SHORT REPORT

Correlation of medial longitudinal arch height with postural stability, sensory integration, balance and fall risk among healthy young adults

Sameera Gul, Hafiza Noor ul Huda, Misha Raza, Muhammad Osama

Abstract

A cross-sectional analytical study was conducted on 165 healthy young adults. With pes rectus and pes planus to correlate the medial longitudinal arch height with postural stability, sensory integration of balance and fall risk. Persons with pes cavus, congenital foot anomalies other than pes planus, leg length discrepancies, recent history of trauma, lower limb amputations, history of serious foot injury, ligamentous laxity, or an active inflammatory disorder were excluded. Outcome measurements included normalised truncated navicular height (NTNH), Chippaux Smirak index (CSI), athletic single leg stability (ASLS) index, fall risk (FR) index, postural stability (PS), clinical test of sensory integration of balance (CTSIB), and balance error scoring system (BESS). Spearman correlation and Mann Whitney U test were used for data analysis. CSI and NTNH were noted to have no significant correlation (*p*<0.05) with PS, FR, CTSIB, ASLS and BESS among healthy young adults. Males were observed to have poorer balance and fall risk as compared to females.

Keywords: Balance, Flat feet, Flat foot, Pes planus, Postural balance, Postural stability.

DOI: https://doi.org/10.47391/JPMA.7214
Submission completion date: 27-07-2022
Acceptance date: 26-06-2023

Introduction

Medial longitudinal arch is an imperative step towards the evolution of bipedal gait adapted by humans, as it not only provides a mechanical advantage to the plantar flexors in lifting the body weight during the stance phase of the gait,[1] but also provides shock absorbing capacity during stride.[2] A decrease in the medial longitudinal arch is known as pes planus or flat feet[3] and can predispose a person to different musculoskeletal impairments, including hallux valgus, plantar fasciitis, knee pain, and low back pain.[4] From a biomechanical point of view, it is hypothesised that foot posture and medial longitudinal arch height may affect postural stability and balance; however, its impact is not as well established in healthy young adults as compared to other factors such as muscle strength (especially those of the back), proprioception, endurance capacity, and body mass index.[5,6] Moreover, literature seems to be conflicting in terms of comparison of pes planus with pes rectus in terms of balance parameters, with some studies showing significant differences,[7-9] whereas others show no significant differences[1,10-13] in terms of static and dynamic postural stability, postural control, limits of stability, and other balance measures. Moreover, the studies that do exist have been conducted on very limited sample sizes. Furthermore, evidence is also deficient in terms of the relationship of medial longitudinal arch with different balance parameters. For this reason, it is very important to look into the relationship of medial longitudinal arch and pes planus with balance parameters as foot is the part of the body which is responsible for standing as well as propelling the body forwards, and impairment in the biomechanics of the medial longitudinal arch of the foot can result in impaired functioning. For this reason, the purpose of the current study was to determine the correlation of normalised truncated navicular height and Chippaux Smirak index with postural stability, fall risk, sensory integration of balance, balance error scoring system and single leg athletic stability among healthy young adults. The findings of the study will help in determining whether decreased medial longitudinal arch height can be a risk factor to impaired postural stability and increased fall risk, as is usually thought of, and is even considered as a basis for exclusion criteria in different professions such as armed forces. Furthermore, findings of the study will also guide on whether improving the medial longitudinal arch height will result in a significant improvement in postural stability and fall risk.

Methods and Results

A cross-sectional analytical study was conducted on 165 healthy young adults both male and female aged 18-26 years, recruited via non-probability consecutive sampling, at the Foundation University College of Physical Therapy (FUCP), Islamabad, from July 2019 to January 2021. Participants with pes rectus and pes planus screened via Chippaux Smirak index (CSI) were included in the study, whereas persons with pes cavus, congenital foot anomalies other than pes planus, leg length discrepancies, recent

Foundation University College of Physical Therapy (FUCP), Foundation University, Islamabad, Pakistan.

Correspondence: Muhammad Osama. e-mail: osamadpt@gmail.com
ORCID ID. 0000-0003-1467-2038

history of trauma, lower limb amputations, history of serious foot injury, ligamentous laxity, or an active inflammatory disorder were excluded from the study. The sample size was calculated keeping a power of 80% i.e. α (two-tailed) of 0.05 and β of 0.20, and the expected correlation coefficient (r) of 0.25, using the formula $N=[(Z\alpha+Z\beta)/C]2+3$.[14,15] The sample size was calculated to be 123, however a sample of 165 participants was included in the study to compensate for any missing data.

Outcome measurements included, normalised truncated navicular height (NTNH), Chippaux Smirak Index (CSI), Athletic Single Leg Stability (ASLS) index, fall risk Index, postural stability, clinical test of sensory integration of balance (CTSIB) and Balance Error Scoring System (BESS). Normalised truncated navicular height (NTNH) was calculated using the formula NTNH = Height of navicular tuberosity from the ground (H) / Length of the truncated foot (L), where the height and length were calculated via Vernier calipers, with an ICC of 0.92-0.94.[16,17] Chippaux Smirak index (CSI) was used for the foot-print analysis by measuring the mid-foot on a smooth surface using the formula CSI% = (Greatest forefoot width / smallest mid foot width) x 100, with an intra-rater ICC of 0.99.[18,19] The values from 0.1% to 45% shows pes rectus (Figure 1a), 45% to 100% shows pes planus (Figure 1b) and when the middle part of foot is missing it shows pes cavus (Figure 1c).[18] Biodex Balance System SD™ was used to measure athletic single leg stability index (ICC=0.70-0.82), Fall Risk Index (ICC=0.80),[20] Postural Stability (ICC=0.64-0.91),[21] clinical test of sensory integration of balance (CTSIB) (ICC3,1=0.75)[22] and Balance Error Scoring System. Ethical approval was obtained from the Foundation University Ethical Review Committee (Ref# FF/FUMC/215-2Phy/19) and informed consent was taken from all the participants before induction in the study. Data was analysed using SPSS v 21.0. Shapiro Wilk test was used to determine the normality of the data, and all the variables were observed to be non-normally distributed ($p<0.05$), thus non-parametric tests of significance were used. Spearman correlation was used to determine the relationship between two variables and Mann Whitney U test was used to compare the variables in terms of gender.

Out of the total 165 participants, 45 (27.27%) were males and 120 (72.73%) were females. The participants' information and averages of outcome measures are shown in Table 1. No significant correlation ($p<0.05$) of NTNH and CSI was observed with postural stability, fall risk, CTSIB, ASLS or BESS (Table 2). Significant differences ($p<0.05$) were observed in terms of height, weight, and body mass index (BMI) between males and females. In terms of balance measures, significant differences ($p<0.05$) were only observed in ASLS (left), postural stability (eyes closed), fall risk (eyes closed) between males and females, with higher scores signifying poorer balance (Table 1). Because of gender based anthropometric differences, significant differences ($p<0.05$) were also observed in terms of smallest mid-foot and greatest forefoot width, as well as navicular height and truncated length but no significant differences ($p>0.05$) were observed in terms of measures of medial longitudinal arch, i.e. NTNH and CSI, between males and

Table-1: Average values of participant characteristics along with gender based comparison.

Variable	Average	Gender Based Comparison		
		Male	Female	*p*-value
		Median (IQR)		
Age (years)	22.00(2.00)	22.00(2.00)	22.00(3.00)	0.35
Height (cm)	162.56 (12.70)	172.72(97.60)	160.02(101.60)	<0.001
Weight (kg)	56.00(15.50)	68.00(12.25)	53.00(11.75)	<0.001
BMI	20.81(4.43)	22.86(3.59)	20.08(4.32)	<0.001
Athletic Single Leg Stability Index (Overall) Right Leg	2.40(1.00)	2.30(1.45)	2.50(1.05)	0.90
Athletic Single Leg Stability Index (Overall) Left Leg	2.50(1.70)	3.00(2.10)	2.40(1.30)	0.02
Fall Risk Score (Eyes Open)	1.00(1.10)	1.00(0.60)	1.00(1.20)	0.57
Fall Risk Score (Eyes Closed)	2.20(1.20)	2.80(1.75)	2.10(0,88)	0.01
CTSIB Composite Score	1.75(0.61)	1.83(0.77)	1.72(0.54)	0.22
Postural Stability Overall Stability Index (Eyes Open)	1.20(0.90)	1.10(0.65)	1.20(1.20)	0.45
Postural Stability Overall Stability Index (eyes Closed)	2.40(1.75)	2.80(3.20)	2.30(1.38)	0.01
Chippaux Smirak Index Score (Right)	30.48(12.80)	32.60(13.15)	29.57(12.43)	0.11
Smallest mid-foot width (Right)	2.60(1.20)	3.00(1.30)	2.50(1.10)	0.001
Greatest forefoot width (Right)	8.70(1.05)	9.50(0.70)	8.50(0.70)	<0.001
Chippaux Smirak Index Score (Left)	30.40(14.16)	31.25(14.10)	30.10(13.73)	0.97
Smallest mid-foot width (Left)	2.70(1.20)	3.00(1.35)	2.60(1.28)	0.04
Greatest forefoot width (Left)	8.60(1.10)	9.50(0.45)	8.40(0.70)	<0.001
NTNH (Right)	2.63(0.50)	2.50(0.63)	2.65(0.51)	0.25
Navicular Height (Right) in mm	43.40(8.75)	46.50(11.65)	42.50(7.70)	0.003
Truncated Length (Right) in mm	16.30(1.60)	17.90(1.10)	16.00(1.10)	<0.001
NTNH (Left)	2.60(0.51)	2.70(0.80)	2.60(0.50)	0.23
Navicular Height (Left) in mm	42.70(8.35)	48.30(12.50)	41.60(6.85)	<0.001
Truncated Length (Left) in mm	16.50(1.55)	17.60(1.10)	16.20(1.48)	<0.001
BESS Composite Score	3.09(0.91)	3.260(1.52)	3.065(0.77)	0.14
BESS errors		**Mean ±S.D**		
	11.08 ±5.15	11.066 ±4.29	11.091 ±5.44	0.99

BMI – Body Mass Index, NTNH – Normalised Truncated Navicular Height, CTSIB – Clinical Test of Sensory Integration of Balance, BESS-Balance Error Scoring System.

Table-2: Correlation of CSI and NTNH with ASLS, fall risk, CTSIB, postural stability & BESS.

Variable	CSI (R)		CSI (L)		NTNH (R)		NTNH (L)	
	r-value	*p*-value	*r*-value	*p*-value	*r*-value	*p*-value	*r*-value	*p*-value
Age (years)	0.09	0.24	0.04	0.60	0.14	0.07	0.14	0.07
Height (cm)	0.09	0.28	0.04	0.76	-0.14	0.09	-0.01	0.92
Weight (kg)	0.15	0.05	0.11	0.18	-0.02	0.85	0.07	0.37
BMI	0.15	0.05	0.12	0.11	0.06	0.47	0.08	0.32
Athletic Single Leg Stability Index (Right)	0.10	0.12	-0.04	0.66	0.001	0.99	0.02	0.77
Athletic Single Leg Stability Index (Left)	0.02	0.81	-0.02	0.76	-0.10	0.19	-0.02	0.79
Fall Risk Score (Eyes Open)	0.04	0.59	-0.003	0.97	-0.03	0.70	-0.02	0.77
Fall Risk Score (Eyes Closed)	0.09	0.27	0.04	0.59	0.02	0.84	0.02	0.83
CTSIB	0.001	0.99	-0.04	0.58	-0.05	0.51	0.11	0.15
Postural Stability (Eyes Open)	-0.37	0.63	-0.04	0.58	0.09	0.26	0.08	0.32
Postural Stability (eyes Closed)	-0.06	0.45	-0.09	0.27	-0.02	0.82	-0.02	0.81
BESS Composite Score	0.07	0.37	0.04	0.59	-0.09	0.26	0.004	0.96
BESS errors	-0.01	0.93	-0.03	0.66	-0.20	0.01	-0.13	0.10
Chippaux Smirak Index Score (Right)	-	-	0.80	<0.001	-0.33	<0.001	-0.33	<0.001
Chippaux Smirak Index Score (Left)	0.80	<0.001	-	-	-0.32	<0.001	-0.34	<0.001
NTNH (R)	-0.32	<0.001	-0.33	<0.001	-	-	0.81	<0.001
NTNH (L)	-0.34	<0.001	-0.33	<0.001	0.81	<0.001	-	-

BMI – Body Mass Index, NTNH – Normalised Truncated Navicular Height, CTSIB – Clinical Test of Sensory Integration of Balance, BESS-Balance Error Scoring System.

females (Table 1).

Discussion

The purpose of the current study was to determine the impact of pes planus on balance and fall risk. Hence, the current study looked into the correlation of normalised truncated navicular height (NTNH) and Chippaux Smirak Index (CSI), with postural stability, fall risk, clinical test of sensory integration of balance (CTSIB), and single leg athletic stability among healthy young adults. No significant ($p<0.05$) correlations were observed. In terms of pre-existing literature a research paper authored by Kim J et al, has shown that persons with flexible pes planus have greater postural sway and higher centre of pressure speed as compared to pes rectus, but no differences in terms of Y balance test were reported.[23] Kolasangiani A et al have also shown a significant difference ($p<0.05$) in postural stability in the medio-lateral direction between pes planus and pes rectus during landing.[9] Another study by Han J-T et al has also shown a decrease in limits of stability and impaired postural balance in pes planus on an unstable surface.[7] Koshino Y and colleagues also showed pes planus to have a significantly impaired postural stability during transition task from double-leg to single-leg stance, as compared to pes cavus and pes rectus.[8] It has also been suggested that impaired postural stability may be one of the mechanisms resulting in an increased risk of lower extremity injuries, especially in transition tasks.[8]

On the other hand according to a study published by Hyong IH et al, no significant differences were observed between pes planus, pes cavus, and pes rectus in terms of dynamic balance ability.[1] Another study by Yunus NFM et al conducted on healthy young adults between the age of 18 and 25 years observed no significant impact of pes planus or pes cavus on standing balance and physical performance.[10] Moreover, Chun W et al showed no significant differences between pes planus and pes rectus in terms of knee isokinetic strength or static postural stability ($p>0.05$), but a significant difference was observed in terms of medio-lateral stability index for dynamic postural stability, only under eyes-closed condition ($p<0.05$).[11] Another study by Hertel J et al has shown a significant difference in terms of postural sway i.e. centre of pressure excursion area, between pes cavus and pes rectus, but no significant differences between pes rectus and pes planus.[12] Another study by Cote KP et al observed that postural stability index was increased in pronators (pes planus) as compared to supinators (pes cavus), but neither group was significantly different from pes rectus.[13]

Even though most studies have been comparative in nature, some studies have also looked into the relationship of pes planus and medial longitudinal arch with balance and postural stability. A study conducted by Fu GQ et al has shown no significant relationship of rear foot alignment with static and dynamic postural balance.[24] Another study Mun K-R et al has shown medial longitudinal arch height to be correlated with postural stability in anteroposterior direction,[25] however the relationship was non-significant ($p>0.05$), similar to the findings of the current study. Moreover, the sample size of Mun K-R's study was small, consisting of only 13 healthy young adults with a mean age of 28.08 years.[25] Chun W et al also showed that foot posture index scores were not significantly correlated with static and dynamic postural stability index, except for dynamic overall (r=0.344, p=0.030) and medio-lateral stability index (r= 0.409, p=0.009) under the eyes closed condition only.[11] Menz HB also showed that foot posture, including foot posture index, arch index and navicular height were not significant contributors of poor balance or risk of falls in older people,[26] similar to the findings of the current study in which no significant correlation of Chippaux Smirak Index Score and normalised truncated navicular height was observed with Fall Risk Index. It is also imperative to point out, that there is a dearth of literature in terms of the relationship of medial longitudinal arch height and Chippaux Smirak Index with fall risk and sensory integration of balance.

Thus, in light of the previous studies and observations of the current study, it can be said that the measures of flat foot and pes planus such as Chippaux Smirak index score and normalised truncated navicular height are not significantly correlated with measures of balance and fall risk such as postural stability, fall risk index, balance error scoring system, clinical test of sensory integration of balance (CTSIB), and athletic single leg stability among healthy young adults. This conclusion is important from a biomechanical and clinical perspective when dealing with persons with flat feet who have issues of balance, fall risk or impaired postural stability, and sensory integration of balance, in the sense that medial longitudinal height should not be the prime concern when treating such patients, and instead other causes of impaired balance and stability should be assessed and treated accordingly. Furthermore, males were observed to have poorer balance and fall risk as compared to females, especially in terms of postural stability and fall risk index with eyes closed and athletic single leg stability on the left side.

Conclusion

Chippaux Smirak index score and normalised truncated navicular height have no significant correlation with postural stability, fall risk, balance error scoring system, clinical test of sensory integration of balance (CTSIB), and Athletic Single Leg Stability among healthy young adults. Moreover, males were observed to have poorer balance and fall risk as compared to females.

Acknowledgement: The authors would like to acknowledge our respected colleagues Laiba Ashfaq, Kiran Tariq, Rida Kainat and Hafiz Ali Bin Asim for their significant contributions in data collection and data entry for this research.

Disclaimer: None.

Conflict of interest: None.

Funding disclosure: None.

References

1. Hyong IH, Kang JH. Comparison of dynamic balance ability in healthy university students according to foot shape. J Phys Ther Sci 2016; 28: 661-4.
2. Ker R, Bennett MB, Bibby SR, Kester RC, Alexander RM. The spring in the arch of the human foot. Nature 1987; 325: 147-9.
3. Dars S, Uden H, Banwell HA, Kumar S. The effectiveness of non-surgical intervention (Foot Orthoses) for paediatric flexible pes planus: A systematic review: Update. PloS one 2018; 13: e0193060.
4. Huang YP, Peng HT, Wang X, Chen ZR, Song CY. The arch support insoles show benefits to people with flatfoot on stance time, cadence, plantar pressure and contact area. PloS one 2020; 15: e0237382.
5. Angyan L, Teczely T, Angyan Z. Factors affecting postural stability of healthy young adults. Acta Physiol Hung 2007; 94: 289-99.
6. Wang Q, Li L, Mao M, Sun W, Zhang C, Mao D, et al. The relationships of postural stability with muscle strength and proprioception are different among older adults over and under 75 years of age. J Exerc Sci Fit 2022; 20: 328-34.
7. Han JT. Comparison of the Limitation of Stability between Flatfeet and Neutral Feet. PNF and Movement 2017; 15: 311-6.
8. Koshino Y, Samukawa M, Chida S, Okada S, Tanaka H, Watanabe K, et al. Postural Stability and muscle activation onset during double-to single-leg stance transition in flat-footed individuals. J Sports Sci Med 2020; 19: 662-9.
9. Kolasangiani A, Mantashloo Z, Salehi S, Moradi M. Examination of postural control of body and the onset time of electrical activity of selected ankle muscles during single-leg landing in subjects with pronated and normal foot. J Mod Rehabil 2019; 13: 79-86.
10. Yunus NF, Zainal NS, Mustafa UT. Impact of different foot arches on standing balance and physical performance among nursing students. Healthscope: The Official Research Book of Faculty of Health Sciences, UiTM 2020; 3: 1-6.
11. Chun W, Kim HS, Park S, Park J, Shim S, Park S. The Influence of Pronated Foot Posture on Knee Isokinetic Strength, Static and Dynamic Postural Stability in Healthy Young Individuals. Phys Ther Korea 2021; 28: 168-76.
12. Hertel J, Gay MR, Denegar CR. Differences in postural control during single-leg stance among healthy individuals with different foot types. J Athl Train 2002; 37: 129-32.
13. Cote KP, Brunet ME, Gansneder BM, Shultz SJ. Effects of pronated and supinated foot postures on static and dynamic postural stability. J Athl Train 2005; 40: 41-6.
14. Anderson C, Horne JA. Do we really want more sleep? A population-based study evaluating the strength of desire for more sleep. Sleep Med 2008; 9: 184-7.
15. Sorensen G, Stoddard AM, Stoffel S, Buxton O, Sembajwe G, Hashimoto D, et al. The role of the work context in multiple wellness outcomes for hospital patient care workers. J. Occup Environ Med 2011; 53: 899-910.
16. Aboelnasr EA, Hegazy FA, Zaghloul AA, El-Talawy HA, Abdelazim FH. Validation of normalized truncated navicular height as a clinical assessment measure of static foot posture to determine flatfoot in children and adolescents: a cross sectional study. Foot 2018; 37: 85-90.
17. Motantasut P, Hunsawong T, Mato L, Donpunha W. Reliability of novice and experienced physiotherapists using the normalized navicular height truncated and the foot posture index-6 for classifying static foot posture in adults. J Phys Ther Sci 2019; 31: 392-7.
18. Tománková K, Přidalová M, Gába A. The impact of obesity on foot morphology in women aged 48 years or older. Acta Gymnica 2015; 45: 69-75.

19. Fascione JM, Crews RT, Wrobel JS. Dynamic footprint measurement collection technique and intrarater reliability: ink mat, paper pedography, and electronic pedography. J Am Podiatr Med Assoc 2012; 102: 130-8.
20. Parraca JA, Olivares PR, Carbonell Baeza A, Aparicio VA, Adsuar JC, Gusi N. Test-Retest reliability of Biodex Balance SD on physically active old people. J Hum Sport Exercise 2011; 6: 444-51.
21. Garcia P, de Oliveira PG, da Silva JF, Abreu AS, Paz LP, Martini LL. Postural Stability and Falls Risk in The Elderly in Biodex Balance System: A Reliability Study. Innov. Aging 2017; 1(Suppl 1): 253.
22. Dawson N, Dzurino D, Karleskint M, Tucker J. Examining the reliability, correlation, and validity of commonly used assessment tools to measure balance. Health Sci Rep 2018; 1: e98.
23. Kim JA, Lim OB, Yi CH. Difference in static and dynamic stability between flexible flatfeet and neutral feet. Gait Posture 2015; 41: 546-50.
24. Fu GQ, Wah YC, Sura S, Jagadeesan S, Chinnavan E, Judson JP. Influence of rearfoot alignment on static and dynamic postural stability. Int J Ther Rehabil 2018; 25: 628-35.
25. Mun KR, Chun S, Hong J, Kim J. The relationship between foot feature parameters and postural stability in healthy subjects. Hum Factors 2019; 61: 1077-85.
26. Menz HB, Morris ME, Lord SR. Foot and ankle characteristics associated with impaired balance and functional ability in older people. J Gerontol A Biol Sci Med J Sci 2005; 60: 1546-52.