# Hip Biomechanics Are Altered in Male Runners with Achilles Tendinopathy

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## ABSTRACT

CREABY, M. W., C. HONEYWILL, M. M. FRANETTOVICH SMITH, A. G. SCHACHE, and K. M. CROSSLEY. Hip Biomechanics Are Altered in Male Runners with Achilles Tendinopathy. *Med. Sci. Sports Exerc.*, Vol. 49, No. 3, pp. 549–554, 2017. **Purpose**: Achilles tendinopathy (AT) is a prevalent injury in running sports. Understanding the biomechanical factors associated with AT will assist in its management and prevention. The purpose of this study was to compare hip and ankle kinematics and kinetics in runners with and without AT. **Methods**: Fourteen male runners with AT and 11 healthy male runners (CTRL) ran over ground while lower-limb joint motion and ground reaction force data were synchronously captured. Hip and ankle joint angles, moments, and impulses in all three planes (sagittal, transverse, and frontal) were extracted for analysis. Independent *t*-tests were used to compare the differences between the AT and the CTRL groups for the biomechanical variables of interest. After Bonferroni adjustment, an alpha level of 0.0026 was set for all analyses. **Results**: The AT group exhibited an increased peak hip external rotation moment ($P = 0.001$), hip external rotation impulse ($P < 0.001$), and hip adduction impulse ($P < 0.001$) compared with the CTRL group. No significant differences in ankle biomechanics were observed. **Conclusion**: This study presents preliminary evidence indicating that male runners with AT display altered hip biomechanics with respect to their healthy counterparts. Because of the retrospective design of the study, it is unknown whether these alterations are a predisposing factor for the disorder, a result of the condition, or a combination of both. The results of this study suggest that optimizing hip joint function should be considered in the rehabilitation of runners with AT. **Key Words:** BIOMECHANICS, KINEMATICS, GAIT, INJURY

Achilles tendinopathy (AT) is a prevalent musculoskeletal condition, accounting for 9% to 15% of all injuries in recreational runners (20,31), and is particularly common in males (14). In runners, AT most commonly involves midportion Achilles tendon pain (17), which can impair function and participation in physical activity. Although the etiology of AT is not fully understood, it is considered multifactorial in nature and has been associated with a range of intrinsic and extrinsic factors (6,23). As intrinsic biomechanical factors have the potential to influence Achilles tendon forces and subsequent tendon microdamage (35), they may play a central role in the condition. Thus, understanding the intrinsic biomechanical factors associated with AT may aid in the development of preventative and/or rehabilitative strategies for the condition.

Lower-limb biomechanical variables, in particular variables related to the foot and ankle, have been proposed to play an important role in AT (6,36). For example, the movement of the rearfoot into eversion during the stance phase of running gait (eversion excursion) has been reported to be increased in runners with AT (9,21). Also, the difference in the time of muscle activation offset between the soleus and the lateral gastrocnemius is greater in runners with AT (37). However, other characteristics of rearfoot movement and triceps surae muscle activation appear to be similar between runners with and without AT (23,37). Although altered movement patterns at the foot and ankle may exist in runners with AT, whether this altered movement translates to altered forces acting on the tendon is not known. The moments, or turning forces, acting at the ankle during stance (i.e., when load on the Achilles tendon is greatest) may provide some additional insight. Given that some studies have found runners with AT to display increased rearfoot eversion excursion (9,21), it is possible that differences in the frontal plane ankle joint moment and impulse exist between runners with and without AT. To our knowledge, no

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study has examined differences in ankle joint kinetics in runners with and without AT.

It is also possible that differences in lower-limb biomechanical variables between runners with and without AT may not be limited to the ankle. In recent years, injuries at the knee have been associated with altered hip biomechanics (29,32). Similarly, hip neuromuscular control appears to differ between runners with and without AT (1,11), which may influence hip biomechanics in runners with AT. Although there is some evidence that sagittal plane hip joint angles do not differ between runners with and without AT (1), to our knowledge, and as reported in a systematic review on the topic (23), differences in frontal and transverse plane hip joint angles as well as hip kinetics in any plane of motion have not previously been explored. Importantly, alterations in hip biomechanics have the potential to influence biomechanics at the ankle (3,4) and may therefore influence Achilles tendon loading. Investigating this link may have important implications for the prevention of and rehabilitation from AT.

The aim of this study therefore was to investigate whether differences in hip and ankle biomechanics during the stance phase of running (joint angles, moments and impulses) exist for runners with AT with respect to their healthy counterparts.

## METHODS

**Participants.** Fourteen males with symptomatic AT and eleven healthy male controls (CTRL) participated in the study. Sample size calculations were based on detecting differences of a large effect with 80% power (10,15). Participants were recruited from the general population of Melbourne, Australia, via advertisements in sports medicine centers, athletic footwear retail shops, and running websites. This cohort was a subgroup of participants recruited for previously published studies that had completed biomechanical testing (5,11,13). The study was approved by the University of Melbourne Human Research Ethics Committee, and all participants provided written informed consent before participation.

For inclusion in either group of the study, participants were to be male, of age greater than 18 yr, currently partaking in running activities involving 20 $km{\cdot}wk^{-1}$ or greater, and have a body mass index less than 32 $kg{\cdot}m^{-2}$. Participants were excluded from either group if they had a history of previous lower-limb surgery, systemic inflammatory disorders, or Achilles tendon trauma or rupture. Aside from the AT group having symptoms of midportion AT (Achilles tendon pain with running, hopping and palpation, morning stiffness, and symptoms affecting exercise activity), both groups were required to have no other lower-limb injury at the time of testing or in the previous 12 months. Females were excluded from this study, as evidence suggests higher rates of AT in males than females and to eliminate any confounding effects of sex on tendon mechanical characteristics (14,18,19).

The confirmation of eligibility for the symptomatic midportion AT group was made using diagnostic ultrasound. The features of tendinopathy required for inclusion in the AT group included tendon thickening and/or a focal tendon lesion (5). CTRL group participants were to have no observable features of tendinopathy on diagnostic ultrasound, and to be free of any symptoms, or history of symptoms, associated with AT, i.e., Achilles tendon pain or stiffness.

The AT group completed the Victorian Institute of Sport Assessment—Achilles questionnaire. This questionnaire is a validated and reliable index of clinical severity of AT, which consists of eight questions that measure the domains of pain, function in daily living and sporting activity (26). Scores range from 1 to 100, where a score of 100 represents an asymptomatic tendon. All questionnaires were completed before the commencement of running trials.

**Procedures.** Participants were required to run at 4 $m{\cdot}s^{-1}$ (±10%), corresponding to 14.4 $km{\cdot}h^{-1}$, along a 25-m walkway in the human movement laboratory. Running speed was fixed as it is known to influence hip and ankle joint mechanics (7,28), and previous work has shown no systematic differences in self-selected running speed between healthy runners and those with AT (1). Timing gates (Jaycar Electronics, Australia) were used to confirm running speed. Participants ran repeatedly along the walkway for approximately 5 min to accommodate themselves to the laboratory environment, standardized footwear (Nike Straprunner IV running sandals; Nike, USA), and prescribed running speed. A minimum of five successful running trials were obtained for analysis. No participant reported that running in the prescribed footwear was uncomfortable or difficult. For the AT group, the symptomatic, or most symptomatic side in the case of bilateral symptoms, was tested. For the CTRL group, the dominant side was tested.

Three-dimensional lower-limb kinematic data were recorded with an eight-camera Vicon 3D motion analysis system (sampling frequency, 120 Hz; Vicon, Oxford Metrics, Oxford, UK). Ground reaction force (GRF) data were synchronously captured with the kinematic data using an AMTI force plate (sampling frequency, 1080 Hz; Advanced Medical Technology Incorporated, Watertown, MA) mounted into the laboratory walkway. Skin-mounted markers were placed to track segment motion consistent with a previously published biomechanical model (28).

**Data processing.** A researcher blinded to participant group processed all kinematic and kinetic data to prevent bias. Vicon Nexus software (Version 1.7) was used to reconstruct the marker coordinate data. These data were then labeled and filtered using a generalized cross-validatory quintic smoothing spline with a predicted mean-squared error of 15 mm (34). GRF data were used to identify gait events (foot strike and toe off) for each trial. All joint kinematic and kinetic data were calculated using Vicon Bodybuilder software (Version 3.6.1). Hip and ankle joint angles

TABLE 1. Participant characteristics (mean ± SD) in runners with and without AT.

| | Control Group ($n$ = 11) | AT Group ($n$ = 14) | $P$ |
|---|---|---|---|
| Age (yr) | 37 ± 9 | 43 ± 8 | 0.12 |
| Height (m) | 1.77 ± 0.06 | 1.79 ± 0.05 | 0.31 |
| Weight (kg) | 73.5 ± 8.6 | 82.3 ± 11.1 | 0.04 |
| BMI (kg·m$^{-2}$) | 23.50 ± 2.39 | 25.73 ± 3.31 | 0.07 |
| Leg length (% height) | 50.89 ± 1.67 | 51.19 ± 1.52 | 0.65 |
| Distance run each week (km) | 35.9 ± 13.6 | 38.1 ± 13.2 | 0.68 |
| VISA-A | — | 70 ± 10 | — |

BMI, body mass index; VISA-A, Victorian Institute of Sport Assessment—Achilles questionnaire.

were calculated using a joint coordinate system approach according to the conventions described by Groot and Suntay (12) and Baker (2), respectively. From these data, peak angles in stance and angular excursions, i.e., the change in joint angle from foot strike to peak angle, were determined. As hip rotation angle during running does not display a systematic profile of internal or external rotation across participants, hip rotation angle at the time of the peak GRF was extracted, consistent with a previously published approach (27).

Hip and ankle joint moments were calculated using a standard inverse dynamics approach to determine peak moments and angular impulses for hip flexion, adduction, and external rotation, and ankle dorsiflexion and eversion. Joint moments referred to in this study are net external joint moments, i.e., the external moments about the hip and ankle joints because of the net effect of the GRF, inertia and gravity. Net external joint moments and angular impulses were normalized by dividing by the participants' body mass.

**Statistical analysis.** Statistical analyses were performed using SPSS (Version 22; IBM Corp., Armonk, NY). Skewness and kurtosis values were obtained to ensure normal distribution of the data. Independent *t*-tests were used to compare the differences between the two groups. To correct for multiple comparisons, the significance level for the biomechanical dependent variables was adjusted using Bonferroni correction; thus, the significance level was reduced to $\alpha$ = 0.0026, i.e., $\alpha$ = 0.05/19. Standardized mean difference values (SMD = mean difference / pooled SD) were calculated to provide an estimate of the effect. SMD values were classified as small (0.2–0.6), medium (0.6–1.2), or large (>1.2) (15). As lower-limb joint moments scale with body size (25), our primary analyses of joint moments were performed on body mass normalized data to isolate the effect of AT upon joint moments. As this comparison has the potential to mask differences in absolute joint moments, secondary analyses of joint moments were performed without normalizing for body size.

## RESULTS

There were no significant differences in age, height, or weekly running distance between the two groups ($P$ > 0.05; Table 1). The AT group was on average significantly heavier (+11%) than the CTRL group ($P$ = 0.04; Table 1). There were no significant differences in hip and ankle joint angles between the runners with and without AT (Table 2). In our primary analyses of joint moments normalized to body mass, the AT group displayed an increased peak hip external rotation moment and impulse compared with the CTRL group ($P$ < 0.001; Fig. 1; Table 3); both of these differences were associated with a large effect size (SMD = 1.62 and 1.86, respectively). The AT group also displayed a higher hip adduction moment impulse compared with the CTRL group ($P$ < 0.001; SMD = 1.64); however, the peak hip adduction moment did not differ between the two groups. None of the ankle joint moment variables differed between the groups. Secondary analyses of absolute joint moments, without normalizing the data to body size, did not change the interpretation of the data, with no significant differences identified at the ankle but higher adduction and rotation moments at the hip (see Table, Supplemental Digital Content 1, absolute lower-limb joint moments, http://links.lww.com/MSS/A790).

## DISCUSSION

The aim of this study was to investigate differences in hip and ankle biomechanics between runners with and without AT. We found the impulse of the hip adduction and external rotation moments as well as the peak hip external rotation moment to be significantly increased in runners with AT compared with their healthy counterparts. However, the two groups displayed similar hip and ankle joint angles as well as ankle joint moments during running. The identified

TABLE 2. Lower-limb joint kinematics (mean ± SD) in runners with and without AT.

| | Control Group ($n$ = 11) | AT Group ($n$ = 14) | Mean Difference (95% CI) | SMD | $P$ |
|---|---|---|---|---|---|
| Ankle | | | | | |
| Peak eversion (°) | 6.46 ± 5.63 | 7.73 ± 6.91 | 1.27 (−4.13 to 6.67) | 0.21 | 0.150 |
| Eversion excursion (°) | 14.55 ± 2.71 | 12.39 ± 3.17 | −2.16 (−4.64 to 0.32) | 0.76 | 0.085 |
| Peak dorsiflexion (°) | 22.10 ± 2.95 | 21.01 ± 3.97 | −1.09 (−4.06 to 1.88) | 0.31 | 0.455 |
| Dorsiflexion excursion (°) | 19.70 ± 4.95 | 18.16 ± 2.89 | −1.54 (−4.81 to 1.73) | 0.41 | 0.340 |
| Hip | | | | | |
| Peak flexion (°) | 39.67 ± 4.84 | 43.86 ± 7.62 | 4.19 (−1.28 to 9.65) | 0.65 | 0.127 |
| Flexion excursion (°) | 1.97 ± 3.05 | 0.73 ± 1.01 | −1.25 (−3.04 to 0.55) | 0.65 | 0.164 |
| Peak adduction (°) | 18.42 ± 3.26 | 17.83 ± 3.48 | −0.60 (−3.42 to 2.22) | 0.18 | 0.666 |
| Adduction excursion (°) | 10.74 ± 2.68 | 12.01 ± 3.43 | 1.27 (−1.33 to 3.88) | 0.41 | 0.322 |
| Rotation at peak vGRF (°)[a] | 0.81 ± 7.90 | −6.52 ± 8.87 | −7.34 (−14.39 to −0.28) | 0.87 | 0.042 |

CI, confidence interval.
[a]Positive values indicate external rotation.

APPLIED SCIENCES

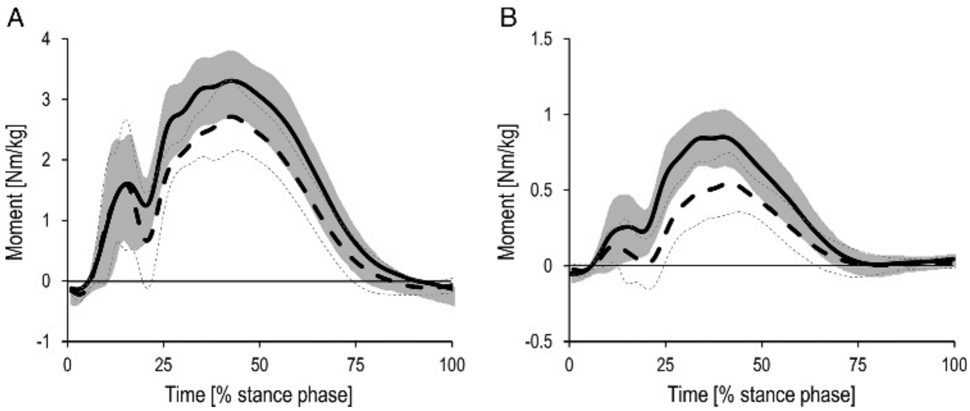


**FIGURE 1—Group mean hip adduction (A) and external rotation (B) moments during the stance phase of running in healthy participants (*broken line*; broken gray line error band) and those with AT (*solid line*; gray shaded error band).**

differences in hip joint biomechanics found in the present study compliments previous research that provided evidence of altered hip neuromuscular control in runners with AT (1,11). Taken together, these findings reinforce the need to consider proximal lower-limb function in the assessment and rehabilitation of runners with AT.

Previous studies have found differences in gluteal muscle activation during running in people with and without AT. Specifically, in runners with AT, the magnitude of activation for gluteus medius is lower during early stance (1), and the duration of activation for both gluteus medius and gluteus maximus is shorter when compared with healthy runners (11). Throughout the range of hip flexion observed during normal running, gluteus maximus acts to extend and externally rotate the hip, whereas gluteus medius abducts the hip and its anterior and posterior fibers act to internally and externally rotate the hip, respectively (8,24). Thus, as a consequence of the lower magnitude and duration of gluteal activation in runners with AT, it might be anticipated that peak hip joint moments (and/or impulses) would also be lower when compared with healthy runners. In contrast to this premise, we found that the peak hip external rotation moment as well as the impulse of the hip adduction and external rotation moments were significantly increased in runners with AT, irrespective of whether data were normalized to body mass. Taken together, such findings may indicate that the contribution toward the moments at the hip of other muscles and/or passive structures, not just gluteus maximus and medius, is altered in runners with AT.

Our observation of differences in hip joint kinetics in the presence of AT, but no differences in ankle kinematics or kinetics, is somewhat surprising. The lower limb is considered to function as a series of linked segments and thus hip mechanics—in all planes—will influence or be influenced by mechanics at the ankle (4,16,30). Given the retrospective design of our study, it is possible that the higher frontal and transverse plane moments at the hip were present before the development of AT and may therefore represent a risk factor for AT development. Alternatively, it is possible that hip moments increased after the development of AT and represent a compensation to facilitate continued function in the presence of the symptoms. To our knowledge, no prospective studies have documented the joint mechanics associated with AT development (23). It is plausible—albeit not proven—that higher frontal and transverse plane ankle moments may lead to greater load on the Achilles tendon and therefore increase the risk of AT development. Thus, to reduce Achilles tendon load and facilitate continued function, greater frontal and transverse plane hip joint moments may be a strategy used by runners with AT to lower ankle joint moments. Without prospective evidence of hip and ankle mechanics before AT development, or knowledge of how

TABLE 3. Lower-limb joint moments (mean ± SD) in runners with and without AT.

| | Control Group ($n$ = 11) | AT Group ($n$ = 14) | Mean Difference (95% CI) | SMD | $P$ |
|---|---|---|---|---|---|
| Ankle | | | | | |
| Peak eversion (N·m·kg$^{-1}$) | 0.40 ± 0.13 | 0.35 ± 0.16 | −0.05 (−0.17 to 0.08) | 0.33 | 0.456 |
| Eversion impulse (N·m·s$^{-1}$·kg$^{-1}$) | 0.03 ± 0.01 | 0.03 ± 0.01 | 0.00 (−0.02 to 0.01) | 0.00 | 0.288 |
| Peak dorsiflexion (N·m·kg$^{-1}$) | 3.53 ± 0.37 | 3.20 ± 0.57 | −0.33 (−0.74 to 0.08) | 0.69 | 0.109 |
| Dorsiflexion impulse (N·m·s$^{-1}$·kg$^{-1}$) | 0.38 ± 0.06 | 0.34 ± 0.07 | −0.04 (−0.09 to 0.02) | 0.57 | 0.173 |
| Hip | | | | | |
| Peak flexion (N·m·kg$^{-1}$) | 3.57 ± 0.55 | 3.64 ± 0.69 | 0.07 (−0.46 to 0.60) | 0.11 | 0.786 |
| Flexion impulse (N·m·s$^{-1}$·kg$^{-1}$) | 0.13 ± 0.03 | 0.12 ± 0.04 | −0.01 (−0.04 to 0.02) | 0.25 | 0.548 |
| Peak adduction (N·m·kg$^{-1}$) | 3.07 ± 0.57 | 3.49 ± 0.63 | 0.41 (−0.09 to 0.92) | 0.69 | 0.102 |
| Adduction impulse (N·m·s$^{-1}$·kg$^{-1}$) | 0.26 ± 0.06 | 0.37 ± 0.07 | 0.11 (0.05 to 0.16)* | 1.64 | 0.0005 |
| Peak external rotation (N·m·kg$^{-1}$) | 0.63 ± 0.16 | 0.86 ± 0.13 | 0.23 (0.11 to 0.36)* | 1.62 | 0.0006 |
| External rotation impulse (N·m·s$^{-1}$·kg$^{-1}$) | 0.04 ± 0.02 | 0.07 ± 0.02 | 0.03 (0.02 to 0.04)* | 1.86 | 0.0001 |

CI, confidence interval.
*Significant difference between groups.

joint moments change after the onset of AT, this possibility remains speculative. Thus, further studies are required to elucidate the full clinical relevance of elevated frontal and transverse plane hip moments in AT.

In this study, we evaluated both peak joint moments and impulses at the hip and ankle throughout the stance phase of running gait. Joint impulses represent the product of the average magnitude of the joint moment and the time over which it acts (stance time). Thus, the joint moment impulse provides an indication of the cumulative moment acting at the joint throughout stance. *Post hoc* analyses of the spatiotemporal characteristics in our cohort (see Table, Supplemental Digital Content 2, spatiotemporal data, http://links.lww.com/MSS/A791) indicate a trend toward a longer stance time in AT runners compared with the CTRL group ($P$ = 0.07), but no other differences in spatiotemporal characteristics. These data suggest that the higher hip adduction and external rotation impulses we observed in the AT runners are a combined result of higher average joint moments acting over a marginally longer period of time (0.01 s).

The absence of significant differences in ankle mechanics between the groups in the current study is somewhat unexpected for two reasons. First, given that hip and ankle mechanics during running are coupled (3,4,16) and between-group differences in hip kinetics were evident in the present study, one may have expected between-group differences to be present at the ankle too. However, ankle kinematic and kinetic variables were not found to significantly differ between runners with and without AT. It is therefore possible that loads on the Achilles tendon were similar between groups at the time of testing. Conceivably, the altered hip mechanics in the AT group may have been a functional adaptation after injury to maintain Achilles tendon loading at levels similar to the healthy control group. Second, it has previously been shown that eversion excursion (from foot strike to peak eversion) is greater in runners with AT (9), yet we found eversion excursion to be nonsignificantly lower by 15% in runners with AT compared with their healthy counterparts (Table 2). This inconsistency in findings between the current study and the earlier work may be explained by differences in participant characteristics. All AT participants (but not control participants) in the study by Donoghue et al. (9) were clinically classified as "pronators," and thus the absolute magnitude of eversion observed in their group was 9° greater than that observed in our study. It is therefore not surprising that eversion excursion was greater in the AT group in the study by Donoghue et al. (9), and greater eversion excursion may not necessarily be a typical characteristic of AT runners *per se* but rather runners with AT that are classified as "pronators."

This study identified the presence of altered hip, but not ankle, mechanics in male runners with AT. Whether the increased frontal and transverse plane hip joint moments and impulses reflect a positive adaptation to allow ongoing function, or a negative characteristic that inhibits rehabilitation, is not known. Irrespective of their effect on function, an appreciation of hip biomechanics in runners with AT may aid the design of appropriate rehabilitation strategies. For example, given the greater frontal and transverse plane hip joint moments, one would expect a commensurate level of muscular strength and endurance within the gluteal muscles of AT runners. Importantly, a consistent link between hip biomechanics and AT has now been established across several studies (1,11). Thus, to further guide appropriate rehabilitation, investigations are required to determine whether, and how, hip biomechanics are associated with symptoms and function in the runner with AT.

When interpreting the results of this study, there are some limitations that need to be considered. First, all participants were tested in an unfatigued state, and running mechanics may vary with the introduction of fatigue (22), as would be expected in distance running. Thus, while we have been able to identify some mechanical differences between AT and healthy runners, exposure to fatigue may reveal further differences. Second, our study was powered to detect differences between groups of a large effect size. It is possible that meaningful differences between groups of a medium or small effect size may exist and may have implications for rehabilitation. Importantly, the current work highlights differences in hip kinetics with a large effect size that are worthy of consideration in the treatment of runners with AT and may be modifiable with gait retraining (33). Finally, because of the cross-sectional nature of the study design, we were unable to investigate the temporal relationship between the altered hip kinetics and AT. It is not clear whether the altered hip kinetics observed in this study are a consequence of the pain and dysfunction associated with AT, a cause of the disorder, or a combination of both. Thus, further prospective studies are merited to determine the temporal relationship between the pathology and running mechanics.

## CONCLUSION

In conclusion, this study found preliminary evidence of altered hip kinetics in male runners with AT. Because of the retrospective design of the study, it is still unknown whether these alterations are a predisposing factor for the disorder, a result of the condition, or a combination of both. Nevertheless, this study provides support for further prospective investigations to determine the role of the hip in the pathomechanics of AT. Furthermore, it highlights the importance of considering hip joint function in the assessment and rehabilitation of runners with AT.

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

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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