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The effect of aging on the hardness of foot sole skin: A preliminary study

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ABSTRACT

Background: Foot problems are common in older people and altered biomechanical parameters under the foot sole has been proposed as a key risk factor for foot lesions. Therefore the aim of this study was to investigate the age-related differences in the hardness of foot sole skin.
Methods: Twenty-six healthy volunteers without foot problems, aged from 26 to 65 years, were examined using shore meter. The hardness of the foot sole under the big toe (area 8), 1st metatarsal head (area 5), 3rd metatarsal head (area 6), 5th metatarsal head (area 7), mid foot (area 3, 4) and hind foot (area 1, 2) were measured. The correlation between age and hardness of foot sole was examined and comparisons were made between two age groups.
Results: From the result we observe statistical significant ($p < 0.05$; $p < 0.01$; $p < 0.005$) differences in hardness between age groups in hind foot, metatarsal heads (1st, 3rd & 5th) and big toe. Strong positive correlations between age and hardness of the foot sole were found at the big toe ($r = 0.57$; $p < 0.005$), 1st metatarsal head ($r = 0.567$; $p < 0.00001$), 3rd metatarsal head ($r = 0.565$; $p < 0.00001$), 5th metatarsal head ($r = 0.55$; $p < 0.00001$), and heel ($r = 0.59$; $p < 0.0001$).
Conclusion: The loss of compliance in the foot sole may be one of the factors responsible for the higher incidence of foot problems in aged people. Routine foot examination and appropriate therapeutic intervention including the use of foot orthoses and optimal hardness of foot wear insole may help to prevent the serious foot injuries.

1. Introduction

Foot problems commonly occur in 1st metatarsal head and heel region but loosely defined pathologic entities is also frequently associated with the aging process [1]. However Hsu et al. [2] stated that the altered biomechanical properties of the heel pad might leads to heel pain and Achilles tendinitis. But the heel and metatarsal head regions of the human foot are specially designed to provide cushioning and shock absorption to the underlying bone during all loading condition [3,4]. Menz and Lord [5] stated that foot structure such as foot deformity [6], reduced range of motion [7,8] and diminished plantar tactile sensation [9] changes with advancing age and cause various orthopedic foot problems may lead to inactivity and subsequently to falls. However knowledge of biomechanical properties of human foot sole skin is very important for geriatric research. Therefore, it is important to identify that foot sole soft tissue properties changes occurs with aging; however it would be interesting to examine these age related difference in terms of foot sole hardness among two age group subjects which has not addressed clearly.

Age is a key factor that may influence the biomechanical properties (i.e. elastic properties) of the foot sole soft tissue [10]. Age related changes occur in human foot sole skin because of decrease in elasticity and changes in elastin collagen network as well as increase in melanin content and advance glycation end product of epidermis [11]. With aging, the stratum corneum becomes thinner because the rate of keratinocytes death exceeds the rate of their replacement and that alter the biomechanical properties of foot sole skin. Hyperkeratosis is also result of abnormal change in biomechanical properties on the foot sole skin which stimulate over activity of the keratinization process. This causes accelerated proliferation of epidermal cells and a decreased rate of desquamation, resulting in hypertrophy of cells [12–14]. Hyperkeratosis or increased foot sole hardness, however, becomes pathological when the keratinized material builds up sufficiently to cause tissue damage, possibly due to the repetitive pressure of the central keratin plugged on underlying nerves [15]. Numerous studies stated that the increased foot sole hardness are most commonly found under the meta tarsal heads due to elevated plantar pressure [16–19]. Hence altered biomechanical parameter changes in foot sole soft tissue under the metatarsal heads has been proposed to be a key risk factor for foot ulcer in diabetes [20]. But other studies focused on the

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Table 1
Demographic details of for various age group subjects.

	Age groups (students and staff community)		p-Values
	Group I Age ranged from 26 to 45 years $n = 13$	Group II Age ranged from 46 to 65 years $n = 13$	
Age (years)	33 (6.08)	53.1 (4.6)	0.0000002*
Gender (M:F)	8:5	8:5	N/A
Height (m)	1.66 (0.07)	1.62 (0.07)	0.43*
body mass (kg)	67.2 (11.2)	69.2 (10.2)	0.27*
Body mass index (BMI)	24.5 (3.02)	26.4 (3.9)	0.18*

Mean (SD); N/A, not applicable.
* $p > 0.05$

heel region and measure biomechanical changes of the foot sole soft tissue [2,21]. Therefore it is important to identify the biomechanical properties of foot sole skin changes under fore foot and hind foot which can provide basic information about the tissue damage [22].

In the brief view presented above that the study of biomechanical properties of foot sole changes is very important with increasing life span in modern societies. However most of the research studies [10,23] have investigated the effects of aging on changes in the biomechanical properties of the total thickness of plantar soft tissue. But it is unclear how aging would influence the change in the biomechanical properties of the hardness of foot sole at various testing sites. Hence by understanding the influence of aging on the biomechanics of foot sole is of great importance to practitioners in the areas of gait and sports mechanics, and knowledge of the biomechanical properties of the sole is also useful for designing footwear and preventing injuries. It is hypothesized that the biomechanical properties of human foot sole can be altered with aging, by an increase in hardness and foot pressure. Therefore the present study was to compare the biomechanical properties of human foot sole, in terms of hardness, among two age groups and gender wise. In addition to, the relationship of these properties with aging was examined. These variables were chosen because they might be associated with increase in foot sole skin hardness due to repetitive pressure on the foot sole areas. We hypothesized that increased foot sole hardness would be more common in women, and would be significantly associated with age.

2. Methods

2.1. The subject's details

In this study 26 healthy volunteers (10 females and 16 males) with age ranging from 26 to 65 years were recruited from college students and staff members of Biomedical and Endocrinological lab AIIMS New Delhi, India. The total subjects were divided into two age groups: 13 group I (age range: 26–45 years) subjects and 13 group II (age range: 46–65 years) subjects. Subjects were excluded if they had (1) foot pain and deformities, (2) acute lower extremity trauma, (3) lower extremity surgery like prosthesis operations of the hip, knee, ankle or foot, (4) leg length discrepancies, (5) problems of cooperation, including eye, ear or cognitive disorders, (6) diabetes or related peripheral neuropathy, (7) vascular insufficiency, (8) walking aids and (9) body mass index (BMI) > 35. All subjects were weighed and their heights were measured to allow calculation of their body mass index (kg/m^2). Foot sole hardness assessment was then performed using Durometer (ASTM-D 2240 standards) to calculate shore value. Demographic details of subjects including age, gender, height (m), weight (kg) and body mass index (BMI) is shown in Table 1. All subjects were voluntarily participated in the study and procedures of the study were explained clearly before their written informed consent was obtained. In order to simplify our analysis, we divided the foot region into eight areas as mentioned in Fig. 1(a): medial hind foot (area 1), lateral hind foot (area 2), medial mid foot (area 3), lateral mid foot (area 4), 1st Metatarsal head (area 5), 3rd Metatarsal head (area 6), 5th Metatarsal head (area 7) and big toe (area 8).

3. Foot sole hardness measurement using Shore meter

The instrument used for measuring the hardness of the foot sole is Shore meter or Durometer or Hardness tester (as per ASTM-D 2240 standards). This instrument is similar to the Durometer used by Piaggesi et al. [24] in evaluating the hardness of foot sole soft tissue in diabetic neuropathic feet. The Shore meter consists of a spring loaded truncated cone tipped indentor. For measuring the hardness of the foot sole, the Shore meter was used with patients lying in the supine position with foot held vertical and toes pointing upwards. Then the Shore meter is pressed perpendicular to the surface of the foot sole as shown in Fig. 1(b). The reading on the dial provides measure of hardness, which corresponds to the depth of indentation below the surface of the foot sole. The Shore meter reads the hardness in degree Shore (characterized as 'S'). Softer material has lower Shore value; harder material such as wood has a value of 100. Thus the Shore meter reads the Shore values from 0 to 100. The Shore meter is pre-calibrated and not for every subjects. Each footprint is divided into eight areas as indicated in Fig. 1(a). Two to three trials are performed at each site of foot sole and the average value noted on the datasheet for subsequent analysis.

3.1. Repeatability of hardness value using Shore meter measurement

Repeatability of durometer reading of each site was obtained from three healthy subjects on three separate days at same time of days. Analysis of variance with repeated measurement design was conducted in order to reveal significance of within site, which was not significant ($p > 0.05$). That means consistent reading was obtained for same site on three separate days [25]. The Shore meter used in this study has been shown to have good repeatability as mentioned in Fig. 2.

4. Statistical analysis

The differences between the age groups with regard to hardness of the foot sole were calculated by student t-test. The level of significance was set at $p < 0.05$. The relationship between age and hardness of the foot sole was calculated using the linear regression to find Pearson correlation coefficient (r).

4.1. Result

In the present study, we have investigated and analyzed 26 healthy subjects. For our result analysis we have divided the foot

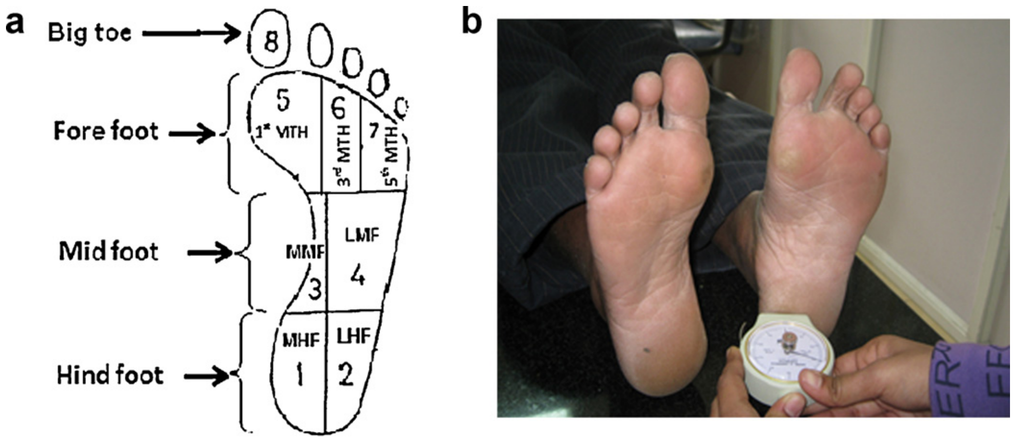

Fig. 1. (a) Division of foot and (b) hardness of foot sole assessed by Shore meter.

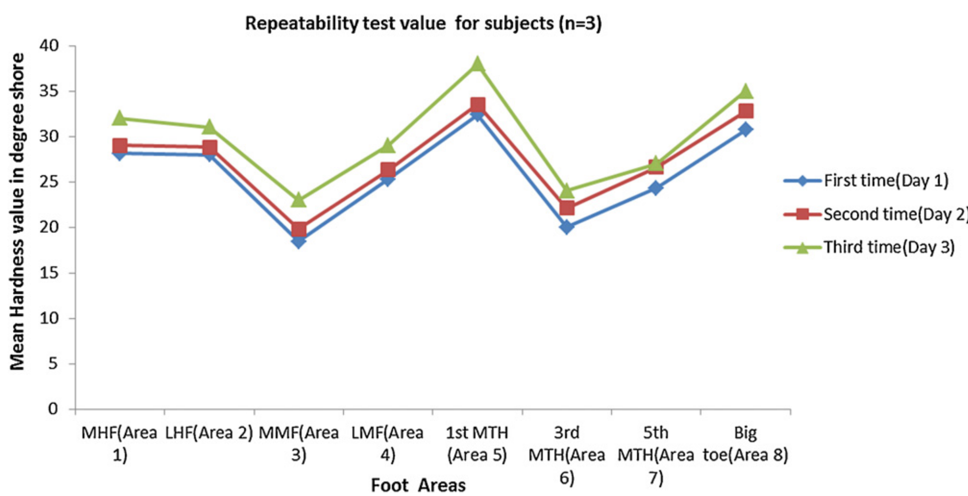

Fig. 2. Repeatability tests hardness of foot sole measurement using Shore meter.

sole areas as shown in Fig. 1(a) and obtain the results of the mean hardness value. The shore meter used in this study has been shown to have good repeatability as mentioned in the Fig. 2. The data was assessed to see if any differences in hardness value between two age groups. Descriptive statistics on the height, weight, and body mass index of different age groups are presented in Table 1. No statistical difference in any of these demographic characteristics was found among the groups. Comparison among age groups (Groups I & II) showed significant increase of hardness value in hind foot, Meta tarsal heads (MTH) and big toe are presented in Table 2. Group I presented statistically higher mean hardness value than Group II ($p < 0.05$, $p < 0.01$, $p < 0.005$) at Meta tarsal heads (MTH), hind foot and big toe. However there was tendency for the hardness to increase towards distal regions, whereas three was tendency for the hardness to decline towards proximal regions. In addition comparison among male and female healthy subject show higher mean hardness value in female healthy as compared to male healthy subjects as mentioned in Table 3 but not statistically significant. This is because of appearance of body composition, choice of footwear worn and increase in the distribution of body fat may increase the

Table 2
Comparison of foot sole hardness between two age groups.

Foot areas	Age groups		
	26–45 years Hardness value in degree shore	46–65 years	Significance *p*-Values
Area 1 (MHF)	28 (3.5)	33.4 (3.7)	0.003***
Area 2 (LHF)	28.7 (4.0)	34.1 (4.9)	0.01*
Area 3 (MMF)	20.5 (3.7)	23.1 (4.8)	0.2
Area 4 (LMF)	23.7 (3.2)	26.5 (3.9)	0.1
Area 5 (1st MTH)	26.9 (5.2)	30.3 (2.8)	0.054**
Area 6 (3rd MTH)	20.5 (4.5)	26 (3.9)	0.01*
Area 7 (5th MTH)	24.4 (4.0)	28.1 (2.7)	0.027**
Area 8 (big toe)	29.6 (3.9)	37.1 (6.5)	0.005***

Mean (SD).
* $p < 0.01$.
** $p < 0.05$.
*** $p < 0.005$.

Table 3
Comparison of foot sole hardness between age groups as well as between genders.

	Hardness value in degree shore			
	Age groups		Gender groups	
	26–45 years (n = 13)	46–65 years (n = 13)	Male (n = 16)	Female (n = 10)
Hind foot (area 1, 2)	28.4 (2.9)	33.8 (4.1)***	30.5 (3.6)	31.7 (5.5)
Mid foot (area 3, 4)	22.1 (3.2)	24.8 (3.9)	22.8 (4.1)	24.2 (3.3)
Fore foot (area 5, 6, 7)	23.9 (2.6)	28.1 (2.2)****	26.03 (3.5)	26 (3.0)
Big toe (area 8)	29.6 (3.9)	37.1 (6.5)***	32.8 (5.6)	34 (7.7)

Mean (SD).
*** $p < 0.005$.
**** $p < 0.001$.

thickness of the foot sole soft tissues may further lead to tissue hardening. The Pearson correlation coefficients (r) for comparison of age with the hardness of the foot sole are presented in Fig. 3. There is a significant correlations between age and hardness of the foot sole were found at the big toe ($r = 0.57$; $p < 0.005$), 1st MTH ($r = 0.567$; $p < 0.00001$), 3rd MTH ($r = 0.565$; $p < 0.00001$), 5th MTH ($r = 0.55$; $p < 0.00001$), and hind foot ($r = 0.59$; $p < 0.0001$), but not in the mid foot (area 3, 4).

5. Discussion

This study investigated the effect of aging on foot sole hardness and compares the hardness of foot sole between two age groups. The result of this study shows that the shore meter measurements are reliable and consistent for measurement of foot sole skin hardness in healthy individuals. In these studies, the investigators were able to show a consistent increase in foot sole hardness from proximal (hind foot) to distal regions (big toe). Although previous studies show that the thickness of the foot sole soft tissue is an important predictor of peak plantar pressure, could lead to skin breakdown due to repetitive plantar pressure while walking [26]. However there are many factors behind the change in the foot sole soft tissue properties of the older people, including choice of footwear, systemic diseases, and gender [5], the present study focused on hardness of foot sole for two different age groups. First major finding of this study show that group I subjects had significant ($p < 0.05$; $p < 0.01$; $p < 0.005$) change in foot sole hardness on the hind foot, the MTH and big toe as compared to group II as shown in Table 2.

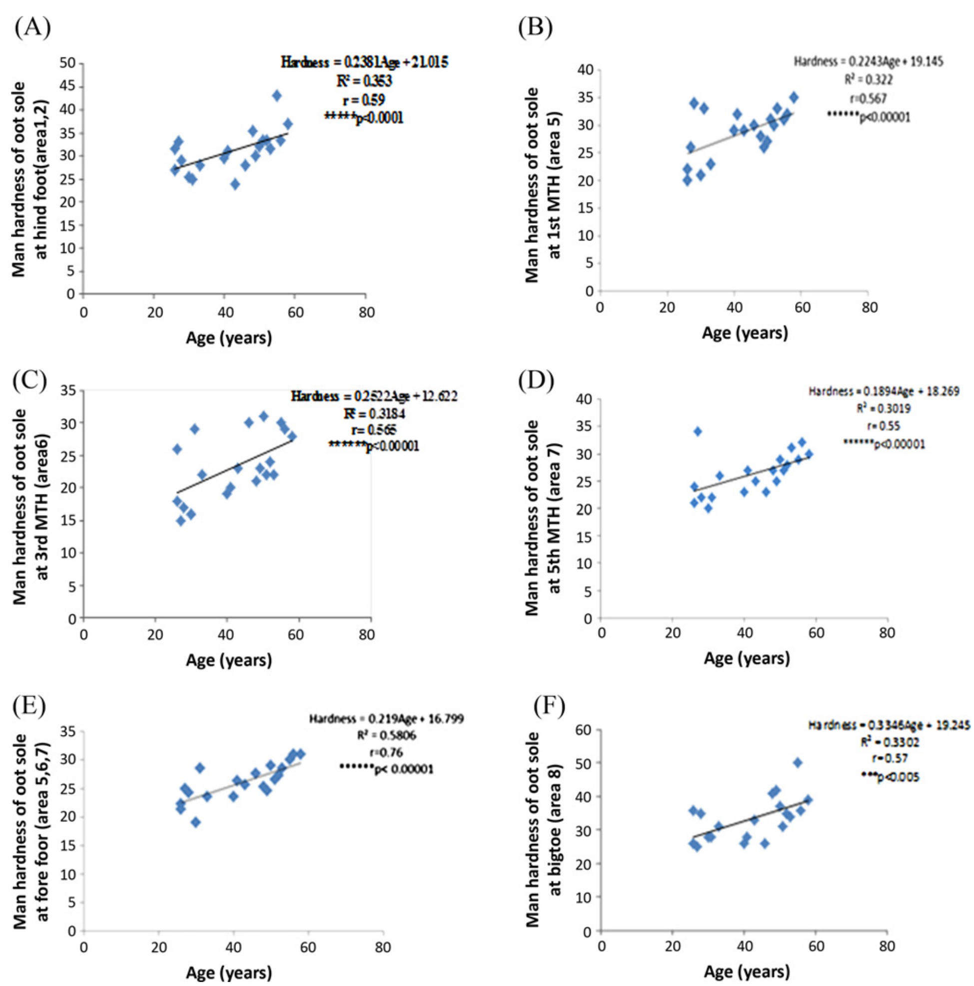

Fig. 3. The linear correlation between age and the hardness of foot sole. *****$p < 0.0001$, ******$p < 0.00001$ and ***$p < 0.005$, a significant correlation was found between age and hardness at (A) the hind foot, (B) 1st metatarsal head, (C) 3rd metatarsal head, (D) 5th metatarsal head, (E) fore foot and (F) big toe.

These are possible because of difference in tissue structures and local hemodynamic variables. However tissues become hard due to loss of elasticity and less able to distribute pressure through deformation. Therefore cushioning property of the foot sole soft tissue is impaired, especially at elevated pressure areas as stated by Gefen [27]. With the effect of aging, the micro-tears on the foot sole are caused by repetitive pressure during standing as well as walking and these changes are expected to be increase for patients with diabetes. Hence this is clearly true for people suffering from peripheral neuropathy, who are prone to developing foot sole ulcerations. Second major findings of this study, female subject showed difference in foot sole hardness as compared to male subject, but not statistically significant. Third major finding was aged people had elevated skin hardness in big toe as compared to other foot sole regions. Furthermore, in the present study we are not focus on other biomechanical parameters such as ankle joint mobility changes on the foot sole due to age.

In general, the foot sole of healthy subject at the hind foot were harder, compared with those at the metatarsal heads (MTHs). From Fig. 3, it is revealed that aged people had different foot sole hardness. These effects mostly occur under MTHs and big toe because of hyperkeratinized, loss of protective sensation due to tissue hardening. These changes may further impair the foot sole to repetitive stress and eventually lead to the development of foot ulcer in the aging people. Therefore periodic lower extremity evaluations and appropriate hardness of footwear insole is suggested for aging persons to prevent foot injuries. In addition we have suggested that increase in hardness of the foot sole may lead to decrease in tactile sensation and hinder afferent sensory feedback. These changes may partly explain why aged people are prone to injurious falls as stated by Boyd and Stevens [28]. Further research is required to determine the most effective strategies for the prevention and treatment of plantar hardness by performing sensory tests in the foot sole to confirm this hypothesis.

5.1. Limitations

Power calculations demonstrate us that the recruitment of subjects to each group has fallen well short but the findings of this study are very encouraging. Another limitation of this study was lack of data on foot sole soft tissue thickness.

6. Conclusion and future work

Our findings demonstrated that the biomechanical properties of foot sole in terms of hardness appear to change with age in healthy individuals. Hence the altered biomechanical properties in foot sole may be responsible for the higher incidence of foot problems in aged people. Therefore, clinicians may consider using durometer to examine the biomechanical properties of the foot sole, and enhancing their clinical prognosis and prescription of footwear for those who are aging or suffering from diabetes to relieve contact pressure is likely to re-distribute the contact pressures and reduce the stresses under the metatarsal heads. Further study is needed to clarify the age related changes in the biomechanical properties of foot sole skin by evaluating the relationship between the altered biomechanical foot sole properties and subcutaneous blood flow by Laser Doppler flow meter (LDF) and the development of foot ulcers for patients with diabetes in weight bearing position.

Conflict of interest statement

All authors declare that they have no conflicts of interest either financial or personal with other people or organizations that could inappropriately influence our work.

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