Evaluating the Effects of an Instrument-Assisted Stretching Technique on Plantar Fascia Mechanics: A Randomized Controlled Pilot Study

Özgür SÜRENKÖK*, Berna Çağla BALKIŞLI**, Gamze AYDIN***, Emine ATICI****

Abstract

Aim: Stretching exercises are a widely employed method in the rehabilitation of foot-ankle pathologies. The purpose of this study was to examine the effectiveness of various stretching exercises, implemented with the aid of a newly designed device, on plantar fascia stiffness in healthy individuals.

Method: A double-blind randomized controlled pilot trial was conducted with nineteen healthy participants. Participants were divided into two groups: plantar fascia-specific stretching (PFSS) and Achilles tendon stretching (ATS). All participants performed the stretching exercises (PFSS or ATS) on their dominant leg using a specially designed instrument, while the non-dominant leg was stretched without it. Plantar fascia stiffness was measured with a myotonometer before and after the intervention. Each stretching session included 10 repetitions, held for 10 seconds. The Mann–Whitney U test was used for between-group comparisons, while the Wilcoxon signed-rank test was used to analyze within-group pre- and post-stretch differences.

Results: Instrument-assisted stretching resulted in a significant increase in plantar fascia stiffness compared to traditional (non-instrument) stretching techniques in both PFSS (p=0.008) and ATS groups (p=0.005). No statistically significant differences were observed between PFSS and ATS with or without the instrument (p>0.05).

Conclusion: This pilot study suggests that the novel instrument has the potential to enhance the effectiveness of stretching interventions for the plantar fascia. Incorporating instrument-assisted stretching techniques into rehabilitation plans may support future clinical applications.

Keywords: Achilles tendon, elasticity, fascia, muscle stretching exercises.

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* Asst. Prof., Istanbul Okan University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Türkiye. E-mail: ozgur.surenkok@okan.edu.tr ORCID https://orcid.org/0000-0003-1558-8989
** Asst. Prof., Istanbul Okan University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Türkiye. E-mail: ptcaglacaglayan@gmail.com ORCID https://orcid.org/0000-0002-2559-9756
*** Asst. Prof., Istanbul Okan University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Türkiye. E-mail: gmzetsn@gmail.com ORCID https://orcid.org/0000-0002-4952-2825
**** Assoc. Prof., Istanbul Okan University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Türkiye. E-mail: emine.atici@okan.edu.tr ORCID https://orcid.org/0000-0002-6547-4798

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Plantar Fasya Mekaniği Üzerinde Alet Destekli Germe Tekniğinin Etkilerinin Değerlendirilmesi: Randomize Kontrollü Pilot Çalışma

Öz

Amaç: Ayak-ayak bileği patolojilerinin rehabilitasyonunda yaygın olarak kullanılan yöntemlerden biri germe egzersizleridir. Bu çalışmanın amacı, tasarlanan yeni bir cihaz desteği ile uygulanan farklı germe egzersizlerinin sağlıklı bireylerde plantar fasya sertliği üzerine etkinliğinin incelenmesidir.

Yöntem: Ondokuz sağlıklı katılımcı ile çift kör, randomize kontrollü bir çalışma yürütüldü. Katılımcılar plantar fasyaya özgü germe (PFSS) ve Aşil tendonu germe (ATS) olmak üzere iki gruba ayrıldı. Tüm katılımcılar, özel olarak tasarlanmış bir alet kullanarak dominant bacaklarında (PFSS veya ATS) germe egzersizlerini yaparken, dominant olmayan bacakları aletsiz şekilde gerildi. Plantar fasya sertliği, müdahale öncesi ve sonrası bir myotonometre ile ölçüldü. Her germe seansı, 10 saniye süreyle 10 tekrardan oluşuyordu. İstatistiksel analizde gruplar arası karşılaştırmalarda Mann-Whitney U testi, gruplar içindeki müdahale öncesi ve sonrası farkları değerlendirmek için Wilcoxon işaretli sıralama testi kullanıldı.

Bulgular: Cihaz destekli germe, hem PFSS ($p=0,008$) hem de ATS ($p=0,005$) gruplarında cihaz desteksiz (geleneksel) germe tekniklerine kıyasla plantar fasya sertliğinde anlamlı bir artışa yol açtı ($p<0,05$). Cihaz destekli veya cihaz desteksiz yapılan PFSS ve ATS arasında istatistiksel olarak anlamlı bir fark gözlenmedi ($p>0,05$).

Sonuç: Bu ön çalışma, yeni tasarlanmış cihazın plantar fasyaya yönelik germe müdahalelerinin etkinliğini artırma potansiyeline sahip olduğunu göstermektedir. Cihaz destekli germe tekniklerinin rehabilitasyon planlarına dahil edilmesi, gelecekteki klinik uygulamaları potansiyel olarak destekleyebilir.

Anahtar Sözcükler: Aşil tendonu, elastisite, fasya, kas germe egzersizleri.

Introduction

Locomotion and postural stability are critically dependent on functional feet. However, a significant public health concern exists due to the high prevalence of foot dysfunction, with studies reporting prevalence rates ranging from 61% to 79%[1]. This dysfunction demonstrably diminishes quality of life. Plantar fasciitis, a prevalent musculoskeletal disorder, emerges as a major clinical challenge affecting individuals across demographic groups and influencing psychological, social, and activity-related outcomes[2]. In the United States alone, estimates suggest it is responsible for exceeding one million physician visits annually[3,4]. Notably, the prevalence is even higher among athletes, particularly runners, with up to 17.4% experiencing the condition[5].

Plantar fascia and posterior crural stretching exercises are widely employed for foot and ankle pathologies due to the biomechanical interactions between the plantar fascia, intrinsic foot muscles, and various tendons (tibialis posterior, soleus, Achilles, flexor hallucis longus, and flexor digitorum longus tendons)[6]. Stretching exercises are a cornerstone of rehabilitation and athletic conditioning programs. While stretching interventions have been shown to improve maximal joint range of motion, often referred to as flexibility, and to decrease inflammation both acutely and chronically, the precise biomechanical mechanisms underlying these benefits remain unclear[7,8]. However, traditional stretching methods primarily focus on the Achilles tendon and manual

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plantar fascia stretching, which may not fully engage the plantar fascia in a targeted manner[9].

Conventional stretching protocols that target the posterior distal crural muscles (gastrocnemius and soleus) and the Achilles tendon may not adequately address the complexity of the plantar fascia. Emerging anatomical evidence highlights the intricate relationship of the plantar fascia with surrounding structures. This includes the division of the mid-plantar aponeurosis, its attachment to and influence on the metatarsal joints (windlass mechanism), the tibialis posterior tendon's interaction with the plantar fascia, and the connection between the Achilles tendon and the plantar fascia[10]. Despite these connections, standard approaches lack an effective means of isolating metatarsophalangeal (MTP9 joint extension to fully activate the windlass mechanism.

This study seeks to evaluate whether the designed stretching instrument offers a more effective clinical approach by directly addressing limitations in current protocols and providing a consistent application of targeted force on the plantar fascia. The research question is: "Does the designed instrument create a greater effect during stretching on the plantar fascia compared to current methods?" Our hypothesis is that this instrument will produce a greater effect and, if so, could also contribute to the treatment of different pathologies in the clinic. This hypothesis is based on the assumption that the designed instrument will enhance the stretching effect on the plantar fascia, leading to more efficient outcomes in the treatment process, and that it could be applied to other foot and ankle pathologies as well.

Material and Methods

Study Design

This study was designed as a double-blind, prospective randomized controlled pilot study. This study was performed between June and December 2024 in the Physiotherapy and Rehabilitation Laboratory at Istanbul Okan University. The study was conducted in accordance with the Helsinki Declaration. All individuals included in the study were informed about the evaluations to be conducted, and an informed consent form stating their voluntary participation was obtained. This study was reported in accordance with the CONSORT guidelines, ensuring transparent and comprehensive reporting of the study's methodology and findings.

Participants

Participants included in our study were healthy and voluntary individualsover the age of 18 with a body mass index (BMI) below 30 kg/m^2. The exclusion criteria for the study were: pregnancy, presence of chronic musculoskeletal disorders, presence of lower extremity injuries and/or surgeries, presence of skin lesions over the measurement areas, and the use of medications affecting the musculoskeletal system.

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Sample Size

As Thabane et al. indicated in feasibility studies, a sample size calculation is not necessary since the presentation of intervention effects is a secondary rather than a primary objective[11]. Therefore, a power analysis was not conducted for the sample size. A total of 19 individuals were included in the study, with 10 and 9 participants in each group.

Randomization

Participants were randomized into groups for Achilles tendon stretching (ATS) and plantar fascia-specific stretching (PFSS) based on the order of assessment and a pre-determined list number. The randomization sequence was manually generated following a predefined allocation order to ensure an unbiased distribution of participants. To maintain allocation concealment, sequentially numbered, opaque, sealed envelopes (SNOSE) were used, which were prepared by an independent researcher who was not involved in the recruitment, assessment, or intervention process. The initial pre-intervention assessments were conducted by the same physiotherapist, while a different physiotherapist, who had no knowledge of the interventions and did not participate in the intervention process or analysis, performed the immediate post-intervention assessments. Accordingly, as both the assessor and the data analysts were blinded to the intervention, our study was designed as a double-blind trial.

Assessments

The demographic data of the participants (age, height, body weight, body mass index) were recorded using an assessment form. Initially, to ensure normal conditions, navicular height values were recorded.

Measurement of Mechanical Properties

The evaluation of mechanical properties was conducted using a myotonometer (MyotonPRO, Myoton AS, Tallinn, Estonia). The myotonometer probe applies an external force to the examined tissue, inducing elastic deformation. The pressure differences between the inner probe and the outer plexiglass frame were measured using customized transducers connected to a computer[12]. Subsequently, the naturally damped oscillations were recorded by sensitive accelerometer sensors located at the distal end of the probe. The device is capable of calculating various mechanical parameters of the evaluated tissue, including oscillation frequency (Hz), stiffness (N/m). Oscillation frequency indicates the baseline intrinsic tension within the soft tissue. Stiffness represents the soft tissue's resistance to external forces that could cause contraction or change in shape and is expressed as the inverse of compliance[13].

Participant data were entered into the MyotonPRO software prior to the assessment, ensuring bilateral evaluation from the center of the tissue and three measurements were taken at rest. The application of perpendicular pressure to the tissue concluded when the red light on the device probe within the plexiglass frame turned green, after which the researcher awaited the completion of the five pulses[14].

For plantar fascia evaluation, participants were positioned prone with the hip joint neutral (0°), knee extended, ankle joint supported and neutral (0°), as confirmed by goniometer control[15]. Participants were positioned prone with their feet hanging off the edge of the table. The plantar fascia was measured in prone position between the first and second metatarsal bone at approximately 1–2 cm distal anterior edge of the inferior calcaneal margin in the posterior part of the PF[16,17].

Interventions

Participants were randomized into two groups: the Achilles Tendon Stretching (ATS) group and the Plantar Fascia-Specific Stretching (PFSS) group. All participants performed the stretching exercises on their dominant leg using a specifically designed instrument. The non-dominant leg received either non-instrumented Achilles tendon stretches (ATS group) or self-administered plantar fascia stretches (PFSS group). Each stretching exercise consisted of 10 repetitions, held for 10 seconds in the final position.

The tool consisted of two main components: an elevated section to lift the toes into extension and a flat platform for stable foot placement. To assist with toe extension, a piece of "pool noodle" (a soft, cylindrical foam material) was attached to the end of a towel, and the foot was placed on this towel. The elevated section was approximately 5 cm in height and 8 cm in width, corresponding to an average MTP joint angle of 30–35°. The base platform measured approximately 25 × 30 cm, allowing full contact of the plantar surface. To facilitate controlled toe extension, a cylindrical foam insert ('pool noodle') of 5 cm diameter and medium density (EVA foam, Shore C hardness ≈ 35) was fixed at the distal end of the towel to prevent slippage. An additional small cushion was placed under the middle of the plantar fascia. It is approximately 1.5 cm in height, conical in shape, and made of durable material. The total mechanical resistance of the setup corresponded to a compressive deformation of less than 10 % under body-weight loading. These details were standardized to ensure consistent positioning and reproducibility across participants. The designed instruments were shown in Figure 1 and stretching applications with and without instruments in both groups were shown in Figure 2.

Figure 1. The designed instrument

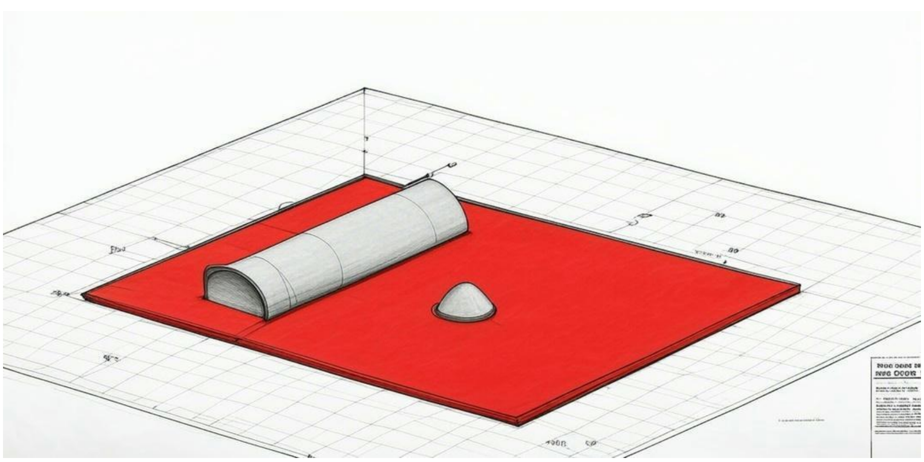
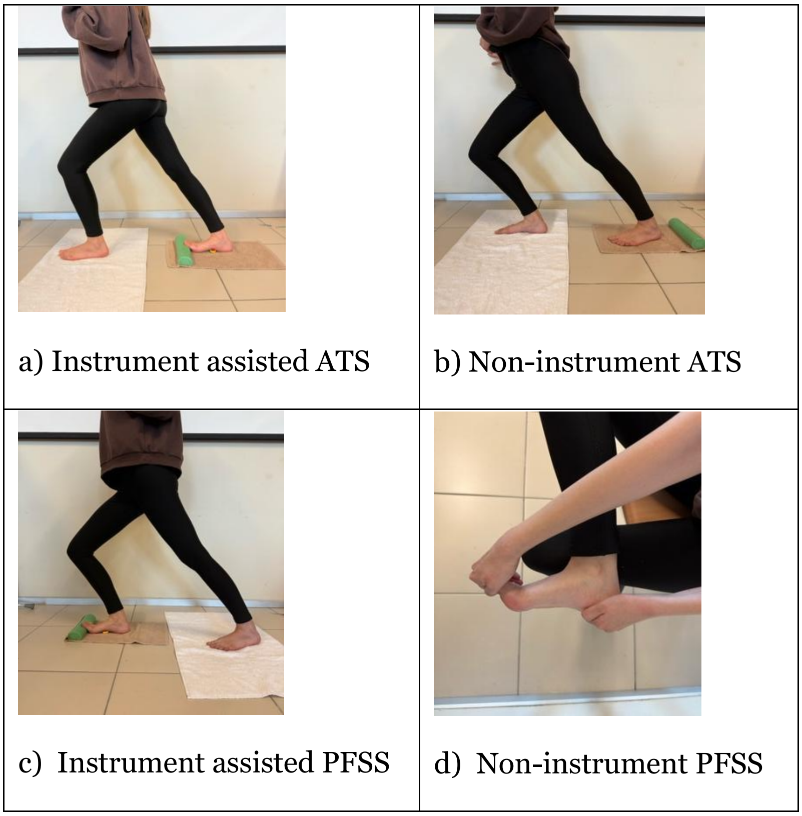


Figure 2. Stretching with and without instrument in both groups



a) Instrument assisted ATS

b) Non-instrument ATS

c) Instrument assisted PFSS

d) Non-instrument PFSS

For the instrument-assisted ATS exercise, the dominant side of the body was stretched using a specialized tool designed to enhance the stretch by extending the toes upward (toe extension). Participants were instructed to position their toes against the pool noodle material. Additionally, a small triangular prism made of sponge was placed under the middle of the plantar fascia to increase tension during the stretch. Using this tool, participants performed the stretch as follows: they extended their toes upward and positioned their dominant leg behind them while placing the other leg in front. The heel of the dominant foot was firmly planted on the ground, with the back knee kept straight, while the front knee was bent forward. The toes of the stretched foot were directed toward the heel of the front foot. The same stretching exercise was also performed on the non-dominant side, but without the use of the instrument. The stretching routine consisted of 10 repetitions, with each repetition held at the final position for 10 seconds (Figure 2a-b).

For the instrument-assisted PFSS exercise, participants utilized a specially designed stretching tool for their dominant side. This tool was structured to hold the toes in an extended position (toe extension). During the exercise, participants moved their knee forward to dorsiflex the foot (bringing the toes closer to the shin (anterior side of leg) while ensuring the heel remained firmly on the ground. For the non-dominant side, participants performed the stretch in a seated position by placing the leg to be stretched over the opposite leg. In this position, they used their hands to gently pull the toes of the foot upward toward the shin, applying pressure just below the MTP joints (the area where the toes connect to the foot). This action was continued until a noticeable tension was felt in the plantar fascia, the tissue on the sole of the foot, in a technique known as self-administered plantar fascia stretching. The stretching routine for both sides involved 10 repetitions, with each repetition held at the final position for 10 seconds (Figure 2c-d).

Ethical Statement

Ethical approval was obtained from the Istanbul Okan University Ethics Committee under decision number 179, dated 05.06.2024 (Clinical Trial Number: NCT06370741, dated: 17.04.2024).

Statistical Analysis

The statistical analysis of the data was conducted using SPSS 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.). Descriptive statistics were presented as number of units (n), percentage (%), mean ± standard deviation, median (M), minimum (min), and maximum (max) values. Non-parametric tests were used in this research due to limited sample size. The Mann-Whitney U test was used to compare two independent groups, while the Wilcoxon signed-rank test was applied to assess pre- and post-stretch measurements within the same group. Between-group effects were evaluated using delta (post–pre) values. The delta value for outcome measures was obtained by subtracting pre-stretching values from post-stretching values. Δ = (Post-stretching mean value) − (pre-stretching mean value). The within-group effect size (ES) was calculated using the formula ()/(standard deviation of the pretreatment evaluation). An ES of ≥ 0.81 was classified as large, an ES of 0.80 to 0.51 as moderate, and an ES of 0.50 to 0.21 as small18. A p-value of less than 0.05 was considered statistically significant.

Results

Nineteen healthy individuals were included in the study, with 9 in the PFSS group and 10 in the ATS group. There were no significant differences in demographic data (age, height, weight, BMI) and navicular height between the groups at baseline. The descriptive data were shown in Table 1.

Table 1. Descriptive characteristics of participants

Descriptives	**PFSS group Mean ± SD**	**ATS group Mean ± SD**	**p***
Age	19.89±1.16	20.90 ±2.76	0.473
Height	1.73±0.12	1.75±0.13	0.712
Weight	68.67±19.35	76.80±14.26	0.326
Body mass index (kg/m²)	22.29±3.72	24.87±3.85	0.165

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Right Navicular height (cm)	3.83±0.43	3.55±0.68	0.195
Left Navicular height (cm)	3.83±0.43	3.55±0.68	0.172
Gender	**n (%)**	**n (%)**	
Female	4 (44.4)	2 (20)	0.252**
Male	5 (55.6)	8 (80)	

ATS: achilles tendon stretching, PFSS: plantar fascia-specific stretching, SD: Standard deviation, *Mann Whitney U test, **Pearson Chi-Square

When comparing the pre- and post-stretching values of instrument-assisted stretching applications by groups, there was a significant difference in the PFSS group for the values of Stiffness (p=0.008) while there was a difference in the ATS group for the values of Stiffness (p=0.005).

When comparing the pre- and post-stretching values of non-instrument stretching applications by groups, there was a statistically significant difference in the PFSS group for the values of Stiffness (p=0.012),while there was no difference in the ATS group for the values of Stiffness (0.241). Comparisons of instrument-assisted and non-instrument applications for the PFSS and ATS groups were shown in Table 2.

Table 2. Comparisons of stiffness value for instrument-assisted and non-instrument applications in both groups

Groups	Type	Stiffness Pre-stretching Mean ± SD Min-Max Median (Q1/Q3)	Stiffness Post-stretching Mean ± SD Min-Max Median (Q1/Q3)	P	ES
PFSS Group	**Instrument-assissted**	434.11±53.22 363-521 431 (385-480.5)	466.33±50.99 385-534 477 (414-508)	**0.008**	0.605
	Non-instrument	416.33±57.85 339-512 411 (368.5/466.5)	435.55±59.00 344-518 448 (383.5/476.5)	**0.012**	0.332
ATS Group	**Instrument-assissted**	430.10±58.59 356-563 437 (384.25/453.5)	462.50±79.10 370-642 468 (402/488.75)	**0.005**	0.552
	Non-instrument	420.10±52.51 327-491 413 (384.5/466.5)	427.50±60.18 330-510 418 (379.5/489.75)	0.241	0.140

ATS: achilles tendon stretching, ES: Effect size, Min: minimum, Max: maximum, PFSS: plantar fascia-specific stretching, SD: Standard deviation, *Wilcoxon Signed Rank test

When comparing intra-group instrument-assisted and non-instrument stretching applications based on delta values, a significant difference in favor of the instrument-assisted group was observed for the PFSS and ATS groups in terms of values (p<0.05). Comparisons of intra-group instrument-assisted and non-instrument stretching applications based on delta values were shown in Table 3.

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When comparing the delta values of PFSS and ATS applications performed with or without instruments, there was no statistical significance between instrument-assisted and non-instrument stretching applications for both PFSS and ATS. The results were similar ($p<0.05$). Comparisons of PFSS and ATS performing with or without instrument were shown in Table 3.

Table 3. Comparisons of groups instrument-assisted and non-instrument stretching applications based on delta values

ΔStiffness	**PFSS Group**	**ATS Group**	p	95% CI
Instrument-assisted Mean ± SD Min-Max Median (Q1/Q3)	32.22±18.50 13-65 26 (18-48)	32.40±24.92 2-79 25(17/46.75)	0.935*	0.008 (-0.892 - 0.909)
Non-instrument Mean ± SD Min-Max Median (Q1/Q3)	19.22±23.69 0-69 8 (5.5-34.5)	7.40±16.46 -14-40 2.5 (-5/21.75)	0.205*	-0.586 (-1.505 - 0.334)
p	**0.052***	**0.019***		
95% CI	-0.612 (-1.949 - 0.725)	-1.184 (-2.528 - 0.16)		

ATS: achilles tendon stretching, CI: Confidence interval, Min: minimum, Max: maximum, PFSS: plantar fascia-specific stretching, SD: Standard deviation, Δ = (Post-stretching value) – (pre-stretching value), *Mann Whitney U test

Discussion

The present study investigated the efficacy of utilizing a novel instrument in conjunction with conventional stretching postures to target the plantar fascia. Our study demonstrates a statistically significant impact on stiffness values (PFSS and ATS) following instrument-assisted stretching compared to traditional techniques. Within the instrument-assisted stretching group, pre- and post-stretching stiffness values (PFSS) showed a statistically significant difference. Despite the application of different stretching protocols, we observed similar stiffness outcomes in the PFSS and ATS groups. This aligns with emerging anatomical evidence that underscores the intricate relationship between the plantar fascia and surrounding structures, including the division of the mid-plantar aponeurosis, its influence on the metatarsal joints via the windlass mechanism, the interaction of the tibialis posterior tendon with the plantar fascia, and the connection between the Achilles tendon and the plantar fascia[10]. These results suggest that our novel instrument, applied in combination with conventional stretching techniques, demonstrates the potential to significantly enhance the effectiveness of stretching interventions for plantar fascia by specifically targeting this tissue.

Stretching exercises are a cornerstone of treatment for ankle and foot conditions. However, limited research has explored the isolated effects of stretching on the plantar fascia or how different joint positions influence its mechanical properties. Further understanding of plantar fascia's biomechanics is crucial for optimizing therapeutic approaches. Recent studies using shear wave elastography (SWE) and Myoton Pro have provided insights into the in vivo viscoelastic properties of the plantar fascia[19–22]. Given the crucial role of plantar fascia biomechanics in treatment, understanding the impact of stretching on this tissue is essential. However, the impact of stretching on the mechanical properties of the musculoskeletal system remains a topic of debate. Muscles, tendons, and fascia may exhibit varying responses to immediate stretching[23].

In this study, dynamic stiffness measurements indicated a significant increase in plantar fascia stiffness immediately after stretching in the instrumented group compared to the non-instrumented group. These findings suggest that our device may acutely enhance tissue stiffness following stretching, contributing to the ongoing debate on how stretching affects soft tissue properties. The observed increase in stiffness reflects an immediate tissue response to the applied force, indicating that the device effectively transmits stretching forces to the plantar fascia. However, previous studies have reported conflicting results regarding the effects of stretching on tendon and fascia stiffness. For example, several studies have reported decreased tendon stiffness following static stretching[22-24]. Conversely, others have shown that stretching reduces muscle and tendon stiffness without altering tendon structure[25-27]. Similarly, Nakamura et al. (2015) observed that 5 minutes of passive stretching increased tendon stiffness[22-28].

Yugi Sugino's research (2023)[9] also indicated that plantar fascia-specific stretching and achilles tendon stretching increased stiffness from 158.9 kPa to 215.8 kPa, aligning with our findings using Myoton Pro. However, in their study, stiffness was measured using shear wave elastography at a single medial site, whereas our study employed MyotonPRO measurements focused on the posterior fascia, which may capture a slightly different mechanical response. Phongpan Tantipoon et al. (2023) demonstrated a correlation between results obtained with SWE and Myoton Pro. Variations in measurement methods, such as the position of tendon measurement (proximal vs. distal), the duration of static stretching (5 minutes vs. 3 minutes), and the types of stretching modalities (isokinetic vs. manual, passive vs. active), could explain the discrepancies among studies. Therefore, these methodological differences may account for the variations in measurement outcomes[29,30].

Additionally, Chiu et al.[25] observed a notable increase in tendon stiffness in the non-dominant leg, contrasting with the findings in the dominant leg. This finding highlights the importance of stress, defined as force per unit area, on inducing mechanical changes in tendons. Research suggests that the magnitude of strain applied to the Achilles tendon must exceed a certain threshold to trigger adaptations in its properties. These strains likely surpass those encountered during daily activities. Our study, consistent with

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earlier research by Sugino[9], revealed heightened plantar fascia stiffness following static stretching. Furthermore, our results suggest that even the dominant side in the instrumented group showed a significant impact. This finding suggests that the new instrument may impose greater stress on the plantar fascia compared to manual toe extension stretching with pressure point which is very similar area of knot of Henry, it may be possible to effect more junction on flexor hallucis longus and flexor digitorum longus tendon[31]. The potential effects on the hypothesized "knot of Henry" warrant further investigation. Research by Huang et al (2018) using Myoton Pro also underscores the impact of foot, ankle, and knee positions on plantar fascia stiffness[32]. Taken together, these findings strongly suggest the superiority of our instrument-assisted stretching technique for targeting plantar fascia stiffness compared to traditional achilles stretching and plantar fascia-specific stretching. However, in addition to these findings, the increase in stiffness may reflect an acute rise in tissue tone or a temporary decrease in compliance rather than improved elasticity. This transient response may represent a normal physiological adaptation to mechanical loading, and further research is needed to determine its long-term clinical relevance.

The plantar fascia and Achilles tendon are anatomically connected via the calcaneus. This anatomical continuity suggests that stretching the Achilles tendon could indirectly influence the plantar fascia due to the interconnected nature of the fascial system[33]. Both the plantar fascia and the Achilles tendon play crucial roles in foot mechanics and load distribution during gait. Consequently, both PFSS and ATS may affect each other due to their functional interdependence within the kinetic chain[34]. Behm et al.[27] indicated that stretching can induce reflexive muscle contractions and adjustments that extend beyond the targeted area, impacting the entire lower limb. This could result in comparable changes in plantar fascia stiffness, regardless of whether the stretch is specific to the plantar fascia or the Achilles tendon. Similarly, our study observed that PFSS and ATS exercises had similar effects on plantar fascia stiffness. In conclusion, both stretching methods, particularly those performed with instruments, can be effectively integrated into rehabilitation programs. Our findings provide valuable clinical guidance, suggesting that these techniques, which significantly improve the stretch of the plantar fascia, can empower physiotherapists to support patients in the clinic. Furthermore, we believe that patients can independently and efficiently perform stretching exercises at home, enhancing both the speed and effectiveness of their recovery.

This study is subject to certain limitations. Firstly, it was a pilot study with a relatively small sample size (n=19). Therefore, to ensure the generalizability of our findings, replication with a larger and more diverse participant pool is warranted. Secondly, we focused on assessing PF elasticity in nineteen healthy young individuals (mean age: 20 years) without abnormal foot alignment or plantar fasciitis. While this allowed us to isolate the instrument's effect on healthy tissue, it is important to note that Wu et al. highlighted age-related and plantar fasciitis-related declines in plantar fascia elasticity[35]. Therefore, further research is needed to determine the instrument's effectiveness in individuals diagnosed with plantar fasciitis. Another limitation of this study is the gender imbalance between groups, with a higher proportion of male participants in the ATS group. Although plantar fascia stiffness does not show significant differences between

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sexes, males generally exhibit greater plantar fascia thickness[36], which could still have a minor influence on the mechanical properties measured. Therefore, future research should aim to include both a larger and more gender-balanced sample, as well as individuals diagnosed with plantar fasciitis, to further validate and expand the applicability of our findings.

Conclusion

In conclusion, this pilot study demonstrates that instrumented stretching may provide a potentially more effective approach for targeting the plantar fascia compared to traditional stretching methods. Further research is warranted to:

- Investigate the physiological mechanisms behind the observed increase in stiffness following instrument-assisted stretching.
- Explore the effectiveness of the instrument-assisted stretching technique with different ankle and knee positions.
- Confirm the effectiveness of this approach in patients diagnosed with plantar fasciitis.

Declarations

Ethics Approval and Consent to Participate: Ethical approval was obtained from the Okan University Ethics Committee under decision number 179, dated 05.06.2024. The study was conducted in accordance with the Helsinki Declaration. All individuals included in the study were informed about the evaluations to be conducted, and an informed consent form stating their voluntary participation was obtained.

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Availability of Data and Materials: All data can be obtained by contacting the corresponding author.

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