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Differences in temporal gait mechanics are associated with decreased perceived ankle joint health in individuals with chronic ankle instability

Kyle B. Kosik[a,*], Masafumi Terada[b], Ryan McCann[c], Abbey Thomas[d], Nathan Johnson[a], Phillip Gribble[a]

[a] University of Kentucky, Lexington, KY, United States
[b] Ritsumeikan University, Kusatsu, Shiga-ken, Japan
[c] Old Dominion University, Norfolk, VA, United States
[d] University of North Carolina at Charlotte, Charlotte, NC, United States

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ABSTRACT

Background: Chronic ankle instability (CAI) is associated with an increased risk of developing post-traumatic osteoarthritis (PTOA). Altered temporal gait parameters likely contribute to the early development and progression of PTOA in CAI. However, it is unknown if increased clinical symptoms of ankle PTOA influence temporal gait parameters among those with CAI.
Research question: Compare temporal gait parameters and Ankle Osteoarthritis Scale (AOS) scores between individuals with and without CAI.
Methods: Thirty CAI participants and 30 healthy-controls volunteered to participate in this retrospective case-control study. Participants completed the Pain and Disability subscales of the AOS. Temporal gait parameters were assessed using a GAITRite® electronic walkway. Participants performed 5 walking trials, which were subsequently combined into a single test. Temporal variables (swing, stance, single-limb support and double-limb support) were extracted for the involved limb and normalized to percent of gait cycle (%GC).
Results: Participants with CAI had higher scores on the Pain ($P < 0.001$) and Disability ($P = 0.001$, $d = 0.87[0.33,1.39]$) subscales of the AOS. CAI individuals spent less time during swing ($P = 0.022$]) and single-limb support ($P = 0.030$) phases and more time during the double-limb support ($P = 0.021$) phase. Single-limb support time was moderately correlated with higher scores on the AOS pain ($r = -0.416$, $P = 0.011$) and disability ($r = -0.473$ $P = 0.004$) subscales.
Significance: Individuals with CAI spend varying times in each phase of the gait cycle compared to uninjured controls. Individuals with CAI may adopt this abnormal gait strategy due to increased clinical symptoms of ankle PTOA. Rehabilitation programs should focus on minimizing the symptoms of ankle PTOA to restore normal temporal gait parameters.

1. Introduction

Ankle post-traumatic osteoarthritis (PTOA) is associated with severe physical limitations, decreased physical activity levels and a lower health-related quality of life [1–3]. This debilitating joint disease is generally diagnosed when irreversible joint damage has occurred and symptoms are intolerable. Yet, researchers have found radiographic signs of PTOA as early as 6 months after an acute ankle sprain [4,5]; and others have demonstrated a loss of collagen fiber integrity and water content within the articular cartilage of the talocrural joint in young-adults (age 18–35 years) with chronic ankle instability (CAI) [6–9]. CAI is a clinical pathology often characterized by recurrent ankle sprains, increased perceived instability and repeated episodes of 'giving-way' [10]. Unfortunately, the prognosis of this early ankle joint degeneration among those with CAI is poor. In fact, end-stage ankle PTOA may occur in up to 78% of patients with CAI and take an average of 34 years to develop [11,12]. Furthermore, with the majority of patients developing CAI as a young-adult, a diagnosis of end-stage ankle PTOA typically occurs approximately 10 years earlier than that of primary end-stage ankle osteoarthritis (OA) [2]. With no viable conservative treatment for end-stage ankle PTOA, more research is needed to understand the early consequences of ankle PTOA, especially among individuals with CAI.

Current research has shown that in young-adults (age 18–35 years)

* Corresponding author at: 206B Wethington Building, 900 South Limestone Street, Lexington, KY, 40536-0200, United States.
E-mail address: kyle.kosik@uky.edu (K.B. Kosik).

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with a history of an ankle sprain, elevated T_2- relaxation times, a magnetic resonance imaging technique to quantify changes within the compositional structure of the articular cartilage, are associated with higher scores on the American Orthopedic Foot and Ankle Score (AOFAS) [8,9]. These findings indicate that early structural changes within the articular cartilage are related to increased clinical symptoms of ankle PTOA. Previous investigators have suggested that the symptoms associated with OA, regardless of the form, lead to patients adjusting their temporal gait mechanics to minimize the pain and disability arising from their affected ankle [13,14].

Despite mixed results, research has shown individuals with CAI modify their temporal walking and running gait mechanics relative to their healthy counterparts [15–17]. Along with other biomechanical factors, modifying the amount of time spent during each phase of the gait cycle is a concern as factors associated with loading (e.g. rate, magnitude, duration) of the articular cartilage influence the progression of PTOA [18]. Therefore, these abnormal cyclic temporal gait mechanics likely influence the duration the articular cartilage is loaded. Prolonged exposure to this decreased cumulative loading of the articular cartilage likely contributes to the progression of ankle PTOA in those with CAI. Subsequently, this may initiate symptoms of ankle joint degeneration that further exacerbate adjustments in temporal gait mechanics. However, there is currently a lack of understanding of this relationship between temporal gait mechanics and symptoms of ankle PTOA in those with CAI. Understanding this relationship may guide future research focused on developing interventions attempting to slow the progression of ankle PTOA in those with CAI. For example, gait training has previously shown to improve self-reported function and gait patterns after only five sessions in those with CAI [19].

Therefore, the primary purpose of this study was to compare temporal gait parameters and scores on the Pain and Disability subscales of the Ankle Osteoarthritis Scale (AOS) between individuals with and without CAI. The AOS is a commonly used disease-specific patient-reported outcome instrument for assessing the severity of pain and disability related to ankle OA [20]. We hypothesized participants with CAI would have altered temporal gait parameters and greater self-reported symptoms on both subscales of the AOS compared to healthy controls. Our secondary purpose was to examine the association between temporal gait parameters and scores on the AOS within the CAI group. We hypothesized temporal gait parameters would be significantly correlated with pain and disability.

2. Methods

2.1. Study design

This investigation employed a case control design. The independent variable was Group (healthy-control and CAI), and the dependent variables were scores on the Pain and Disability subscales of the AOS scores and temporal gait parameters (swing, single-limb support and double-limb support phases). Participants reported to the research laboratory for a single testing session to complete the study.

2.2. Participants

Sixty participants between the ages of 18 and 35 years of age were recruited from a large local university and the surrounding community. All participants provided written informed consent approved by the university's ethical review board.

Inclusion criteria for the CAI group were based on recommendations set by the International Ankle Consortium [10]. Participants with CAI were required to have at least one or more acute lateral ankle sprains that resulted in pain, swelling, and/or temporary loss of function occurring more than 6 months prior to enrollment. Additionally, participants with CAI reported having at least 2 episodes of "giving-way" in the previous 6 months, a score ≥ 11 on the Identification of Functional Ankle Instability (IdFAI). In the event a participant self-reported having bilateral ankle sprain history, the limb with the higher number of "giving-way" and the greatest amount of perceived ankle instability based on the IdFAI was selected as the involved limb.

Participants allocated to the healthy-control group were required to: 1) never have had an acute lateral ankle sprain, 2) never experienced "giving-way" at the ankle and 3) have a score of '0' on the IdFAI. The test limb was randomly selected for the healthy-control group.

Exclusion criteria for both groups consisted of: 1) any diagnosed balance, vestibular or respiratory disorder; 2) history of low back pain in the previous 6 months; 3) previous history of fracture or surgery in the lower extremity; 4) history of seizures; 5) history of concussion in the past 6 months; 6) history of neurological injuries or diseases; 7) and/or previous history of any self-reported musculoskeletal or neurovascular injuries; and 8) any other injury in the lower extremity within the previous 6 months other than a lateral ankle sprain.

2.3. Instrumentation

2.3.1. Ankle osteoarthritis scale

The AOS is a patient-reported outcome (PRO) that has been shown to be valid, reliable and reponsive to change for assessing the severity of pain and level of disability assoicated with ankle OA [20]. The AOS consists of two nine-item subscales (Pain and Disability) and participants were asked to rate their level of pain or disability for each litem along a scale of 100.

2.3.2. Temporal gait patterns

Temporal gait parameters were measured using a GAITRite® (CIR Systems, Inc. Havertown, PA USA) electronic walkway with an approximate active collection zone within a length of 7.32 m and a width of 0.61 m. Data were sampled at 120 Hz and processed using GAITRite Platinum software v.4.7.7 (CIR Systems, Inc., Havertown, PA USA). The GAITRite System has been shown to be valid and reliable for assessing temporal gait parameters [21,22].

2.4. Procedures

Participants first completed the PRO instruments, including a general health history questionnaire, the IdFAI and the AOS. Next, participants walked barefoot across the electronic walkway at a self-selected pace while focused on a target on the wall approximately five meters from the end of the walkway. Each trial was initiated and terminated 3 m before and after the walkway to avoid any acceleration or de-acceleration effect, respectively. Each participant was provided three practice trials and then performed five test trials. Participants were provided 30 s of rest between each trial. Trials were discarded and repeated if the participant: 1) stopped or slowed down while on the walkway; 2) tripped or took a double-step; and/or 3) did not keep their eyes looking forward.

2.5. Data analysis

2.5.1. Ankle osteoarthritis scale

The sum of each AOS subscale (Pain and Disability) was divided by the total number of possible points on each subscale (900). A higher percentage score on both subscales represents greater levels of pain and disability related to ankle OA [20].

2.6. Temporal gait patterns

The data from all five trials were collapsed and combined into a single overall test trial. Data from all five trials were combined into a single test trial to provide a better representation of the stride-to-stride temporal gait parameters, rather than comparing one gait cycle between groups [23]. Data from each footfall were then averaged across the entire test trial for each participant. Next, temporal data representing each phase of the gait cycle were extracted for the involved limb and used for statistical analysis. Specifically, single-limb support was quantified as the time between the last contact of the one footfall to the first contact of the next football of the same foot. The double-limb support phase was determined as the amount of time both feet were in contact with the ground simultaneously throughout the entire gait cycle. The swing phase was defined as the amount of time between toe off until contact was made again with the same foot. Each temporal measures was normalized as a percentage of gait cycle (%GC).

Gait speed is known to influence temporal gait parameters [24]. Therefore, gait speed was extracted for the test trial and normalized to each participants leg length (%LL). Leg length was measured as the distance from the Anterior Superior Iliac Spine (ASIS) to the most distal portion of the medial malleolus.

2.7. Statistical analysis

Separate Independent T-tests were used to determine group differences for all demographic and primary outcome measures. *Hedge's g* with corresponding 95% confidence intervals (CI) were calculated for each primary outcome measure to determine the magnitude of group differences. Effect sizes were interpreted as weak ($0.20 \geq d \leq 0.49$), moderate ($0.50 \geq d \leq 0.79$), and strong ($d \geq 0.80$) [25].

Pearson product moment correlations were used to assess the relationship between temporal gait parameters and scores from each AOS subscale within the CAI group. Correlation coefficients were interpreted as weak ($0.0 < r < 0.40$), moderate ($0.41 < r < 0.69$), or strong ($r > 0.71$) [26].

All significance levels were set a priori at $p < 0.05$. All statistical analyses were performed using IRB SPSS Statistics, version 24 (IMB, Corp., Armonk, NY, USA).

3. Results

Demographic information and associated p-values are presented in Table 1. There were no significant between group differences for any demographic variable. Participants with CAI scored higher on the IdFAI compared to the healthy-control group (Table 1).

Group means and standard deviations for all primary outcome measures are described in Table 2. The CAI group had significantly higher scores on the Pain (14.3% ± 18.3 vs. 1.1% ± 2.3, $p < 0.001$) and Disability (13.1% ± 19.7 vs. 0.9% ± 1.3, $p = 0.001$) subscales of the AOS compared to the healthy-control group, which were supported by strong effect sizes (Table 2). Additionally, participants with CAI spent less time during the swing (38.7%GC ± 1.1 vs. 39.4%GC ± 1.3, $p = 0.022$) and single-limb support (38.6%GC ± 1.1 vs. 39.3%GC ± 1.2, $p = 0.030$), but more time during the double-limb support (22.7%GC ± 2.0 vs. 21.3%GC ± 2.4, $p = 0.021$) phase. Normalized gait speed was not significantly different between the CAI (1.4 L L/sec ± 0.14) and control (1.5 L L/sec ± 0.20, $p = 0.103$).

Single-limb support phase was moderately and negatively correlated with greater scores on the AOS Pain ($r = -0.416$, $p = 0.011$) and Disability ($r = -0.473$, $p = 0.004$) subscales in participants with CAI (Table 3). All other correlations were not statistically significant ($p > 0.05$).

Table 1
Group Means ± SD for Key Demographic Outcomes Measures.

	CAI (n = 30)	Control (n = 30)	P-value
Age (years)	24.1 ± 3.6	24.7 ± 3.4	p = 0.512
Height (cm)	166.7 ± 9.5	169.9 ± 9.6	p = 0.189
Weight (kg)	73.8 ± 16.3	69.3 ± 14.5	p = 0.261
Leg Length (cm)	88.72 ± 5.5	89.71 ± 6.0	p = 0.514
IdFAI	18.2 ± 3.7	0.0 ± 0.0	**p < 0.001***
# of acute LAS	3.3 ± 3.7	0.0 ± 0.0	**p < 0.001***
First LAS (years)	7.0 ± 4.6	0.0 ± 0.0	**p < 0.001***
Most recent LAS (months)	33.3 ± 34.8	0.0 ± 0.0	**p < 0.001***
# of "giving-way" past 6 months	4.8 ± 5.2	0.0 ± 0.0	**p < 0.001***

Abbreviations: Identification of Functional Ankle Instability (IdFAI); Lateral Ankle Sprain (LAS). *Statistically significant between group difference.

4. Discussion

Up to 78% of patients with CAI develop end-stage ankle PTOA [11]. Given no viable conservative treatment exists for end-stage ankle PTOA, more research is needed to understand the possible early consequences that joint degeneration may have on patients with CAI to aid in the development of interventions designed to minimize its long-term impact. Therefore, the primary purpose of our investigation was to determine if participants with CAI experience greater symptomatology associated with PTOA and demonstrate altered temporal gait parameters compared to participants without CAI. We hypothesized that individuals with CAI would: 1) report greater amounts of pain and disability associated with the presence of PTOA; and 2) have abnormal temporal gait parameters. Our results support each hypothesis as individuals with CAI had greater scores on the AOS and spent varying times during each phase of the gait cycle compared to the uninjured control group.

Investigators have demonstrated compositional changes within the articular cartilage among young-adults with CAI are associated with increased scores on the American Orthopedic Foot and Ankle Score (AOFAS) questionnaire [8,9]. The AOFAS is constructed using both patient-reported and physician-reported data. In the current study we used the Ankle Osteoarthritis Scale (AOS), which relies on patient-reported information, and found increased levels of self-reported pain and disability commonly associated with the presence of ankle OA. Our findings provide further evidence that young-adults with CAI self-report having symptoms of ankle joint degeneration. It is important to note that we did not confirm the presence of ankle PTOA using an imaging modality. Because of this we cannot rule out the pain and disability reported by our participants on the AOS might reflect any un-resolved symptoms from their most recent ankle sprain. However, the average time since the most recent self-reported ankle sprain by our participants was 2.5 years (Table 1), which exceeds the average timeframe for symptoms for an acute ankle sprain.

Comparing our results with previous research, it does not appear that the symptoms of ankle PTOA self-reported by the CAI group are as severe as those with end-stage symptomatic ankle PTOA. For example, Wikstrom et al [27] reported scores of 25.9% and 26% on the Pain and Disability subscales of the AOS, respectively, among a cohort of patients with end-stage ankle PTOA. This apparent difference between previously reported scores on the AOS and those in the current study is likely because the average time since the first self-reported ankle sprain among our participants with CAI is 7.4 years (Table 1). Therefore, considering the estimated time between a ligamentous ankle injury and end-stage symptomatic ankle PTOA is 34.3 years [28], it is likely that the early symptoms of ankle PTOA reported by our participants with CAI may worsen with time.

Our results also demonstrated participants with CAI spent ˜1% less time in the swing and single-limb support phase, and ˜1% more time in the double-limb stance phase. These between group differences were supported by moderate effect sizes with 95% confidence intervals that did not cross zero (Table 2). Therefore, a 1% difference in the amount of time spent during each phase of the gait cycle does appear to be clinically meaningful. Our findings are aligned with previous research demonstrating between group differences (0.9%–2.3%) in temporal gait metrics among those with and without CAI [15]. However, these authors found participants with CAI walked slower compared to their healthy counterparts. This difference in gait speed may account for the larger between group differences in temporal gait mechanics than those

Table 2
Group Means ± SD for the Ankle Osteoarthritis Scale and Temporal Gait Variables Derived from the Test Summary.

	CAI (n = 30)	Control (n = 30)	P-value	T-statistic	*Hedge's g* (95% CI)
Ankle Osteoarthritis Scale					
Pain (%)	14.3 ± 18.3	1.1 ± 2.3	**p < 0.001***	t_{58} = 3.935	1.00 (0.46,1.54)
Disability (%)	13.1 ± 19.7	0.9 ± 1.3	**p = 0.001***	t_{58} = 3.400	0.86 (0.33, 1.39)
Temporal Gait Parameters					
Gait Speed (LL/sec)	1.4 ± 0.14	1.5 ± 0.20	p = 0.103	t_{58} = -1.658	0.57 (0.06, 1.09)
Swing (%GC)	38.7 ± 1.1	39.4 ± 1.3	**p = 0.022***	t_{58} = -2.352	0.57 (0.06, 1.09)
Single-limb Support (%GC)	38.6 ± 1.1	39.3 ± 1.2	**p = 0.030***	t_{58} = -2.227	0.60 (0.08, 1.12)
Double-limb Support (%GC)	22.7 ± 2.0	21.3 ± 2.4	**p = 0.021***	t_{58} = 2.367	0.63 (0.11, 1.14)

Abbreviations. Leg Length (LL); Percent of Gait Cycle (%GC). * Statistically significant between group difference.

Table 3
Association Between Temporal Gait Mechanics and AOS subscale within CAI Participants.

	Pain		Disability	
	r	p-value	r	p-value
Gait Speed (LL/sec)	−0.016	p = 0.468	0.152	p = 0.216
Swing (%GC)	0.066	p = 0.346	−0.260	p = 0.446
Single-limb Support (%GC)	−0.416	**p = 0.011***	−0.473	**p = 0.004***
Double-limb Support (%GC)	0.269	p = 0.076	0.277	p = 0.069

Abbreviations. Leg Length (LL); Percent of Gait Cycle (%GC). *Statistically significant correlation.

reported in the current study. In contrast, the results from the current study differ from those by Dingenen et al [16] as they did not find a difference in the duration of the swing or stance phase of the gait cycle between those with and without CAI. This discrepancy might be related to the methods used to examine temporal gait mechanics. Similar to Gigi et al [15], we utilized an electronic walkway that allowed for the collection of multiple steps in succession rather than taking the average of isolated trials. Previous research has suggested examining and quantifying cyclic movement patterns across a series of trials rather than average of discrete time points [23]. Future research should continue to examine cyclic movement patterns across multiple trials rather than separate trials.

We can only speculate towards the significance of the adjustments in temporal gait mechanics observed by the participants with CAI relative to the healthy-control group because its exact consequence is not known. One possible concern is that persistent exposure to this aberrant cyclical gait pattern might contribute to declines in long-term joint health. This is because reducing the duration the ankle joint is loaded during the stance phase can lower the overall cumulative load applied to the articular cartilage of the involved limb [18]. Therefore, the adjustment in temporal gait mechanics might contribute to the progression and high prevalence rate of end-stage PTOA in those with CAI [11,12]. However, the development of ankle PTOA is multi-factorial and other key factors such as the rate and magnitude of loading also likely contribute to joint degeneration. Moreover, repetitive trauma to the articular cartilage caused by multiple ankle sprains or the recurrent episodes of 'giving way' can influence long-term joint health. Certainly, prospective studies are needed to confirm or refute our speculation which may also advance our current understanding of joint degeneration in those with CAI.

We also observed a moderate negative association between both subscales of the AOS and the amount of time spent in single-limb stance (Table 3). Thus, as levels of pain and disability increase, the time individuals with CAI spend on their involved limb decreased. In turn, while maintaining the same walking speed as healthy individuals, it appears they reduce the amount of time spent on the involved limb by increasing the amount of time during double-limb stance. The potential positive association between both subscales of the AOS and the amount of time spent in double-limb stance supports this theory (Table 3). The relationship between the AOS and temporal gait mechanics might reflect their attempt at adopting a similar pain-avoidance gait strategy that is commonly seen in those with end-stage ankle OA [13]. However, it is also reasonable to suspect that the gait strategy observed by the CAI group could be leading to increased levels of pain and disability. Unfortunately, the retrospective design of our study prohibits a clear understanding of this relationship. Similar relationships have been observed between the physical component of the Short Form-36 and temporal gait parameters [15]. More prospective research is needed to appreciate how symptoms of ankle joint degeneration may impact temporal gait mechanics.

Understanding the interaction of ankle PTOA symptomatology and temporal gait patterns provides an avenue for rehabilitation specialists and future research. Specifically, therapeutic interventions targeting pain and disability arising from the ankle may aid in restoring normal temporal gait mechanics and the proper duration of load placed on the articular cartilage. Moreover, rehabilitation efforts should focus on improving spatiotemporal gait patterns through gait re-training.

5. Limitations

There are some limitations to this study that should be considered. For example, our findings are based on self-reported data and we were unable to verify the presence of ankle PTOA in our participants. Additionally, with enrolling younger-aged adults, we are unaware if they will develop end-stage symptopmatic ankle PTOA later in life. The development of PTOA is multi-factorial and other factors following a joint injury may also contribute to joint degeneration in those with CAI. Follow-up studies using imaging modalities should consider examining the relationship between patient-reported outcomes, temporal gait parameters and the strucutal arthitecture/integrity of the ankle joint. In addition, we did not evaluate any kinematic or kinetic varibles. Vertical ground reaction forces could help further illustrated our reported observations by understanding the amount of load transmitted across the ankle. More work is needed to understand how kinematic and/or kinetic changes interact with the development of PTOA in CAI. Finally, we enrolled 8 participants with bilateral symptoms of CAI and 22 participants with unilateral CAI. However, in a follow-up analysis, we did not find any signficant difference for any primary outcome measure between those with unilateral and bilateral CAI ($p > 0.05$).

6. Conclusion

In the present study, individuals with CAI reported increased PTOA-related symptomatology and altered temporal gait parameters compared to uninjured controls. Further, the increased self-reported ankle PTOA-relatedsymptomatology was associated with differences in temporal gait parameters. Future research should consider using advanced imaging to confirm the presence of ankle PTOA in an effort to link self-reported symptomatology with joint health and temporal gait parameters. Linking such measures would provide health care professionals with non-invasive surrogate markers of PTOA in patients with previous ankle sprains.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

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