versa. If tendon structure dictates physiological capacity, then symptomatic patients with minimal alterations in tendon structure may present with minimal functional impairment.[61] Future research is needed to explore how activity-dominant patients respond to treatment. Due to the apparent minimal impact on tendon health, activity-dominant individuals may represent the majority of patients who achieve good to excellent results following 12 weeks of treatment.[7,45,53,65]

Psychosocial-dominant participants demonstrated minimal tendon structure and mechanical property alterations, similar to the activity-dominant subgroup, yet the subgroup performed significantly worse on the functional test battery and averaged more than 25 points lower on the VISA-A compared to the activity-dominant subgroup (**TABLE**). The higher degree of psychological impact reported by the psychosocial-dominant subgroup may provide some explanation. Kinesiophobic patients may avoid excessive loading due to fear of pain, making their condition worse. Fear-avoidance behaviors are associated with pain intensity[38,40] and could affect loading test performance (premature test cessation

TABLE Comparison of Patient Characteristics

Domain/Measure	Total Sample (n = 145)[a]	Latent Subgroup[a]: Activity[b]	Psychosocial[c]	Structure[d]	P Values: ANOVA	Activity Versus Psychosocial	Activity Versus Structure	Psychosocial Versus Structure
Symptoms								
VISA-A score	53 ± 21	66 ± 16	40 ± 18	47 ± 19	<.001[e]	<.001[e]	<.001[e]	.254
Pain with hopping (NPRS)[f]	2 ± 4	3 ± 2	3 ± 2	0 ± 3	.485	.663	.799	.510
Lower extremity function								
Physical Activity Scale[f]	5 ± 2	5 ± 1	3 ± 2	3 ± 2	<.001[e]	<.001[e]	<.001[e]	.999
CMJ height, cm	6.4 ± 3.6	8.6 ± 3.0	3.5 ± 1.9	4.2 ± 2.1	<.001[e]	<.001[e]	<.001[e]	.701
Drop CMJ height, cm	6.6 ± 3.5	8.5 ± 3.3	3.2 ± 2.3	3.6 ± 2.9	<.001[e]	<.001[e]	<.001[e]	.949
Heel-rise work, J[f]	1470 ± 1209	1832 ± 838	1062 ± 1415	336 ± 937	<.001[e]	<.001[e]	<.001[e]	.037[e]
Heel-rise endurance test, repetitions	21 ± 13	28 ± 9	16 ± 14	10 ± 10	<.001[e]	<.001[e]	<.001[e]	.061
Patient-related factors								
Age, y	51 ± 14	44 ± 13	55 ± 12	62 ± 8.7	<.001[e]	<.001[e]	<.001[e]	.048[e]
BMI, kg/m²	27.6 ± 6.74	24.3 ± 3.8	30.7 ± 7.1	30.7 ± 5.9	<.001[e]	<.001[e]	<.001[e]	.999
Sex, n[g]					.001[e]	.087	.042[e]	.001[e]
Male	73	37	19	17				
Female	72	30	37	5				
Duration of symptoms, mo[f]	10.2 ± 25.7	12 ± 25.1	10.3 ± 20.4	8 ± 20.6	.409	.949	.380	.526
FAOS-QoL score	44 ± 19	54 ± 16	32 ± 15	43 ± 14	<.001[e]	<.001[e]	.014[e]	.011[e]
Injury location, n					.643	.976	.708	.624
Midportion	100	48	36	16				
Insertional	36	16	16	4				
Both	9	3	4	2				
Bilateral symptom incidence, n (%)[g]	67 (46)	34 (51)	22 (39)	11 (50)	.420	.418	.998	.672
Psychological factors								
Tampa Scale of Kinesiophobia	38 ± 5	36 ± 5	41 ± 4	38 ± 5	<.001[e]	<.001[e]	.181	.081
Pain Catastrophizing Scale[f]	5 ± 8	6 ± 8	9 ± 13	5 ± 8	.002[e]	.002[e]	.942	.065
Tendon structure								
Achilles tendon CSA, cm²	1.0 ± 0.56	0.77 ± 0.3	0.88 ± 0.31	2.06 ± 0.14	<.001[e]	.158	<.001[e]	<.001[e]
Achilles tendon thickness, cm	0.78 ± 0.28	0.65 ± 0.2	0.74 ± 0.24	1.22 ± 0.14	<.001[e]	.052	<.001[e]	<.001[e]
Shear modulus, kPa	97.76 ± 16.55	97.25 ± 16.26	97.47 ± 15.32	100.24 ± 20.90	.791	.998	.781	.821
Viscosity, kPa·s	52.59 ± 12.60	55.60 ± 11.44	52.86 ± 12.26	41.69 ± 12.11	<.001[e]	.465	<.001[e]	.003[e]

Abbreviations: ANOVA, analysis of variance; BMI, body mass index; CMJ, countermovement jump; CSA, cross-sectional area; FAOS-QoL, Foot and Ankle Outcome Score foot and ankle–related quality of life subscale; NPRS, numeric pain-rating scale; VISA-A, Victorian Institute of Sport Assessment-Achilles.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*n = 67 (46%).*
[c]*n = 56 (39%).*
[d]*n = 22 (15%).*
[e]*Significant post hoc comparison (P<.05).*
[f]*Values are median ± interquartile range.*
[g]*The chi-square test was used to compare distribution among subgroups.*

or suppressing maximal jump height).[29,55] Research is needed to determine how psychological factors influence recovery times in patients with Achilles tendinopathy who are treated with exercise.[33,50] Loading the Achilles tendon through tolerable pain is safe and nondetrimental[59] to recovery. Future research should evaluate whether psychosocial-dominant patients are more reluctant to load their tendon due to kinesiophobia, and explore potential implications for rehabilitation compliance and progress.

The structure-dominant subgroup had the fewest members. This subgroup had the greatest degree of tendon alteration, demonstrated by measures of increased tendon thickness and CSA and decreased tendon viscosity (**FIGURE 2**). Accordingly, 32% of structure-dominant participants were unable to perform 1 heel-rise repetition, which may have indirect effects on other aspects of tendon health. Consistently, Corrigan et al[11] reported that greater tendon thickening and lower viscosity were associated with worse calf muscle endurance. Some of the differences observed between the structure-dominant subgroup and the other subgroups might also be due to body mass and age. In this subgroup, 86% were obese (BMI greater than 30 kg/m^2), which can increase Achilles tensile load 6 to 10 times for every 1 lb (0.45 kg) of excess weight.[1,22,67] From a general health viewpoint, this subgroup's patient-related factors raise concerns for comorbidities (eg, metabolic disease, sarcopenia, menopause) that could negatively affect tendon healing and lengthen the recovery timeline.[2,50] The extent to which tendon structural changes are reversible in response to nonsurgical and surgical treatments is still being debated.[6,15] Evidence supports the possibility of recovery of mechanical properties with aging.[41] Animal studies suggest that there is no decline in tendon synthesis capacity with aging; therefore, it is possible that detectable changes in tendon structure may require a greater length of time than previous studies have captured.[36] Because symptomatic recovery is achievable without functional recovery,[60] we considered the structure-dominant subgroup to have the greatest impairments in tendon health. Further research is warranted to determine whether this subgroup's propensity for recurrent injury differs compared to the general population. Further study is needed to determine how structure-dominant patients respond to exercise therapy, and whether tendon structural adaptations are achievable for these patients.

Limitations and Future Directions

It is possible for patients to fit into more than 1 subgroup in clinical practice, and clinical expertise should not be superseded by any model. The clinical classification model was developed without cross-validation using another sample. Therefore, further validation studies are needed. We acknowledge that additional subgroups might exist in youth and elite athletes or other unrepresented cohorts. Although we tried to be as exhaustive as reasonably possible, we were limited to the variables included in both parent studies. Differences in sex distribution among subgroups were an interesting and unexpected result and merit future research. Future prospective studies are needed to determine how subgroups respond to standardized treatment and to investigate the effectiveness of patient-centered treatment based on tendon health deficits.

CONCLUSION

The purpose of this study was to identify unobserved heterogeneity among patients with Achilles tendinopathy. We identified 3 Achilles tendinopathy subgroups (activity dominant, psychosocial dominant, and structure dominant) among the general population with Achilles tendinopathy that were distinct in their patient characteristics and clinical attributes. ◉

KEY POINTS

FINDINGS: Subgroups exist among patients diagnosed with Achilles tendinopathy in the general population. Patients can be classified as activity dominant, psychosocial dominant, or structure dominant.
IMPLICATIONS: Clinicians should evaluate for subgroup membership and conduct a comprehensive clinical examination that appraises all aspects of tendon and patient health. Our clinical classification model can inform clinical reasoning to recognize previously unobserved heterogeneity among patients.
CAUTION: Patient subgrouping is meant to elucidate the heterogeneous clinical presentation of patients and requires further validation. Regardless of subgroup membership, exercise therapy remains the treatment recommendation for patients with Achilles tendinopathy.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors planned the study. Shawn L. Hanlon performed the mixture modeling analysis under the supervision of Dr Pohlig. Dr Pohlig performed the statistical analysis for the clinical classification model. All authors contributed to the interpretation of results and the writing of the manuscript. All authors approved the final manuscript.
DATA SHARING: Data are available on reasonable request from the corresponding author.
PATIENT AND PUBLIC INVOLVEMENT: Patients and the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

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APPENDIX A

SUMMARY OF MISSING DATA

		Missing, n			
Variable	**n**	**Total**	**Activity Subgroup**	**Psychosocial Subgroup**	**Structure Subgroup**
BMI	144	1	0	1	0
CMJ	109	36	7	19	10
Tendon CSA	143	2	1	0	1
Drop CMJ	90	55	10	30	15
FAOS-QoL	144	1	1	0	0
Pain with hopping	77	68	21	32	15
Heel-rise work	139	6	1	3	2
Physical Activity Scale	144	1	1	0	0
Pain Catastrophizing Scale	142	3	2	1	0
Shear modulus	125	20	6	10	4
Symptom duration	138	7	4	2	1
Tendon thickness	144	1	1	0	0
Tampa Scale of Kinesiophobia	134	11	3	4	4
VISA-A	138	7	2	1	4
Viscosity	125	20	6	10	4
Age	145	0	0	0	0
Sex	145	0	0	0	0

Abbreviations: BMI, body mass index; CMJ, countermovement jump; CSA, cross-sectional area; FAOS-QoL, Foot and Ankle Outcome Score foot and ankle–related quality of life subscale; VISA-A, Victorian Institute of Sport Assessment-Achilles.

APPENDIX B

SUMMARY OF FIT STATISTICS[a]

Fit Statistic	2-Subgroup Model	3-Subgroup Model	4-Subgroup Model
AIC	12736.371	11736.4	12586.82
BIC	12873.3	11909.05	12819.01
SABIC	12727.74	11725.516	12572.19
Entropy	0.916	0.899	0.889
VLMR test	*P*<.001	*P* = .16	*P* = .63
SAVLMR test	*P*<.001	*P* = .16	*P* = .62
BLR test	*P*<.001	*P*<.001	*P*<.001

Abbreviations: AIC, Akaike information criterion; BIC, Bayesian information criterion; BLR, bootstrap likelihood ratio; SABIC, sample-adjusted Bayesian information criterion; SAVLMR, sample-adjusted Vuong-Lo-Mendell-Rubin; VLMR, Vuong-Lo-Mendell-Rubin.
[a]*The 3-subgroup model demonstrated the best fit.*