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RESEARCH ARTICLE

EFFECTS OF AGEING AND VITAMIN D LEVEL ON PLANTAR FASCIA STIFFNESS

Tulay Cevik Saldiran[1], Ilke Kara[2], Ozgul Ozturk[3]

[1] Bitlis Eren University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Bitlis, Turkey.
[2] Dokuz Eylul University, Institute of Health Sciences, Department of Physical Therapy and Rehabilitation, Izmir, Turkey
[3] Acıbadem Mehmet Ali Aydınlar University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Turkey

ORCID: T.C.S. 0000-0003-4048-1251; I.K. 0000-0003-4974-533X; O.O. 0000-0002-5207-1893

Corresponding author: Tulay Cevik Saldiran, E-mail: tlyfztcvk@gmail.com

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ABSTRACT

Purpose: The study aimed to examine plantar fascia stiffness in individuals over and under 65 years of age, and to question the predicted effect of age and vitamin D level on the dominant side plantar fascia stiffness.
Material and Methods: Forty adults were included to the study. The participants were divided into two groups as equal or above 65 years and below 65 years. Plantar fascia stiffness was evaluated using a digital hand-held myotonometer. Data on vitamin D levels were extracted from medical records.
Results: Plantar fascia stiffness was higher in the right (∆= 141.80±39.86 N/m, p=.001), and left foot (∆=116.85±38.45 N/m, p=.004), and in the dominant side (∆= 153.6±38.2 N/m, p<.001) in participants over 65 years of age. Age had a significant positive predicted effect on plantar fascia stiffness (β=.595, R2= 0.35, p<.001). Vitamin D level had a significant negative effect on plantar fascia stiffness (β=-.328, R2 =.108, p=.03).
Conclusion: The results of the research showed that plantar fascia stiffness was higher in individuals over 65 years of age. The stiffness of PF is slightly decreased as the vitamin D level improved.

Keywords: Soft tissue, biomechanics, ageing, vitamin D

INTRODUCTION

The plantar soft tissue is a multilayered structure consisting of skin, fat cells, and fascia (1). The plantar fascia begins at the anteromedial edge of the calcaneal tuberosity and ends at the base of the proximal phalanges (2). It provides mobility by transferring the tension produced from the foot muscles to the other structures and directs joint movements. Fascia is tightly attached to the underlying muscle tissue along its peripheral length (3). Changes in the mechanical structure of the fascia (e.g., stiffness) may limit muscular flexibility and joint movement (4). According to sonographic images, increased stiffness of the heel pad as a result of ageing is accompanied by increased plantar fascia thickness and decreased echogenicity (2, 5). Ultrasound elastography results confirmed that the plantar fascia thickened in the presence of pathology (6). The thickness of plantar fascia has been reported as higher in individuals above 45 years according to sonographic findings (2). Contrary to these reports, results of the sonoelastography study in healthy people above and below 50 years of age revealed that the plantar fascia softens with age (7). To sum up, there is no consensus on which diagnostic method should be used to examine the plantar fascia changes. Quantitative demonstration of the stiffness of the PF in addition to the thickening with ageing may

help to understand the change in the biomechanics of the foot more clearly. While plantar fascia thickness gives us information as an anatomical section, it may be valuable to examine the biomechanical property of stiffness responses. Due to being inexpensive, simple, and quick, myotonometer evaluation is considered appropriate to assess the stiffness of the plantar fascia. When the studies have done so far were examined, it was seen that the plantar fascia assessment with a myotonometer was performed in only seven studies (6, 8-13). No study examined the differentiation in plantar fascia stiffness with ageing using a myotonometer.

Vitamin D takes part in many biological processes including immune system modulation, and its relationship with connective tissue is not yet clear (14). The importance of vitamin D in the musculoskeletal system is due to its role in calcium and bone metabolism (15). It increases the absorption of calcium, and positively affects bone mineralization and muscle function (16). In addition, vitamin D is a steroid hormone whose importance is known especially for the structure and functions of the musculoskeletal system (17). In adults aged 65 and over, the endogenous synthesis of vitamin D is reduced by 25% compared to young adults (18). Decreases in vitamin D levels trigger secondary hyperparathyroidism, leading to loss of bone mass and muscle strength (16). There is also evidence that low vitamin D levels are associated with sarcopenia (19). In the literature, the relationship between vitamin D deficiency and muscle dysfunction is thought to be based on the loss of vitamin D receptor functions, increased oxidative stress, and impaired mitochondrial function (20). The number of studies on the efficacy of vitamins directly in soft tissue is limited. While it is well known that vitamin C deficiency causes a decrease in the tensile strength of abnormal collagen fibers and fibrous tissues in connective tissue (21) however, no research has been conducted on vitamin D effect on plantar fascia stiffness yet.

Ageing is the most common cause of vitamin D deficiency (18), biomechanical dysfunction of the foot (22), and thickened plantar fascia. However, to date, only limited information has been reported on the effects of vitamin D status on fascial tissue structure. Moreover, it is unclear whether ageing and vitamin D levels are associated with plantar fascia stiffness. On this basis, this research aimed to examine the effects of ageing and vitamin D levels on plantar fascia stiffness.

MATERIAL AND METHODS

This descriptive, cross-sectional study was carried out with 40 adults who were invited to the research laboratory by e-mail or telephone. This study was in agreement with the standards set by the Declaration of Helsinki and approved by Acıbadem Mehmet Ali Aydınlar University, Medical Research Review Board (ATADEK) (Date: 30.09.2022, Decision No: 2022/15/15). All participants signed informed consent. The participants were divided into two groups as equal or above 65 years and below 65 years. A comparison of plantar fascia stiffness by age was performed by dividing the participants into two groups, over age ≥ 65 years and underage < 65 years. The dominant extremity was questioned and recorded with the individual feedback of the participants. Estimated effect analysis of age and vitamin D levels on the dominant side plantar fascia stiffness were performed with all participant data.

Participants

Individuals with a medical history other than hypertension were not invited to the study. The exclusion criteria were; i) history of peripheral vascular disease, ii) history of active plantar fasciitis, iii) existence of plantar fascial ulceration, low or high longitudinal arch, retrocalcaneal bursitis, Achilles tendinopathy, and skin lesions around the heel, iv) history of surgery or trauma around the heel, v) history of neuropathic or radicular pain, vi) existence of diabetes, vii) history of rheumatologic, neurological disease and neuroarthropathy, viii) existence of malignancy. Individuals who were 18 years or older, had more than 10° ankle dorsiflexion and normal medial longitudinal arch height, had no pain around the heel, and had a vitamin D evaluation record within the last week were included in the study. Demographic and anthropometric information [height (cm), weight (kg), body mass index (kg/m2)], and the dominant side of the participants were recorded. Data on vitamin D levels were extracted from medical records of the blood tests performed a month before the assessments, of participants.

Evaluation of Plantar Fascia Stiffness

Plantar fascia stiffness was evaluated using a myotonometer (MyotonPRO, Myoton AS, Tallinn, Estonia). An external force is sent from the probe of the myotonometer to the tissue to be examined (muscle body, muscle-tendon junction, fascia, tendon, skin, etc.). This mechanical impulse creates

an elastic deformation in the tissue. Pressure changes occurring between the inner probe and the outer plexiglass frame during measurement are detected by computer-connected customized transducers (12). The oscillations are recorded with the frictionless and sensitive accelerometer sensors located at the other end of the probe. Tissue stiffness can be determined in this way. Stiffness [N/m], is a biomechanical property and is defined as the resistance to external forces that will cause the examined tissue to change its shape. Stiffness is stated to be the opposite of compliance. Detailed information can be found in the user guide of the device (23) and the video at the link (https://www.youtube.com/watch?v=PwAB84JLVwg) The use of a myotonometer is reliable in the evaluation of plantar fascia stiffness (8). However, measurements can be affected by different ankle positions (9). A study showed that physical activity causes an increase in the thickness of the distal part of the plantar fascia and that the proximal part is not affected by the level of physical activity (24). As a result of this information, positioning was standardized before measurements. The participants were asked to lie prone, the hip and ankle joints were positioned in neutral (0^o) and the knee was in extension. A prior to the evaluation, the information related to the participants and the pattern were entered. All measurements were performed bilaterally and three times in the resting position and the data were recorded in the MyotonPRO software. The device was programmed to take 5 pressure-displacement measurements (every 5 beats, the duration of 1 pulse is 15 ms and the interval between beats was 8 ms) per recording prior to administration. Three measurements were taken from the reference point (25) where the calcaneal distal anterior corner and the inner corner of the medial longitudinal arch meet for the borderline between the first and second metatarsal bones (9) and the proximal beginning of the plantar fascia (8), and the average of the measurements was recorded. When the red light on the plexiglass frame of the device probe turned green, the practitioner stopped the pressure application perpendicular to the relevant tissue and waited until 5 strokes were performed. After each application, the acceleration graph was examined and the measurements were repeated if there were any deviations from the normal. Recordings were reloaded into the software and reported for each participant. Care was taken not to move the device during the application and to maintain its correct position. All the evaluations were performed at neutral room temperature and at the same time of day.

Statistical Analysis

Data analysis was performed with the Statistical Package for Social Science (SPSS) program, version 25 (IBM Inc., Chicago, IL, USA). In descriptive data, the continuous numerical variables were presented as mean±SD and categorical variables were presented as frequency. To determine whether the parameters were normally distributed skewness and kurtosis (-1.5 and +1.5) were used (26). The Chi-square test was used to analyze differences in nominal and categorical data by groups. The Independent Sample t-Test was used in the analysis of the differences between the groups since the parameters were normally distributed (27). Linear Regression Model was used to examine the effect of age and vitamin D levels on dominant side plantar fascia stiffness. Before the regression analyses, linear relationship, cook's distance, normal distribution, homoscedasticity checks, and correlation level analyzes were performed (27). The two hypotheses were developed to examine the relationship between age, D vitamin levels, and plantar fascia stiffness. First, the study claims that there will be a positive relationship between age, and plantar fascia stiffness (H1: Age affects the plantar fascia stiffness level). Second, a lower level of D vitamin will increase the plantar fascia stiffness (H2: The vitamin D levels affect the plantar fascia stiffness level). Statistical significance was deemed to be a p-value of $<.05$.

In power analysis with the G*Power software (version 3.1.9.2), the t-test confirmed that our sample size was sufficient in the model of differences (effect size=.95, p=.05, n1/n2=1, and n=20) between two independent means (greater than $1-\beta= 0.95$) (28).

RESULTS

The baseline characteristics of the participants are shown in Table 1. Forty individuals with a mean age of 55.4±12.4 years were included in the present study. While the mean age was 66.3±1.6 years in Group 1, which included participants aged 65 and over, in Group 2, which included participants aged 65 and under, the mean age was 44.5±8.0 years. 75% (n=30) of the participants were female and the gender distribution in both groups was equal. Each group included 5 men and 15 women. 35 of the participants

(87.5%) had right-side dominance. Of 5 people with left dominance (12.5%), two were in Group 1 (10%) and three were in Group 2 (15%). The mean BMI of all participants was 28.2±5.4 kg/m^2, the mean of Group 1 was 29.7±3.5 kg/m^2, and the mean of Group 2 was 26.7±6.5 kg/m^2 (p = .08). The mean level of vitamin D was found to be 38.6±25.7 ng/mL in all participants. In Group 1 this means was 31.2±18.9 ng/mL and 46.0±29.7 ng/mL (p = .07) in Group 2.

The plantar fascia stiffness differences according to the age groups of the participants are shown in Table 1. The right (mean difference = 141.8±39.9 N/m, p = .001) and left foot (mean difference = 116.9±38.5 N/m, p = .004) plantar fascia stiffness was higher in the group over 65 years of age. While the mean plantar fascia stiffness of the dominant side was 577.3±142.6 N/m in all participants, it was 654.2±113.7 N/m in Group 1 and 500.5±128.1 N/m in Group 2 (mean difference = 153.6±38.2 N/m,

Table 1. Characteristics and clinical features of participants

		Total	**Group 1 age ≥ 65 years**	**Group 2 age < 65 years**
Female Gender n (%)		30 (75%)	15 (75%)	15 (75%)
Left Side Dominance n (%)		5 (12.5%)	2 (10%)	3 (15%)
Age (year)	mean±SD (min-max)	55.4±12.4 (31-70)	66.3±1.6 (65-70)	44.5±8.0 (31-58)
Vitamin D (ng/mL)	mean±SD (min-max)	38.6±25.7 (4.70 – 108.1)	31.2±18.9 (14.0 – 88.4)	46.0±29.7 (4.7-108.1)
Presence of Hypertension n (%)		17 (42.5%)	14 (70%)	3 (15%)

Plantar Fascia Stiffness (N/m)	**Groups**	**Mean±SD**	***p***	**95 CI%**
Right Plantar Fascia Stifness	Age ≥ 65 Years	654.5±114.9		
	Age < 65 Years	512.7±136.3		
	Mean Difference	141.8±39.9	.001	61.1 to 222.5
Left Plantar Fascia Stifness	Age ≥ 65 Years	636.5±103.2		
	Age < 65 Years	519.7±137.5		
	Mean Difference	116.8±38.4	.004	39.0 to 194.7
Dominant Side Plantar Fascia Stifness	Age ≥ 65 Years	654.2±113.7		
	Age < 65 Years	500.5±128.1		
	Mean Difference	153.6±38.2	<.001	76.1 to 231.1
Dominant Side Plantar Fascia Stifness	Male	583.8±151.42		
	Female	557.9±117.1		
	Mean Difference	25.90±52.5	.625	-80.5 to 132.3

p<.05 significance level. p repesents significance level of T-test. SD: Standard Deviation. N/m: Newton/meter. ng/mL refers to nanograms/millilitre.

p<.001). No statistically significant difference was observed in dominant side plantar fascia stiffness in all participants (583.8±151.42 N/m vs 557.9±117.1 N/m) and groups (661.2±125.2 N/m vs 633.0±75.9 N/m in Group 1 and 506.4±137.7 N/m vs 482.8±104.8 N/m in Group 2) according to gender (p>.05).

The hypothesis results are represented in Table 2. In a significant regression model (F(1, 38)=20.85, p <.001), 35% of the variance (R2= .35) in dominant side plantar fascia stiffness was explained by the age variable. Accordingly, the age variable predicts the dominant side plantar fascia stiffness positively and significantly (β=.595, t(38)= 4.56). The model for vitamin D level (F(1, 38)=4.58, p = .03) was also significant. 10.8% of the variance (R2= .108) in dominant side plantar fascia stiffness was explained by the vitamin D variable. Accordingly, the vitamin D variable predicted dominant side plantar fascia stiffness negatively and significantly (β=-.328, t(38)= - 2.14).

DISCUSSION

This study aimed to investigate the effects of age and the level of vitamin D on plantar fascia stiffness. Both hypotheses were confirmed by the findings of the present study. One of our hypotheses was that increasing age would have resulted in higher stiffness of the plantar fascia. In line with our hypotheses, individuals above 65 years had a higher level of stiffness compared to middle-aged individuals and age had an interaction with plantar fascia stiffness. Our second hypothesis was related to vitamin D concentration which was confirmed by showing the association between improved vitamin D concentration and decreased plantar fascia stiffness. Studies using myotonometer have reported that plantar fascia stiffness as average of 446.4 N/m (mean age: 27.8±5.1 years) (13), 476.0 N/m (mean age: 28.95±2.8) (10), 511.7 N/m and 533.2 N/m (mean age: 35.53±15.0 years) (11) in healthy individuals. In this research, plantar fascia stiffness ranged from 500.5 N/m to 519.7 N/m in the group under 65 years of age (mean age: 44.5±8.0 years), and between 654.5 N/m and 636.5 N/m in the group 65 years and older (mean age: 66.3±1.6 years). The number of studies examining plantar fascia stiffness with different evaluation methods under the effect of age variable is limited (2, 5, 7, 22). It can be said that, unlike the sonoelastography results (7) the linear increase of the plantar fascia stiffness, which was previously shown in sonographic images (2, 5) was demonstrated once again in our research results with the myotonometer evaluation of the linear increase with age. In this direction, our findings may support the hypothesis that plantar fascia stiffness increases with ageing. Advancing age also results in altered plantar pressure distribution by increasing pressure and force variables (29). Differentiated pressure distribution of the plantar surface, such as increased contact area and the maximum force causes higher stiffness of the plantar fascia (30). Also, age itself leads to an alteration in muscle stiffness (31), our results are in line with the above-mentioned literature and older adults had higher stiffness values than middle-aged individuals. Advancing age predicts a 35% increase in plantar fascia stiffness. Therefore,

Table 2. Age and vitamin D predicted effect on the dominant side plantar fascia stiffness

H1: Ageing affects the dominant side plantar fascia stiffness level

	Dominant Side Plantar Fascia Stiffness							
	B	Std. Error	*Beta coefficient*	*t*	R^2	*df*	*F*	*p*¶
Age (year)	6.85	1.5	.595	4.56	.354	1, 38	20.85	<.001

H2: Vitamin D levels affect the dominant side plantar fascia stiffness level

	Dominant Side Plantar Fascia Stiffness							
	B	*Std. Error*	*Beta coefficient*	*t*	R^2	*df*	*F*	*p*¶
Vitamin D (ng/mL)	-1.82	.85	-.328	-2.14	.108	1, 38	4.58	.039

p¶: Linear Regression Model. Std. Error: Standard Error. N/m: Newton/meter. ng/mL refers to nanograms/millilitre.

we can propose that ageing has an undeniable effect on the stiffness of plantar fascia.

Cheng et al. showed that PF thickness was higher in males than females by sonographic examination in 28 healthy individuals (14 females, aged: 20-79 years) (5). Similarly, Taş et al., reported that the thickness of the plantar fascia was higher in males than females by ultrasonography in 60 healthy sedentary individuals (30 females, aged: 19-50 years) (32). However, in our research results, no difference was observed in myotonometer results at the plantar fascia stiffness level by gender. The reason for these results may be related to the fact that the differentiation by gender cannot be evaluated with myotonometer as much as sonography and ultrasound, or due to the majority (75%) of male participants in this study. The effect of gender in the plantar fascia stiffness evaluation with a myotonometer should be examined in research setting that includes equal numbers of male and female participants.

Low vitamin D level was observed in individuals with calcaneal spurs (33). In our study, the stiffness of PF was negatively predicted by the vitamin D level of 10.8%. A striking finding of our study is that vitamin D influences the mechanical structures of PF. Moreover, a study reported that an increase in transforming growth factor-beta (TGF-β) because of vitamin D deficiency, leads to myofibroblast differentiation by enhancing mitochondrial reactive oxygen species production in patients with Dupuytren's contracture (34). TGF-β is also involved in palmar and plantar fibromatosis (35) and Vitamin D deficiency leads to up-regulation of TGF-β in serum (34). This information suggests that with the indirect TGF-B effect, vitamin D may play an important role in maintaining a well-balanced facial tissue microenvironment. Based on these findings, the effects of vitamin D concentration on plantar fascia tissue should be investigated with a longitudinal design. We can say that the strengths of this study are (i) examining the interaction of vitamin D and PF alone for the first time and (ii) investigating the effect of both age and vitamin D on plantar fascia at the same time.

The main limitation of this study is that we did not examine the plantar pressure distribution. Further studies may include an assessment of plantar pressure distribution and question its possible association with the stiffness of plantar fascia. Also, more research is needed including the examination of the effects of calcium metabolism, lipid levels, and hormonal alterations on plantar fascia stiffness. In addition, given the limitation of myotonometer use in the evaluation of tissues located below other tissue layers, it is likely to record better results in further studies using a combination of sonoelastrography, ultrasound, sonography, and myotonometer for changes in plantar fascia stiffness. Another limitation is that we do not have the opportunity to evaluate the subcutaneous fat thickness on the sole of the foot. Further studies could perform subcutaneous fat thickness for plantar fascia evaluations.

CONCLUSION

In conclusion, the results of this study suggest that plantar fascia stiffness increases with ageing and is also slightly affected by vitamin D levels. Interventions to reduce plantar fascia stiffness can be included in primary prevention to prevent the adverse effects of ageing on foot health. The effect of vitamin D supplements on plantar fascia stiffness should be examined in further studies.

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