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Talar-Cartilage Deformation and Spatiotemporal Gait Patterns in Individuals With and Those Without Chronic Ankle Instability

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Context: Individuals with chronic ankle instability (CAI) present with alterations in the compositional structure of their talar articular cartilage. These alterations likely influence how the talar cartilage responds to the loading associated with activities of daily living, such as walking. Ultrasonography has emerged as an alternative imaging modality for assessing the amount of cartilage deformation in response to loading because it is clinically accessible and cost effective for routine measurements.

Objectives: To (1) compare talar-cartilage deformation in response to a standardized exercise protocol between those with and those without CAI and (2) examine the association between spatiotemporal walking gait parameters and cartilage deformation.

Design: Case-control study.

Setting: Research laboratory.

Patients or Other Participants: A volunteer sample of 24 participants with self-reported CAI (age = 23.2 ± 3.9 years, body mass index [BMI] = 25.1 ± 3.7 kg/m^2) and 24 uninjured controls (age = 24.3 ± 2.9 years, BMI = 22.9 ± 2.8 kg/m^2).

Main Outcome Measure(s): Spatiotemporal walking gait was first assessed from 5 self-selected trials using an electronic walkway with data sampled at 120 Hz. An 8- to 13-MHz linear-array ultrasound transducer placed transversely in line with the medial and lateral malleoli captured 3 images before and after a standardized loading protocol consisting of 30 single- and double-limb squats, 2-minute single-limb balance, and 10 single-legged drops from a 40-cm-height box.

Results: After controlling for BMI, we found that the participants with CAI had greater deformation than the uninjured control participants (P = .034). No other between-groups differences were observed (P values > .05). No significant partial correlations were noted between talar-cartilage deformation and spatiotemporal gait parameters when controlling for BMI (P > .05).

Conclusions: Individuals with CAI had greater talar-cartilage deformation in response to a standardized exercise protocol than control individuals. The amount of talar-cartilage deformation was not associated with the spatiotemporal walking gait.

Key Words: ultrasonography, walking, ankle sprain, case-control study

Key Points

- Compared with uninjured control participants, individuals with chronic ankle instability had a 37% increase in talar-cartilage deformation assessed via ultrasonography after a standard loading protocol.
- Individuals with chronic ankle instability did not adjust their spatiotemporal walking gait patterns.
- The amount of talar-cartilage deformation in response to a mechanical loading protocol and determined via ultrasonography was not associated with the spatiotemporal walking gait.

Posttraumatic osteoarthritis (PTOA) accounts for the majority of all end-stage ankle osteoarthritis cases.[1] This pathology is the result of a well-defined precipitating insult from a traumatic joint injury, such as a lateral ankle sprain (LAS). Adolescents and young adults have the highest incidence rate for sustaining an LAS.[2] Unfortunately, 40% to 70% of individuals never fully recover and develop chronic ankle instability (CAI),[3] a clinical condition characterized by recurrent joint injury, perceived instability, and repeated episodes of "giving way" at the ankle.[4] The repetitive nature of this complex clinical pathology likely explains the outcomes of prior epidemiologic studies in which CAI was the second leading cause of ankle PTOA, with most people diagnosed by their mid-50s.[1] Thus, researchers need to begin identifying the factors that contribute to the relationship between CAI and ankle PTOA.

Magnetic resonance imaging (MRI) is the most commonly used modality for in vivo assessments of articular cartilage health. However, the costs associated with MRI prohibit routine cartilage assessments of the many individuals who sustain ankle sprains throughout their life span. Routinely monitoring cartilage health could yield valuable insight into its decline as individuals transition from an index ankle sprain to recurrent ankle sprains and, ultimately, joint degeneration. Similarly, monitoring cartilage health could also provide insight into the effectiveness of different treatments in delaying cartilage degradation. Therefore, identifying methods that can provide economical and feasible measures to monitor changes in talar-cartilage integrity is important.

Ultrasonography has emerged as a reliable (intraclass correlation coefficient > 0.93) imaging modality for assessing the normalized cross-sectional area (CSA) of the talar cartilage.[5] Ultrasound measurements of the talar cartilage (eg, normalized CSA) have also been suggested as a possible surrogate for MRI-based measures of talar-cartilage volume ($r > 0.64$).[5,6] The added benefit of ultrasonographic measures of talar cartilage is that they are clinically accessible and a cost-effective method for routine evaluations.[5,6] Gross morphologic assessments (eg, thickness, volume) of articular cartilage can provide an overall estimate of cartilage structure. However, authors[7,8] have shown that individuals with CAI display changes in the compositional structure of the talar cartilage without gross morphologic degradation within 10 years postinjury. It is well established that the cartilage's compositional structure has a large influence on its response to mechanical loading. Because of this relationship, the early compositional changes, despite any morphologic degradation, would suggest that individuals with CAI might be more susceptible to talar-cartilage deformation after physical activity. Thus, assessing cartilage deformation (eg, changes in cartilage thickness) may provide valuable insight into early alterations of the talar cartilage among those with CAI before any declines occur in cartilage thickness.[6]

Prior investigators[9,10] using dual-orthogonal fluoroscopic and MRI techniques determined that the talar cartilage undergoes large deformations during activities of daily living. Walking is the most common activity of daily living, and individuals with CAI exhibited alterations in spatiotemporal gait mechanics compared with uninjured control participants.[11,12] Aberrant gait mechanics have been theorized to contribute to joint degeneration, given that abnormal cartilage loading could adversely affect the joint's ability to absorb forces properly.[6] This is supported by researchers who demonstrated that simple changes in the spatiotemporal gait parameters, such as gait speed, affected the ability of the knee cartilage to absorb forces[13] and its compositional structure.[14] However, no authors have examined the relationship between spatiotemporal gait parameters and cartilage deformation in those with CAI. Understanding the influence of gait parameters on cartilage deformation may help inform the development of evidence-based rehabilitation strategies for patients with CAI to mitigate or delay the onset of PTOA after an ankle sprain.

The purpose of our study was to compare ultrasound measurements of talar-cartilage deformation in response to a standardized exercise protocol and spatiotemporal walking gait parameters between individuals with and those without CAI. We hypothesized that participants with CAI would have greater talar-cartilage deformation than uninjured control participants. Additionally, we hypothesized that individuals with CAI would display decreased gait speed, take fewer and shorter strides, and spend less time in the single-limb support phase while walking compared with uninjured control individuals. The second purpose was to examine the association between ultrasound measurements of talar-cartilage deformation and spatiotemporal walking gait parameters. We hypothesized that talar-cartilage deformation in response to a standardized exercise protocol would be correlated with spatiotemporal walking gait parameters.

METHODS

Study Design

A case-control study design was used. The independent variable was group (CAI, uninjured control). The dependent variables were talar-cartilage deformation and spatiotemporal gait parameters. This study was approved by a university institutional review board. All participants read and signed an informed consent approved by the board before enrollment.

Sample Size Calculation

The previous literature[12] demonstrated that the average single-limb support time was 38.7% of the gait cycle (%GC) for individuals with CAI and 40.1%GC for uninjured control participants. Using $\alpha = .05$ and power = 80%, we estimated the required sample size at 24 per group.

No authors have investigated the influence of spatiotemporal gait measures on ankle cartilage deformation. Earlier authors who examined knee cartilage deformation and walking speed reported the estimated correlation as $r = 0.48$.[13] Using $\alpha = .05$ and power = 80%, we estimated the total sample size at 23 participants.

Based on these estimates, 24 participants were enrolled in each group. All a priori sample size estimates were calculated using G*Power (version 3.1; Heinrich-Heine-Universität Düsseldorf).[15]

Participants

We recruited participants between 18 and 35 years of age from a large university and the surrounding community. Participants were required to (1) have ≥ 1 acute LASs that resulted in pain, swelling, or temporary loss of function more than 6 months before enrollment; (2) report having at ≥ 2 episodes of giving way of the ankle in the 6 months before enrollment; and (3) score ≥ 11 on the Identification of Functional Ankle Instability tool and ≥ 5 on the Ankle Instability Instrument.[4] The limb with the higher number of giving-way episodes and greatest amount of perceived ankle instability was selected as the involved limb if a participant self-reported a bilateral ankle sprain history.

Participants were included in the uninjured control group if they (1) self-reported not having had an acute LAS, (2) had never experienced giving way at the ankle, and (3) scored 0 on the Identification of Functional Ankle Instability tool and the Ankle Instability Instrument. The test limb was randomly selected for the uninjured control group.

Participants were not eligible to volunteer if they had (1) been diagnosed with any balance, vestibular, or respiratory disorder; (2) a history of low back pain in the previous 6 months; (3) any history of fracture or surgery to the lower extremity; (4) any history of seizures; (5) a history of concussion in the past 6 months; (6) any history of neurologic injury or disease; (7) any history of self-reported musculoskeletal or neurovascular injuries; or (8) any injury to the lower extremity in the previous 6 months other than an LAS.

Instrumentation

Cartilage Deformation. A portable ultrasound unit (model LOGIQ e 2008; GE Healthcare) with an 8- to 13-MHz linear-array transducer (model 12L-RS; GE Healthcare) was used to collect images of the talar cartilage. All images were exported and uploaded to ImageJ software (National Institutes of Health) for manually segmenting of the thickness of the talar cartilage.

Spatiotemporal Gait Parameters. A GAITRite electronic walkway (CIR Systems Inc) was used to measure spatiotemporal gait parameters. The active collection zone of the electronic walkway is 7.32 m long and 0.61 m wide. Data were sampled at 120 Hz and processed using GAITRite Platinum software (version 4.7.7; CIR Systems Inc).

Procedures

Participants were instructed to refrain from any physical activity within 24 hours of the testing session. They reported to the research laboratory for a single testing session, at which they first completed all required paperwork, including a standard health history questionnaire and the Foot and Ankle Ability Measure, and then performed all walking trials before undergoing the procedures used to assess cartilage deformation.

Cartilage Deformation. Talar-cartilage deformation was assessed using a published protocol[16–18] to examine cartilage deformation of the talus in healthy adults using MRI. First, participants assumed the long-seated position on a standard treatment plinth with the back supported against a wall for 30 minutes. Then, while still seated against the wall, the hip and knee were positioned in 90° of flexion and the foot was placed flat on the plinth (approximately 140° of plantar flexion).[5] The ultrasound transducer was placed transversely in line with the most prominent aspect of the medial and lateral malleoli of the involved ankle and rotated to maximize the reflection of the talar cartilage.[5] Once the talar cartilage was properly identified in the field of view, 3 ultrasound images were captured.

Next, participants performed a standardized exercise protocol while barefoot (Figure 1). The standardized exercise protocol consisted of (1) 30 bilateral knee bends to maximal ankle dorsiflexion in 1 minute, (2) 30 unilateral knee bends to maximal ankle dorsiflexion on the involved limb in 1 minute, (3) 10 single-limb drops on the involved limb from a 40-cm-tall box, and (4) a 2-minute unilateral static balance task in maximal ankle dorsiflexion on the involved limb. All participants completed the exercises in the same order supervised by an investigator.

Returning to the plinth immediately after the standardized exercise protocol, the participant and transducer were placed in the same positions as for the baseline ultrasound images. Three additional ultrasound images were captured

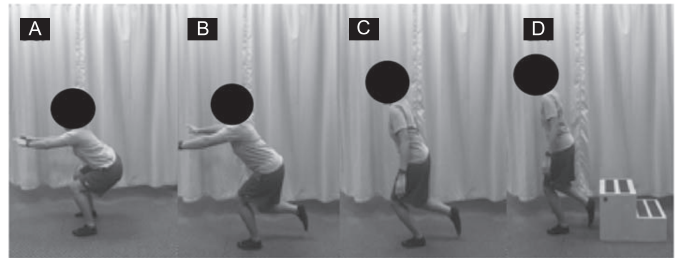

Figure 1. The standardized exercise protocol for assessing the amount of talar-cartilage deformation in response to mechanical loading. [a] Double-limb squat. [b] Single-limb squat. [c] Static balance. [d] Drop landing.

once the talar cartilage was properly identified in the field of view.

Spatiotemporal Gait Parameters. Participants were fitted with standard laboratory shoes (model Xccelerator; Nike) and provided 5 minutes for self-selected warm-up and stretching. They stood 3 m from the beginning of the electronic walkway and were instructed to walk across the mat at a self-selected pace while staring straight ahead. Each trial was terminated 3 m after the walkway to avoid any deceleration effect. Participants were provided 3 practice trials and then performed 5 test trials, with a 30-second rest period between trials. Test trials were discarded and repeated if the participant (1) stopped or slowed down while on the walkway, (2) tripped or took a double step, or (3) did not keep the eyes looking forward.

Data Analysis

Cartilage Deformation. We manually outlined the talar cartilage in each ultrasound image using ImageJ software based on previously described methods.[5] First, the talar cartilage was outlined using the polygon tool. The overall CSA area (mm^2) was calculated and normalized to the length of the talus (millimeters) in the corresponding image. The normalized CSAs for all 3 images captured before or after the standardized exercise protocol were averaged for each time point. Next, the raw average thicknesses for both time points were used to calculate percentage change scores to represent the amount of cartilage deformation. The following equation was used to calculate cartilage deformation, with a lower score indicating more deformation:

$$\text{Talar Cartilage Deformation} = \frac{\left(\text{Mean}_{\text{post}} - \text{Mean}_{\text{pre}}\right)}{\text{Mean}_{\text{pre}}} \times 100$$

The investigator (K.B.K.) responsible for collecting and processing all images was a certified athletic trainer with 8 years of clinical practice experience and 2 years of experience conducting ultrasound assessments. The investigator's intrarater reliability for 5 randomly selected participants was excellent (intraclass correlation = 0.976; 95% CI = 0.771, 0.998).

Spatiotemporal Gait Parameters. The data were analyzed using published methods.[11] Specifically, footfall data collected from each of the 5 trials were collapsed into a single overall test trial and averaged for each participant. Spatiotemporal data were processed and extracted for the involved limb using the GAITRite Platinum software.

Table 1. Participants' Anthropometric Data and Characteristics and Study Inclusion Criteria

Variable	Group (n) Chronic Ankle Instability (24)	Uninjured Control (24)
	Mean ± SD	
Age, y	23.2 ± 3.9	24.3 ± 2.9
Height, cm	166.5 ± 10.1	167.5 ± 6.9
Mass, kg	69.5 ± 11.9	64.4 ± 9.7
Body mass index, kg/m^2	25.1 ± 3.7	22.9 ± 2.8
Ankle Instability Instrument score	6.2 ± 1.6	0.0 ± 0.0
Identification of Functional Ankle Instability score	18.5 ± 5.0	0.0 ± 0.0
Lateral ankle sprains, No.	3.5 ± 3.1	0.0 ± 0.0
Giving-way episodes, No.	5.3 ± 6.4	0.0 ± 0.0
Foot and Ankle Ability Measure score, %		
Activities of Daily Living	85.5 ± 13.2	100.0 ± 0.0
Sport	72.5 ± 14.8	100.0 ± 0.0
	Yes, No. (%)	
Modify activity?	10 (40)	0 (0)
Feel at risk of reinjury?	16 (64)	0 (0)
Received rehabilitation?	10 (40)	0 (0)

The spatial parameters extracted for the involved limb were step length and stride length. The average step length and stride length extracted were normalized to each participant's height based on published methods.[11] The normalized step and stride length for the involved limb were then used for statistical analysis.

The temporal parameters extracted for the involved limb were gait speed, cadence, and each phase of the gait cycle. The average gait speed and cadence extracted were normalized using the nondimensional normalization procedures described earlier to minimize the effect of body size.[19,20] Normalized gait speed and cadence for statistical analysis were calculated using the following formulas :

$$\text{Normalized Gait Speed} = \frac{\text{Gait Speed}}{\sqrt{\left(\frac{9.81\text{m/s}^2}{\text{Height}}\right)}}$$

$$\text{Normalized Cadence} = \frac{\text{Cadence}}{\sqrt{\left(\frac{9.81\text{m/s}^2}{\text{Height}}\right)}}$$

The specific phases of the gait cycle extracted were the swing phase, stance phase, single-limb support, and double-limb support. The *swing phase* was defined as the time from toe-off of the involved limb until ground contact was made again. The *stance phase* was defined as the time between initial contact of the involved limb and toe-off. The *single-limb stance phase* was defined as the time between toe-off of the uninvolved limb and the first contact of the next footfall. The *double-limb support phase* was defined as the amount of time both feet were in contact with the ground simultaneously. Data representing each phase of the gait cycle were normalized as %GC and used for statistical analysis.

Statistical Analysis

We calculated descriptive statistics of all anthropometric data and primary outcome measures for both groups. All data were normally distributed based on the Shapiro-Wilk test ($P > .05$). First, separate independent-samples t tests were conducted to compare all anthropometric data between groups. Age, height, and mass were not different between groups (P values $> .05$); however, the average body mass index (BMI) was higher in the CAI group than in the uninjured control group ($P = .029$).

A between-groups analysis of covariance to control for BMI was performed to compare the amount of talar-cartilage deformation in response to the standardized exercise protocol. Secondly, separate analyses of covariance controlling for BMI were conducted to compare the descriptive data for all spatiotemporal gait parameters. Hedges g effect sizes with associated 95% CIs were determined for all primary outcome measures. Effect sizes were interpreted as *weak* ($\leq$0.39), *moderate* (0.40–0.69), or *large* ($\geq$0.70).[21]

We computed partial correlations to examine the relationships between all primary outcome measures while controlling for BMI. Correlation coefficients were interpreted as *weak* ($0.0 < r < 0.40$), *moderate* ($0.41 < r < 0.69$), or *strong* ($r > 0.70$).

All significance levels were set a priori at $P < .05$. All statistical analyses were performed using SPSS (version 25.0; IBM Corp).

RESULTS

Group means and SDs for all anthropometric data, inclusion criteria, and participant characteristics are listed in Table 1.

Ultrasound Measures

After we adjusted for BMI, the CAI group had greater talar-cartilage deformation ($F_{1,47} = 4.779$, $P = .03$) than the uninjured control group (Table 2). This was associated with a moderate effect size (–0.66; 95% CI = –1.23, –0.08). The unadjusted group means and SDs and individual data points are presented in Figure 2 to show the dispersion of the data.

Spatiotemporal Gait Parameters

The groups did not differ in any spatiotemporal gait parameters after we adjusted for BMI (Table 3).

Table 2. Ultrasound Measures of the Talar Cartilage Before and After the Standardized Exercise Protocol

Group (n)	Normalized Cross-Sectional Area, Group Mean (95% CI), mm[a] Pre-Exercise	Postexercise	Cartilage Deformation, % Change
Chronic ankle instability (24)	0.46 (0.42, 0.49)	0.38 (0.34, 0.41)	−17.3 (−20.3, −14.3)
Uninjured control (24)	0.43 (0.40, 0.47)	0.38 (0.34, 0.41)	−12.5 (−15.6, −9.5)

[a] Adjusted for body mass index.

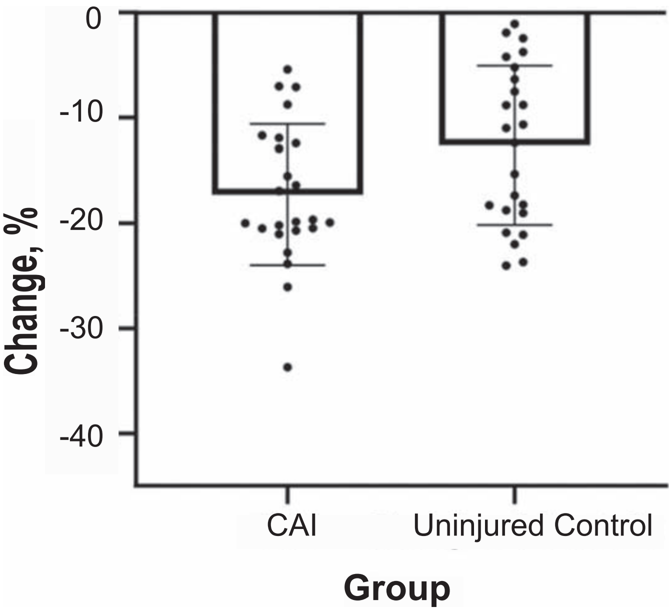

Figure 2. Talar-cartilage deformation unadjusted group means, SDs, and individual data points.

Relationship Between Deformation and Spatiotemporal Gait Parameters

Nonsignificant weak partial correlations were observed between talar-cartilage deformation and all spatiotemporal gait parameters when controlling for BMI (Table 4).

DISCUSSION

We sought to compare talar-cartilage deformation and spatiotemporal walking gait parameters between individuals with CAI and uninjured individuals. Secondly, we examined the association between spatiotemporal walking gait and talar-cartilage deformation. Talar-cartilage deformation was, on average, greater in participants with CAI than in the uninjured control group. However, spatiotemporal gait parameters did not differ between groups. Further, talar-cartilage deformation was not associated with any spatiotemporal gait parameter. Therefore, our results indicate that CAI was associated with greater talar-cartilage deformation in response to a standard exercise protocol, but this was not related to spatiotemporal gait.

Prior authors examining talar-cartilage deformation in response to weight-bearing exercises primarily applied MRI-based techniques. Van Ginckel et al[16,17] used the same weight-bearing exercises as we did but examined cartilage deformation in response to each of the 4 exercises separately. The average deformation across the entire talar surface ranged from 7.7% after 30 unilateral knee bends to 14.5% after a 2-minute unilateral static balance task among otherwise healthy individuals. In comparison, we examined cartilage deformation after participants completed all 4 weight-bearing exercises. The average adjusted talar-cartilage deformation in our CAI and uninjured control groups was 17.3% and 12.5%, respectively. Thus, our ultrasound-based method and exercise protocol of static and dynamic exercises for imposing a mechanical load through the ankle seems to have produced similar deformation levels as those in earlier studies.

Previous authors[5,8] demonstrated that cartilage morphology (eg, volume) based on MRI or resting-state ultrasound did not differ between college-aged individuals with CAI and age-matched uninjured individuals. In contrast, earlier MRI-based assessments (eg, T2 and T1ρ relaxation times) showed alterations in the compositional structure of the talar cartilage among young adults with CAI.[7,8] Therefore, researchers have suggested that alterations of the compositional structure in the absence of differences in talar-cartilage morphology among college-aged adults reflect the early pathogenesis of ankle PTOA. Our results support this hypothesis because the group averages for the resting-state ultrasound measurements before and after the standardized exercise protocol were fairly similar (Table 2). However, the individual changes (eg, cartilage deformation) in the resting-state ultrasound measurements in response to the standardized exercise protocol were different between

Table 4. Pearson Product-Moment Correlation Coefficients Controlling for Body Mass Index

Variable	Deformation, % Change	*P* Value
Normalized Value		
Gait speed	−0.221	.13
Cadence	−0.040	.79
Length, % of Height		
Step	−0.173	.24
Stride	−0.190	.20
Phase, % of Gait Cycle		
Swing	−0.079	.59
Stance	0.081	.58
Single-limb support	−0.100	.50
Double-limb support	0.124	.40

Table 3. Spatiotemporal Gait Parameter Measures

Variable	Group Mean (95% CI) Chronic Ankle Instability (n = 24)	Group Mean (95% CI) Uninjured Control (n = 24)	*P* Value	Hedges *g* (95% CI)
Normalized Value				
Gait speed	0.57 (0.55, 0.60)	0.58 (0.55, 0.60)	.93	0.01 (−0.57, 0.57)
Cadence	46.9 (46.0, 47.8)	47.1 (46.2, 48.0)	.74	0.01 (−0.57, 0.57)
Length, % of Height				
Step	44.1 (42.3, 45.9)	44.2 (42.3, 46.0)	.96	0.01 (−0.57, 0.57)
Stride	88.7 (85.2, 92.3)	88.2 (84.7, 91.8)	.84	0.01 (−0.57, 0.57)
Phase, % of Gait Cycle				
Swing	38.2 (37.6, 38.8)	38.4 (37.6, 38.8)	.98	−0.20 (−0.76, 0.37)
Stance	61.8 (61.2, 62.3)	61.7 (61.2, 62.3)	.97	0.21 (−0.36, 0.78)
Single-limb support	37.9 (37.3, 38.4)	38.0 (37.4, 38.5)	.83	−0.36 (−0.93. 0.21)
Double-limb support	24.1 (23.0, 25.2)	24.1 (23.0, 25.2)	.99	0.30 (−0.27, 0.87)

groups. Our findings support the current hypothesis because the cartilage response to mechanical loading is largely dependent upon its compositional structure.[22,23] Yet it is important to note that we did not confirm whether our participants presented with similar alterations of the compositional structure within the talar cartilage. Because of this, we can only speculate about the reason for our results.

Our data demonstrating a between-groups difference based on the individual changes in normalized CSA after the standardized exercise protocol highlight important considerations moving forward. Hertel and Corbett[24] recently described how individuals with CAI were not a homogeneous patient population. Similarly, the structural and functional variations in the talar cartilage are also likely not homogeneous across this patient population because of the participants past injury history or other biological characteristics (eg, sex). Thus, if the group average resting-state ultrasound measurement is the only comparator, then valuable information pertaining to the talar cartilage might be missed. In contrast, comparing the amount of change in response to mechanical loading may provide more insight into the effect of CAI at the individual level than at the group level. This can be seen in Figure 2, in which the individual amounts of change for all the participants in each group are represented. More specifically, the data in Figure 2 demonstrate how some participants experienced more noticeable changes in the normalized CSA than others. However, on average, participants with CAI generally experienced larger changes in the normalized CSA in response to the standardized exercise protocol than those in the uninjured control group. Researchers should build upon these findings by exploring other factors associated with CAI that might influence the magnitude of change in talar-cartilage deformation.

Our results demonstrated no differences in spatiotemporal walking gait between participants with CAI and the uninjured control group. Hence, our participants did not modify their spatiotemporal walking gait in response to chronic dysfunction after an ankle sprain. We hypothesized that participants with CAI would have aberrant spatiotemporal walking gait parameters consistent with outcomes in earlier studies[11,12] that used an electronic walkway and data-processing method similar to ours. The reason our findings are not aligned with this prior research could be related to subtle differences in how the data were collected. For instance, in both previous studies,[11,12] participants were required to walk barefoot at a self-selected speed across the electronic walkway. In contrast, we assessed spatiotemporal walking gait under a shod condition to increase the generalizability of our data to more common activities of daily living. Investigators need to consider these subtle methodologic differences when designing future studies so that the data can begin to be synthesized and more definitive conclusions can be drawn.

Finally, we did not observe a relationship between spatiotemporal walking gait and the magnitude of talar-cartilage deformation. We anticipated a relationship between these outcomes because results from prior MRI-based studies indicated that the talar cartilage undergoes large deformations during common activities of daily living.[9,10,25] Walking is the most frequent activity of daily living, and adjustments in spatiotemporal gait parameters likely affect the mechanical loading characteristics at the ankle. For example, adjusting the amount of time spent in each phase of the gait cycle may influence the duration of cartilage loading and perhaps the amount of cartilage deformation. This possible relationship is supported by the work of prior researchers,[9] who demonstrated that talar-cartilage deformation continued to increase under a sustained load for 15 seconds. Therefore, the reason why we did not observe a relationship between spatiotemporal walking gait and the magnitude of talar-cartilage deformation is less apparent. One possible explanation might be that our standardized exercise protocol was not specific enough to reflect the deformation that the talar cartilage undergoes during walking gait. Considering the type of exercises that made up our loading protocol, the induced deformation might reflect how the talar cartilage responds during more vigorous activities such as running, jumping, or landing. Another explanation might be that our spatiotemporal gait parameters were not based on the individual change after a standardized loading protocol similar to cartilage deformation. Instead, our spatiotemporal gait parameters provided a descriptive understanding of how participants with and those without CAI walk. As a result, the talar-cartilage deformation we observed is likely due to the standardized exercise protocol and the underlying ankle pathology rather than the spatiotemporal walking gait.

This study had limitations that should be taken into account. A primary concern associated with the ultrasound imaging technique is that only the anterior-superior aspect of the talar cartilage was captured. Not capturing the talus's entire surface prevented us from describing the total amount of deformation the talar cartilage underwent in response to a standard exercise protocol. Another limitation was that only 1 author, who was not blinded to group assignment, was responsible for acquiring the ultrasound images and segmenting the talar cartilage. However, we followed previously described methods for acquiring the ultrasound images and segmenting the talar cartilage. Moreover, we demonstrated excellent intrarater reliability in segmenting the talar cartilage. Thus, although only 1 investigator was responsible for acquiring the ultrasound images and segmenting the talar cartilage, we are confident that our data align with previously published research.[5] Another limitation was that only college-aged adults were enrolled, which decreases the generalizability of our data beyond early adulthood. Similarly, we did not directly assess the level of pain while walking or during the standardized exercise protocol. In the future, assessing the level of pain participants experience during each phase may provide further insight into these results. Lastly, we required each participant to wear the same type of shoe during the walking gait assessment to reduce the potential influence shoe wear had on outcomes. Despite this approach, the shoe we used might not be as common as other shoe types, forcing participants to walk in a shoe that was unfamiliar to them.

In conclusion, our data suggest the talar-cartilage deformation in response to a standardized exercise protocol was, on average, greater among individuals with CAI than uninjured control individuals. Secondly, the amount of talar-cartilage deformation in response to a standardized exercise protocol was not associated with spatiotemporal gait parameters.

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