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Biomechanical and Viscoelastic Properties of the Achilles Tendon and Plantar Fascia in Pregnant Women with Pelvic Girdle Pain: A Case–Control Study

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ABSTRACT

This cross-sectional study examined the biomechanical and viscoelastic properties of the Achilles tendon (AT) and plantar fascia (PF) and analyzed their relationship in pregnant women with pelvic girdle pain (PGP). The study was conducted in a public hospital between January and May 2021. Forty-four pregnant women (PGP+, n: 22; PGP–, n: 22) and 21 non-pregnant women were included. Navicular drop was determined and the tonus, stiffness, and creep of PF and AT were measured by Myometer. Navicular drop was significantly different between the PGP+ and the non-pregnant group in both feet (Right, $p = .001$; Left, $p =< .001$), and the PGP– and the non-pregnant group in the left foot ($p = .009$). At the right AT, the stiffness was found to be higher in non-pregnant women compared to the PGP+ group ($p = .007$). Furthermore, creep was higher in PGP– compared to the non-pregnant group ($p = .016$). Tissue properties of PF were similar in all groups ($p > .05$). A correlation between tissue properties and the presence of PGP was not found. No findings indicated that the biomechanical and viscoelastic properties of the AT and PF were affected by the physiology of pregnancy. Moreover, no relationship was observed between the presence of PGP and the tissue properties of the AT and PF.

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Muscle tonus; musculoskeletal disease; pregnancy; sacroiliac joint

Introduction

Pregnancy causes a series of changes in female musculoskeletal system to create space for the developing fetus. Additionally, biomechanical adaptation as the center of gravity shifts forward is critical for pregnancy (Talbot and Maclennan 2016). Adaptations occur especially in soft tissues, joints, and posture. Increased levels of relaxin, estrogen, and progesterone hormones result in the relaxation of soft tissues (Anselmo et al. 2017). Furthermore, musculoskeletal changes such as increased lumbar lordosis, posterior tilt of the sacrum, instability in lower extremity, increase in pelvic mobility, and anterior pelvic tilt (Thabah and Ravindran 2015). All these factors adversely affect the health and quality of life of pregnant women by causing difficulties in daily activities (Bertuit et al. 2018), increasing the risk of falling (Ersal, McCrory, and Sienko 2014), and/or causing lower back/pelvic girdle pain (PGP) (Thabah and Ravindran 2015).

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PGP refers to pain that arises in muscles, ligaments, and joint capsules in the pelvic region (Ostgaard, Roos-Hansson, and Zetherström 1996). The onset of pain occurs at 18 weeks and reaches its peak intensity at 24 to 36 weeks (Wu et al. 2004). Although it is often confused with lower back pain, PGP is characterized by pain between the posterior iliac crest and the gluteal fold, especially in the sacroiliac joint (SIJ). In addition, symphysis pubis pain, which is not observed in lower back pain, is frequently reported in pregnancy-related PGP (Vleeming et al. 2008).

The cause of PGP has not yet been fully elucidated. The most important risk factor has been reported to be a history of pain/trauma in the lower back and pelvis region before pregnancy (Vleeming et al. 2008). In addition, studies have shown that pregnancy-related PGP occurs as a result of an increased mobility in the SIJ due to hormonal and biomechanical changes (Aldabe, Milosavljevic, and Bussey 2012; Vleeming et al. 2008). Owing to the pelvic position, the SIJ is an overloaded area and has minimized mobility. Optimal SIJ stability is provided by its anatomical structure (form closure) and the surrounding soft tissue (force closure) (Bhardwaj and Nagandla 2014; Vleeming and Schuenke 2019). During pregnancy, an increase in mobility of the SIJ occurs due to weakening of the force closure associated with hormone-related soft tissue relaxation (Talbot and Maclennan 2016; Vleeming et al. 2008), and disrupted form closure as a result of increased anterior pelvic tilt (Thabah and Ravindran 2015). However, hormonal factors have also been demonstrated to not cause the development of SIJ pain (Aldabe, Milosavljevic, and Bussey 2012). Interestingly, there is no clear relationship between serum relaxin levels and peripheral joint laxity/PGP (Bhardwaj and Nagandla 2014).

Another region where postural changes are evident in pregnant women is the foot. Increased body weight and pregnancy hormone levels have been reported to reduce the height of the foot arch that in turn increases the support surface (Thabah and Ravindran 2015). This may be accompanied by changes in foot anthropometric characteristics (foot length, width, volume increase, etc.) (Augustina et al. 2019). Similarly, it has been shown that ankle stiffness increases in pregnant women to maintain balance (Ersal, McCrory, and Sienko 2014).

Changes in the foot structure may affect the lower limb, pelvis, and vertebral column in the biomechanical chain (Khamis and Yizhar 2007; Woźniacka et al. 2019). The relationship between the foot-lumbar region and foot-pelvic region pain has been reported in various studies (Mansourpour et al. 2019; Melkersson et al. 2017). To the best of our knowledge, the effect of pregnancy on the biomechanical (tone-Hz and stiffness-N/m) and viscoelastic (creep) properties of foot tissues and whether it is associated with the manifestation of PGP have not been sufficiently studied. The plantar fascia (PF) is one of the most important structures that maintains arch height, and performs its functions in interaction with the Achilles tendon (AT) (Orner et al. 2018). Therefore, the tissue properties of the PF and AT are important in terms of foot function. Considering these studies, pregnancy has been speculated to change the foot tissue properties. These changes may also affect the upper segments through the biomechanical chain, which contribute to the development of PGP. This study aimed to examine the biomechanical and viscoelastic properties of the PF and AT in pregnant women with PGP, and to examine their relationship with PGP. Furthermore, tissue properties of PF and AT in pregnant women with PGP, without PGP, and non-pregnant women were also compared.

We hypothesized that (1) the passive tone and stiffness of the PF and AT will decrease, while creep will increase in both pregnant groups, more so in pregnant women with PGP; (2) parallel with this, navicular drop will be higher in pregnant women with PGP; and (3) a positive relationship will exist between PGP and tissue properties.

Materials and methods

Participants

Ethics committee approval (22.07.2020/166) was obtained from the Clinical Research Ethics Committee of the Zeynep Kamil Women and Children Diseases Training and Research Hospital. Women and Children Diseases Training and Research Hospital. Participants were informed about the

purpose and content of the study, and signed informed consent was obtained. The study was conducted in accordance with the principles of the Declaration of Helsinki and the clinical trial record (04620993) was obtained.

The cross-sectional study was conducted at the Gynecology and Obstetrics Department, Zeynep Kamil Women and Children Diseases Training and Research Hospital, between January and May 2021. The study included primiparous pregnant women in the second (>18 weeks) and third trimesters of pregnancy, those with PGP (PGP+) and without PGP (PGP−), and non-pregnant women who did not have a history of birth/miscarriage or were not menstruating at the time of measurement. Pregnant women with multiple pregnancies (twins, etc.), a history of miscarriage, pregnancy-related complications (preeclampsia, toxemia, etc.), and a history of lumbopelvic pain/trauma, and those (pregnant/nonpregnant) with diabetes for at least 3 years, lumbopelvic region pain that persisted for at least 3 months, orthopedic and neurological problems that may cause deterioration in the biomechanical alignment of the lower limbs, a history of foot–ankle fracture and surgery in the last 6 months, and connective tissue disease were not included in the study.

In the study, a total of 49 pregnant women with PGP+ ($n = 25$) and PGP− ($n = 24$), and 24 non-pregnant women were assessed. Eight participants due to erroneous measurements (which Myotone measurements were mistakenly taken with the protocol of another study) were excluded from the study. The study was completed with 65 participants. The participants were classified into three groups:

Group 1: PGP+ pregnant women ($n = 22$; mean age = 27.18 ± 4.17 years).
Group 2: PGP− pregnant women ($n = 22$; mean age = 26.31 ± 3.83 years).
Group 3: Non-pregnant women ($n = 21$; mean age = 28.10 ± 4.43 years).

Study design

The participants were asked to refrain from consuming any stimulant or sedative drugs and to not apply any substance to the measurement area for a period of 24 hours before examination. All measurements were performed by the same researchers at similar room temperature (23°–24°) and relative humidity <50 percent.

The sociodemographic data (age, height, weight, gained weight, marital status, physical activity level, and smoking status) and pregnancy-related information (gestational week, history of miscarriage, and presence of Gestational Diabetes Mellitus) were collected through face-to-face interviews. The circumference of umbilicus (CU) and diameter between Spina Iliaca Anterior Superiors (SIAS) were measured and registered. Following the data gathering process, pelvic pain provocation tests, navicular drop test, and measurement of tissue properties were performed (Figure 1).

Pelvic girdle pain diagnostic tests

Pain provocation tests and the active straight leg raise (ASLR) test were performed for diagnosis. Pain provocation tests consisted of (a) posterior pelvic pain provocation test, (b) Patrick's Faber test, (c) modified Trendelenburg test, and (d) symphysis pubis pain provocation test. The ASLR test (e) was conducted to determine the level of difficulty that may be experienced due to PGP. If the level of difficulty felt during testing was 2 or higher, the test was considered to be positive (Aldabe, Milosavljevic, and Bussey 2020; Vleeming et al. 2008). If one of the (a) and (e) tests was positive on the right/left or both sides and at least one of the (b), (c), and (d) tests was positive, the findings were considered sufficient for the diagnosis of PGP (Elden et al. 2016).

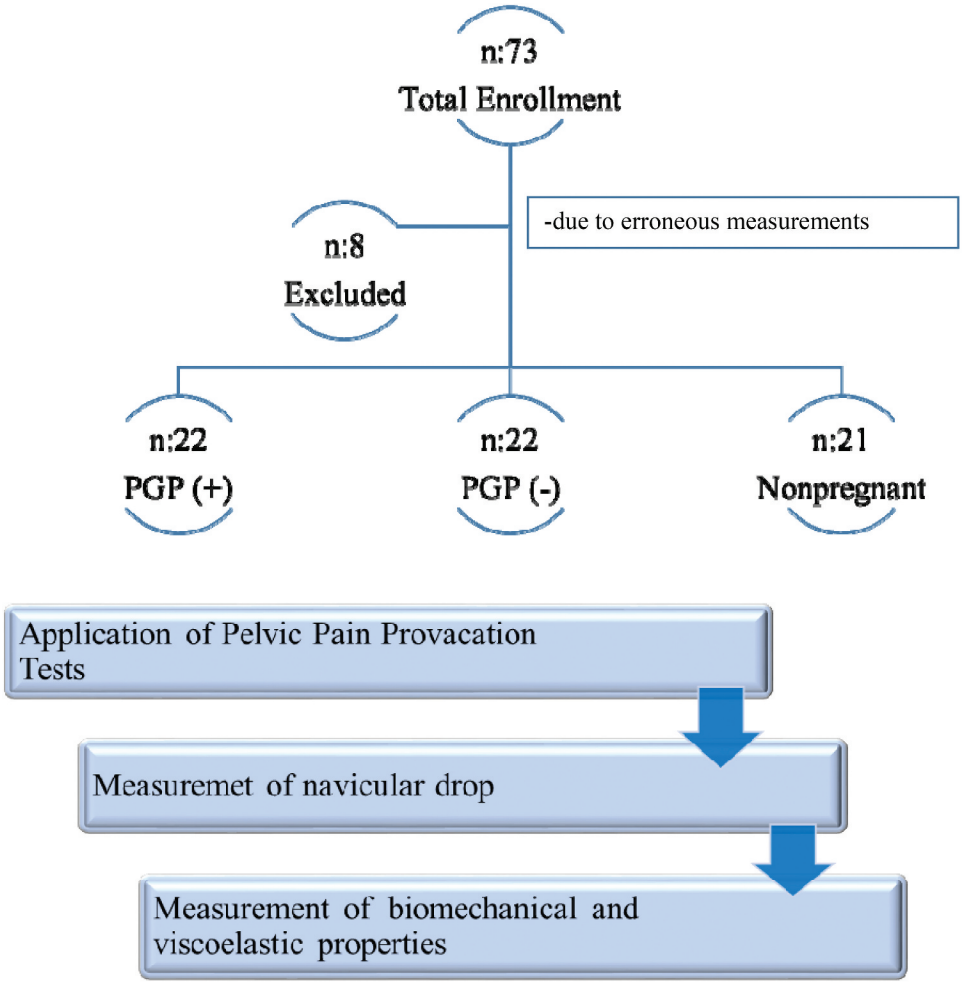

Figure 1. Flow chart of study.

Navicular drop test

The distance between the navicular prominence and the ground was measured using a card measuring tape in the sitting position with the subtalar joint neutral, the hip–knee joint in 90° flexion, and in the standing position with equal weight on both extremities. The difference between the navicular heights obtained in the two positions was recorded as the amount of navicular drop (mm) (Adhikari et al. 2014).

Biomechanical–viscoelastic properties of the AT and PF

Tissue properties of participants were measured by using Myometer (Myoton Pro, Myoton AS, Tallinn, Estonia) in the side-lying position, when participants were completely relaxed. Measurements of AT properties were performed at the midpoint between the projections of both malleolis on the AT with the knee extended and the ankle in neutral (0°) position (Figure 2). PF properties were measured at the midpoint between the center of the calcaneus and the second metatarsophalangeal joint with knee in 90° flexion, first metatarsophalangeal, and the ankle in neutral position (Sakalauskaite and Satkunskiene 2012) (Figure 3). The biomechanical (passive tone; intrinsic

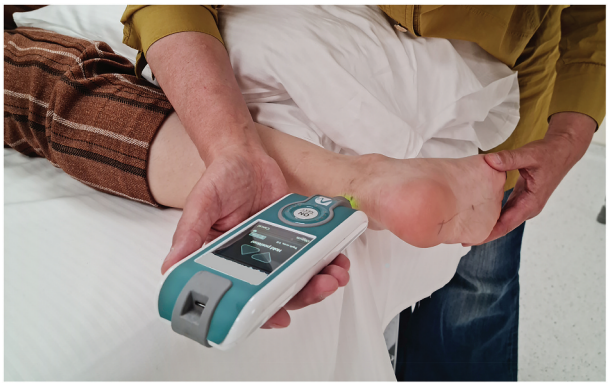

Figure 2. Measurement position of tissue properties of achilles tendon.

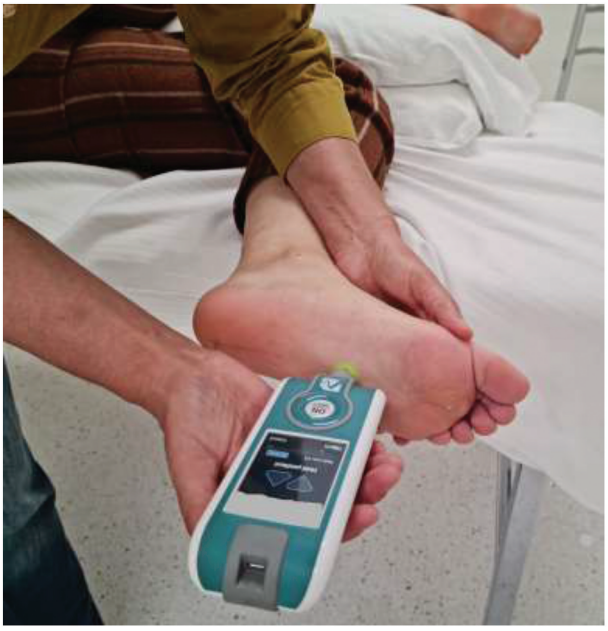

Figure 3. Measurement position of tissue properties of plantar fascia.

tension of the tissue at resting state without any voluntary contraction and stiffness; the resistance of the tissue to deformation caused by applied force) and viscoelastic (creep; the gradual elongation of a tissue over time under a constant tensile) properties were calculated by averaging the tissue-generated oscillator responses against three repetitive mechanical stimuli (.40N, 15 ms). The validity and reliability of the Myometer has been described elsewhere (Huang et al. 2018).

Statistical analysis

The Post-Hoc power analysis of the study was performed using G*Power 3.1.9.2 (Kiel University, Kiel, Germany) (Faul et al. 2007). In the post-hoc analysis using partial η^2 of the primary outcomes (tissue parameters-stiffness and creep) of the present study, the effect sizes (f) of the present study were found to be large (.395–.410) and the power of the study (1-β) for One-Way Analysis of Variance was calculated as 80–83 percent (Type I error/.05).

Statistical analyses were performed using IBM SPSS software for Windows (Version 22.0., IBM Corp., Armonk, NY, USA). The significance level was set at $p \leq .05$ for all evaluations. Significance values were adjusted by the Bonferroni correction for multiple tests (Adj. Sig. ≤.016). Descriptive statistical tests (mean, standard deviation, frequency) were performed to define the groups. The normal distribution was analyzed using the Shapiro–Wilk test. If skewness and kurtosis values were between +2 and −2, then the data was considered to fit the normal distribution. For comparisons between the two groups, an Independent Samples *t*-Test was used. For comparisons between the three groups, a One-Way Analysis of Variance Test was used. Post-hoc comparisons were made using the Bonferroni test, and the relationship between the parameters was examined by Spearman's Correlation. The difference between qualitative/categorical variables was analyzed using the Pearson Chi-square test (χ^2). In cases where the χ^2 test was not valid based on the observed and expected values, a Fisher's exact test was used. Effect size (d) was calculated by using differences between means divided by the pooled standard deviations of the two groups to reveal a clinically significant difference. According to Cohen's guidelines, ≤.20 was taken as small effect, .20 to .50 as moderate effect, .50–.80 large effect, and ≥.80 as very large effect (Cohen 1988).

Results

Actual weight (PGP+, $P = .003$; PGP− $p < .001$) and body mass index (PGP+, PGP− $p < .001$) were found to be significantly different between the pregnant groups and the non-pregnant group. Sociodemographic and pregnancy-related characteristics of the pregnant groups were found to be similar (Table 1). None of the participants were doing regular physical activity (inactive). The right foot was the dominant side in all subjects.

In terms of the navicular height obtained from both right and left foot, differences between the PGP − pregnant group and the non-pregnant group were significant (Right, $p = .004$, d = 1.13; Left, $p = .012$, d = .95). The navicular drop showed a significant difference between the PGP+ and the non-pregnant group in the right foot ($p = .001$, d = 1.29), and between both pregnant groups and the non-pregnant group in the left foot (PGP+ $p = < .001$, d = 1.40; PGP− $p = .009$, d = 1.19) (Table 2). Intragroup comparisons showed that the navicular height and navicular drop values of the right and left feet were similar in all groups ($p > .05$).

Paired comparisons showed that there was a significant difference between PGP+ and the non-pregnant group in terms of stiffness ($p = .007$; d = .98) of the right AT. In addition, the creep of the right AT ($p = .016$; d = 1.04) was found to be statistically different between the PGP− group and the non-pregnant group (Table 3). Intragroup comparisons showed that passive tone, stiffness, and creep of AT as well as those of PF were found to be similar between the right and left feet in all groups ($p > .05$).

The pregnant groups showed similar characteristics in terms of navicular height, navicular drop, and tissue properties ($p > .05$). There was no significant relationship between the presence of PGP and any of the measured parameters (navicular height, drop, and tissue properties) ($p > .05$) (Table 4).

Discussion

In this study, the tone, stiffness, and creep values of the AT and PF in pregnant women and the relationship of these features with PGP were examined. Furthermore, the data of PGP+ pregnant women were compared with those of PGP− pregnant women and non-pregnant women. Navicular drop values were found to be higher in the pregnant groups compared to those in the non-pregnant group, but the values were similar between the pregnant groups. The tissue properties were similar in both pregnant groups; however, the stiffness of right AT was found to be higher in the non-pregnant women compared to PGP+ pregnant women. Furthermore, the creep of the right AT was found to be higher in PGP− pregnant women compared to non-pregnant women.

Table 1. Demographic and descriptive characteristics of participants (A) and frequency of positive response of provocation tests (B).

Parameters		Groups			
		PGP (+) (n: 22)	PGP (-) (n: 22)	Nonpregnant (n: 21)	
A		mean ± SD	mean ± SD	mean ± SD	P
Age (years)		27.18 ± 4.17	26.31 ± 3.83	28.10 ± 4.43	.386
Height (cm)		160.45 ± 7.23	161 ± 4.72	163.65 ± 4.76	.199
Weight (kg)	Actual	70.84 ± 15.77	73.85 ± 9.93	58.52 ± 7.29	<.001
	Gained	9.90 ± 5.53	10.08 ± 5.49	-	.918*
Actual BMI (kg/cm^2)		27.43 ± 5.24	28.32 ± 4.12	21.85 ± 2.66	<.001
CU		100.34 ± 15.70	104.46 ± 14.55		.429*
Diameter-SIAS		29.39 ± 4.18	29.87 ± 2.54		.691*
Gestational Week		28.18 ± 6.47	28.59 ± 7.11	-	.843*
		% (n)	% (n)		P**
Trimester	Second	45.50 (10)	50.00 (11)	-	.989
	Third	54.50 (12)	50.00 (11)	-	
Marial Status	Married	100 (22)	100 (22)	9.52 (2)	
	Single	-	-	90.48(19)	
Smoker		13.63 (3)	9.09 (2)	4.76 (1)	
GDM		22.72 (5)	9.09 (2)	-	
B		Side	PGP (+) (n: 22) % n	PGP (-) (n: 22) % n	P**
Pelvic Pain Provacation (P4) Test		Right	54.50 (12)	9.10 (2)	.002
		Left	50.00 (11)	0 (0)	<.001
Patrick Faber Test		Right	40.90 (9)	9.10 (2)	.023
		Left	68.20 (15)	13.60 (3)	.001
Modifiye Trendelenburg Test		Right	31.60 (6)	0 (0)	.020^{FT}
		Left	26.30 (5)	0 (0)	.047^{FT}
Active Straight Leg Rise Test		Right	47.60 (10)	4.50 (1)	.002
		Left	52.40 (11)	4.50 (1)	.001
Symphsis Pubis Palpation Test		-	61.90 (13)	13.60 (3)	.002

PGP: Pelvic Girdle Pain; BMI: Body Mass Index; kg: Kilogram; cm: Centimeter; CU: Circumference of Umbilicus.
SIAS: Spina Iliaca Anterior Superior; GDM: Gestational Diabetes Mellitus; P: One-way ANOVA; *: Independent t test; **: Pearson Chi-square test.; ^{FT}:Fisher's Test; $P \leq .05$.

Table 2. Navicular height and drop values of participants.

Parameters	Side/Position	Groups	mean ± SD	P	Post-Hoc	P*
Navicular Height (mm)	Right/Sitting	PGP (+) (n:22)	46.04 ± 4.66	.004	PGP (+)-PGP (-)	1.000
		PGP (-) (n:22)	48.50 ± 6.57		PGP (+)-Nonpreg.	.043
		Nonpreg. (n:21)	41.80 ± 5.11		PGP (-)-Nonpreg.	.004
	Right/Standing	PGP (+) (n:22)	35.63 ± 6.12	.063	PGP (+)-PGP (-)	-
		PGP (-) (n:22)	39.71 ± 6.44		PGP (+)-Nonpreg.	-
		Nonpreg. (n:21)	35.95 ± 5.85		PGP (-)-Nonpreg.	-
	Left/Sitting	PGP (+) (n:22)	45.63 ± 5.98	.007	PGP (+)-PGP (-)	1.000
		PGP (-) (n:22)	46.18 ± 5.32		PGP (+)-Nonpreg.	.029
		Nonpreg. (n:21)	41.14 ± 5.23		PGP (-)-Nonpreg.	.012
	Left/Standing	PGP (+) (n:22)	34.86 ± 6.35	.175	PGP (+)-PGP (-)	-
		PGP (-) (n:22)	38.19 ± 5.20		PGP (+)-Nonpreg.	-
		Nonpreg. (n:21)	36.00 ± 5.88		PGP (-)-Nonpreg.	-
Navicular Drop (mm)	Right	PGP (+) (n:22)	10.40 ± 3.83	.001	PGP (+)-PGP (-)	.158
		PGP (-) (n:22)	8.14 ± 4.22		PGP (+)-Nonpreg.	.001
		Nonpreg. (n:21)	5.85 ± 3.13		PGP (-)-Nonpreg.	.160
	Left	PGP (+) (n:22)	10.77 ± 5.02	<.001	PGP (+)-PGP (-)	.300
		PGP (-) (n:22)	8.80 ± 3.53		PGP (+)-Nonpreg.	<.001
		Nonpreg. (n:21)	5.14 ± 2.51		PGP (-)-Nonpreg.	.009

PGP: Pelvic Girdle Pain; Nonpreg: Nonpregnant; mm: Milimeter; SD: Standard Deviation; P: One-way ANOVA.
P*: Bonferroni Test; $P \leq .05$; Adj. Sig ≤.016.
The right foot was the dominant side in all subjects.

Table 3. Biomechanical and viscoelastic properties of Achilles Tendon and Plantar Fascia.

			Groups					
Tissue	Side	Parameters	PGP (+) mean ± SD (n: 22)	PGP (-) mean ± SD (n: 22)	Nonpregnant mean ± SD (n: 21)	P	Post-Hoc	P**
Achilles Tendon	Right	Tone (Hz)	31.50 ± 3.39	34.14 ± 6.06	35.11 ± 2.73	.024	PGP (+)-PGP (-)	.154
							PGP (+)-Nonpreg.	.026
							PGP (-)-Nonpreg.	1.000
		Stiffness (N/m)	888.00 ± 142.94	937.90 ± 124.44	1006.23 ± 89.53	.009	PGP (+)-PGP (-)	.560
							PGP (+)-Nonpreg.	.007
							PGP (-)-Nonpreg.	.217
		Creep	0.39 ± .06	0.41 ± .09	0.34 ± .03	.013	PGP (+)-PGP (-)	1.000
							PGP (+)-Nonpreg.	.071
							PGP (-)-Nonpreg.	.016
	Left	Tone (Hz)	32.60 ± 4.28	31.82 ± 4.47	34.30 ± 2.95	.124		
		Stiffness (N/m)	923.23 ± 155.16	907.28 ± 129.08	979.04 ± 86.73	.166		
		Creep	0.39 ± .09	0.39 ± .05	0.35 ± .03	.187		
Plantar Fascia	Right	Tone (Hz)	24.43 ± 3.04	24.27 ± 2.30	24.70 ± 3.27	.887		
		Stiffness (N/m)	526.59 ± 91.64	527.72 ± 78.32	531.95 ± 103.25	.980		
		Creep	0.66 ± .10	0.66 ± .08	0.66 ± .11	.986		
	Left	Tone (Hz)	24.22 ± 2.20	24.51 ± 2.94	24.83 ± 2.94	.760		
		Stiffness (N/m)	525.40 ± 88.79	531.86 ± 96.32	538.00 ± 86.13	.902		
		Creep	0.67 ± .09	0.66 ± .10	0.65 ± .10	.765		

PGP: Pelvic Girdle Pain; Hz: Hertz; N/m: Newton per meter; P: One-way ANOVA; P**: Bonferroni Test; SD: Standard Deviation; $P \leq .05$; Adj. Sig ≤.016.
The right foot was the dominant side in all subjects.

Table 4. Correlation analysis of the presence of PGP with navicular height/drop and tissue properties.

		Presence of PGP				Presence of PGP		
Tissue		Parameters	P	r		Parameters	P	r
	Right	Navicular Height	.354	0.143	Left	Navicular Height	.617	0.077
		Navicular Drop	.082	−.268		Navicular Drop	.263	−.174
Achilles Tendon		Tone (Hz)	.123	0.242		Tone	.544	−.096
		Stiffness (N/m)	.246	0.183		Stiffness	.683	−.065
		Creep	.862	−.028		Creep	.655	0.071
Plantar		Tone (Hz)	.954	0.009		Tone	.808	0.038
Fascia		Stiffness (N/m)	.808	0.038		Stiffness	.982	−.004
		Creep	.685	−.063		Creep	.669	−.066

PGP: Pelvic Girdle Pain; P: Spearman's Correlation; $p \leq .05$.

It was reported that increased laxity, which causes the talus head to fall (pronation of the foot) and high body mass index (BMI), results in a decrease in foot arch height (Alcahuz-Griñan et al. 2021). It was claimed that the change in foot structure and decrease in the arch height are particularly evident in the first pregnancy and affect the changes that may occur in future pregnancies (Segal et al. 2013; Thabah and Ravindran 2015; Vlasova et al. 2020). In this study, the fact that either the arch height was significantly higher or at a similar level in the pregnant groups compared to that in the non-pregnant group suggests that pregnancy may not have an effect on the arch height. On the other hand, arch height in pregnant women significantly decreased when transitioning from sitting to standing compared to that in the non-pregnant group. The biomechanical and viscoelastic properties of the PF were similar in all groups, suggesting that the decrease in arch height was not due to relaxation of the PF. Considering that the BMI values of the pregnant groups were similar, the decrease in the arch height may have been due to the increased body weight compared to the non-pregnant group (Chiou et al. 2015).

A decrease of <10 mm in the arch height was reported to be normal; however, a decrease of >10 mm was found to be abnormal (Augustina et al. 2019) indicating that it caused atypical load in the musculoskeletal system (Segal et al. 2013). In the present study, although the decrease in arch height was >10 mm in both feet in the PGP+ group, no relationship was found between the amount of decrease in arch height and the presence of PGP.

The relationship between foot position and pelvic position has been shown (Khamis and Yizhar 2007). The increased pronation creates an extra load on the lumbar region structures (Ribeiro, Joao, and Sacco 2013). Similarly, asymmetrical pronation in the subtalar joint causes asymmetry in the pelvis, asymmetrical movement, and a locking mechanism in the SIJ, which may be associated with the presence of PGP (Aldabe, Milosavljevic, and Bussey 2012; Khamis and Yizhar 2007). In the present study, although the pregnant groups showed similar and symmetrical pronation, the presence of PGP was observed in one group. No relationship was found between the presence of PGP and the decrease in arch height. The similarity of the tissue properties of both feet in the pregnant groups suggests that the biomechanical and viscoelastic properties of the AT and PF do not have an effect on the exposure of PGP, which is also supported by the fact that no relationship was found between the presence of PGP and tissue properties.

Orner et al. (2018) examined the quantitative tissue values of the AT and PF in the non-pregnant population. It is appearing that tone (AT/PF, Right: 34.95 ± 3.08/25.7 ± 2.19; Left: 35.05 ± 3.04/24.89 ± 2.12) and creep (AT/PF, Right: .41 ± .04/.67 ± .09; Left: .041 ± .05/.68 ± .09) values obtained by Orner et al. (2018) were similar to those of pregnant women evaluated in this study. However, the stiffness (AT/PF, Right: 824.36 ± 99.14/524.31 ± 66.72; Left: 826.53 ± 95.51/506.62 ± 65.55) values of the mentioned study were found to be lower than the present study. From this point of view, based on the findings obtained, mentioning the hormone-induced relaxation for both tissues is not possible. The fact that most of the tissue properties were found similar in all groups in this study also supports this idea. On the other hand, in the PGP+ group, stiffness of the right AT was lower than those in the non-pregnant group. In the PGP− group, creep was higher than those in the non-pregnant group. In experiments conducted on mice, it was determined that stiffness in the pelvic and spinal ligaments decreased during pregnancy (Samuel, Coghlan, and Bateman 1998). Similarly, PF elasticity increased during the ovulation period (Petrofsky and Lee 2015). It has been determined that collagen synthesis changes based on the sex hormone level (Fede et al. 2019). In the PGP+ group, low AT stiffness was consistent with those of previous studies. However, there are studies showing that patellar tendon stiffness (Bey et al. 2019) and *levator ani* muscle stiffness do not decrease (Davidson et al. 2020) in pregnant women. This suggests the opposite of the idea that tissue stiffness decreases during pregnancy. In this study, the difference in some tissue properties between groups may be due to the genetic characteristics of their tissues rather than the pregnancy-related effects (Langevin et al. 2009; Schutte et al. 2016).

The most important risk factors (history of lumbo/pelvic pain/trauma) associated with the development of PGP in previous studies were accepted as exclusion criteria in this study, and the demographic and pregnancy-related data of the pregnant groups were similar. This design strengthens the study in terms of determining the relationship between the biomechanical and viscoelastic properties of the AT and PF with the development of PGP. On the other hand, not including pregnant women with different number of pregnancies into the present study is a limitation of this study, which makes it impossible to examine the effect of repeated pregnancy on tissue properties. Changes in body temperature may affect the elasticity of the connective tissue for physiological reasons, such as menstruation (Martinez-Marti et al. 2015). The body temperature was not measured in this study, which is another limitation of the present study. Hormone-induced increase in elasticity creates mechanical stress on the soft tissue around the lumbar vertebrae and pelvis, and this increase in elasticity is higher in pregnant women with PGP (Awad et al. 2019). Future studies should focus on determining the level of relaxin hormone, and the tissue properties of different parts of the body simultaneously to see the effects of pregnancy physiology on different body regions. This will be of great importance to determine whether relaxin levels are factors for the development of PGP. We

could not compare the results to literature because there are no normative values of tissue parameters of the AT and PF in pregnant women. There is a need to carry out studies that include the determination of trimester-specific tissue parameters in pregnant women.

Conclusions

In this study, there were no findings indicating that the biomechanical and viscoelastic properties of the AT and PF were affected by the physiology of pregnancy. Moreover, no relationship was observed between the presence of PGP and tissue properties of the AT and PF. The decrease in plantar arch height in pregnant women is not related to tissue properties of the PF.

Ethical approval statement

The study was approved (22.07.2020/166) by the Ethical Committee of Zeynep Kamil Women and Children Diseases Training and Research Hospital and all participants provided written informed consent.

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