Original Article

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Associations Between Heel Height, Lower-Limb Flexibility, and Lumbar Curvature in Female Workers: A Cross-Sectional Study

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Abstract:

Objective: To examine the relationships between heel height, lower-limb flexibility, and lumbar curvature among female retail workers who regularly wear high-heeled shoes.

Material and Methods: We conducted a cross-sectional study among female employees at shopping centers in Southern Thailand. Heel height was measured using a ruler. Plantar flexor and hip flexor flexibility were measured using a digital inclinometer, while lumbar curvature was measured via a Body Level/Scoliosis tool. Data were analyzed using descriptive statistics, correlation analyses, multiple linear regression models controlling for body mass index (BMI) and cumulative heel exposure, and regression-based mediation analyses with bootstrap resampling.

Results: Higher heel height was significantly associated with reduced plantar flexor flexibility (r=-0.358, p-value=0.023). Plantar flexor flexibility was positively correlated with hip flexor flexibility (r=0.320, p-value=0.044), and hip flexor flexibility was associated with lumbar curvature (r=0.362, p-value=0.022). Multiple regression showed that heel height was not a significant predictor of plantar flexor flexibility or lumbar curvature, whereas BMI (β=0.21, p-value = 0.034) and cumulative heel exposure (β=−0.05, p-value=0.015) were associated with lumbar curvature. Mediation analyses indicated no significant indirect effects through plantar or hip flexor flexibility.

Conclusion: These findings suggest that heel height alone was not the primary determinant of lower-limb flexibility or lumbar curvature. Cumulative heel exposure and anthropometric factors may play a more important role in musculoskeletal adaptations among regular high-heel users. These findings highlight the importance of an integrative approach to footwear recommendations.

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Keywords: high heels, kinetic chain, lumbar lordosis, muscle shortening, musculoskeletal adaptation

Introduction

High-heeled shoes are commonly used by women for aesthetic reasons such as enhancing height, posture, and perceived femininity[1,2]. In retail settings, such as shopping centers, prolonged high heel use is often enforced by dress codes, potentially increasing the risk of musculoskeletal problems. Hence, women working in these occupations represent a relevant group for examining both health and social impacts of regular high heel use.

Wearing high-heeled shoes places the ankle in a constant plantar flexed position, which can gradually shorten the calf muscles, especially the gastrocnemius and soleus, and limit the flexibility of the ankle joint[3,4]. Reduced flexibility in ankle dorsiflexion can interfere with normal walking, increase the risk of falling, and contribute to overuse injuries[5]. Additionally, wearing high heels may alter biomechanics and lead to adaptations throughout the kinetic chain from the foot and ankle to the lumbar spine. These changes have been shown to affect trunk and hip extensor muscle coordination patterns[6] and influence pelvic rotation[7].

Previous studies have investigated the effects of high-heeled footwear on individual biomechanical outcomes, such as ankle range of motion and muscle flexibility[8-10]. However, the interrelationships among plantar flexor flexibility, hip flexor flexibility, and lumbar curvature within a kinetic chain remain unclear, particularly in women who wear high heels regularly as part of their occupation. Thus, this study investigated the associations between heel height, plantar flexor flexibility, hip flexor flexibility, and lumbar curvature in female shopping center workers who are routinely exposed to high-heeled footwear as part of workplace dress requirements. It was hypothesized that higher heel height would be associated with greater lumbar curvature and reduced ankle and hip flexibility, indicating compensatory postural adaptations to prolonged high-heel use.

Material and Methods

Study design and setting

This cross-sectional study was conducted in the Hat Yai region of Southern Thailand, at four major shopping malls within Hat Yai City.

Study participants

Our study participants were full-time female employees in retail roles at four major shopping malls. They were recruited through voluntary response sampling. Eligible participants were women aged 20 to 45 years who reported wearing high-heeled footwear (heel height ≥5 cm) for occupational purposes for at least 6 hours per workday for a minimum duration of 6 months, consistent with previous studies on habitual exposure[3,8]. Individuals with current lower limb injuries or spinal disorders were excluded. The presence of these conditions was assessed through a structured interview during participant screening.

Study procedures

Participants completed a two-part questionnaire designed to collect both demographic and footwear usage data relevant to the study objectives. The first part gathered basic demographic information, including age, height, and weight. The second part focused on high heel use, wherein participants were asked to report the duration of regular use in months, the frequency of use per week in days, and the average number of hours worn per day. Participants were asked to bring the high-heeled shoes they commonly wore to work. Heel height was then measured directly by the researcher using a ruler and recorded in centimeters as the

vertical distance from the base of the heel to the ground (Figure 1A). The questionnaire was developed specifically for this study and reviewed by three experts in biomechanics and occupational health to ensure content validity.

We assessed plantar flexor flexibility using a digital inclinometer (JTech Medical, USA). The test was performed barefoot. Participants began in a neutral standing position with equal weight bearing and the ankle at approximately 90 degrees. They then stepped one leg backward and dorsiflexed the ankle to its maximum range while keeping the knee extended and the heel in contact with the floor. The inclinometer was used to measure the tibial angle relative to a vertical imaginary line. Both legs were tested, and the mean value was used for analysis. Leg dominance was recorded, but not used in the analysis, as measurements from both legs were averaged. The position of participants for the measurement (Figure 1B) was the same as that used in a previous study[11].

We evaluated hip flexor flexibility with a digital inclinometer (JTech Medical, USA). Participants lay in a supine position and brought both hips and knees into full flexion, as required for the modified Thomas test. They then lowered the testing leg toward the ground, while keeping the opposite leg in position. We measured the angle of hip extension relative to the neutral position. To minimize anterior pelvic tilt, pelvic stabilization was maintained through manual contact during the movement. The position of participants for the measurement (Figure 1C) was the same as that used in a previous study[12]. Both legs were tested, and the mean value was used for analysis.

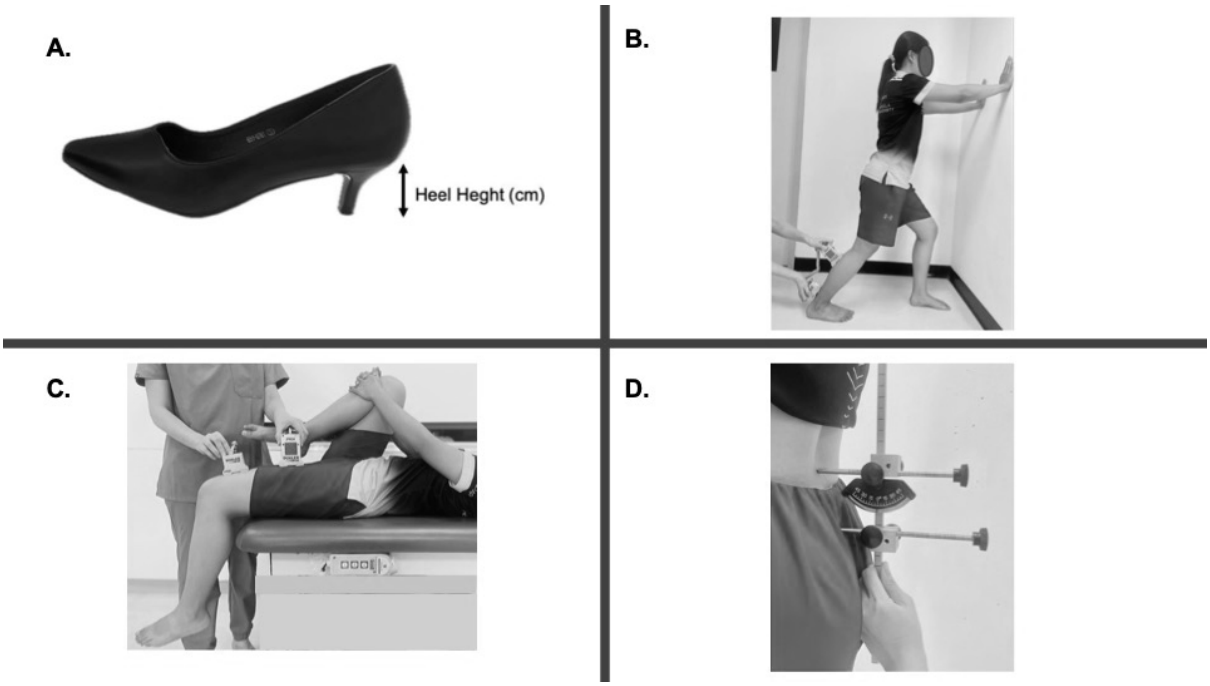

Figure 1 Measurements of heel height, flexibility, and lumbar curvature. A. Definition of heel height and types of high-heeled shoes worn by participants at work, with representative images and heel height measurement; B. Plantar flexor flexibility measurement; C. Hip flexor flexibility measurement; D. Lumbar curvature measurement

We assessed lumbar curvature using the Baseline Metal Body Level/Scoliosis tool (Model MDSP121091, Baseline, USA), which measures the angulation between the spinous process of L5 and the sacrum (Figure 1D). The procedure for the measurement was the same as that used in a previous study[13], with no additional modification. Participants stood upright with their feet together in a relaxed posture. The upper rod of the device was placed at the L5 level, while the lower rod was positioned over the most prominent point of the sacral curvature. The lower rod was adjusted until the gauge read zero, then locked in place, and the linear measurement of lumbar curvature depth was recorded in centimeters. Given the workplace-based nature of this study, non-invasive methods with acceptable reliability[13] are considered appropriate for field-based data collection.

A physical therapist, with over ten years of clinical experience and specialized training in musculoskeletal assessment, carried out all measurements. To ensure consistency, we provided standardized instructions and demonstrated the procedure prior to testing. Prior to the main study, intra-rater reliability of the measurement procedures was evaluated, demonstrating excellent reliability across all variables. The intraclass correlation coefficient (ICC) values ranged from 0.993 to 0.999 for plantar flexor flexibility, 0.993 to 0.999 for hip flexor flexibility, and 0.991 to 0.999 for lumbar curvature. Based on these results, all measurements were conducted by the same tester.

Statistical analysis

An a priori power analysis was performed using G*Power 3.1.9.7. For a correlation analysis with an expected effect size of r=0.35, α=0.05, and power=0.80, the target sample size was n=61. However, due to the specific recruitment criteria and the limited geographic setting (female retail workers in a small city), a final convenience sample of n=40 was obtained.

We conducted statistical analyses using R (version 4.4.0; R Core Team, 2023). We calculated descriptive statistics for all variables and used the Shapiro-Wilk test to assess the normality of the data. We first conducted Pearson correlation analysis to examine the pairwise correlations between heel height, plantar flexor flexibility, hip flexor flexibility, and lumbar curvature. The assumptions of linearity and homoscedasticity were evaluated using scatterplots and residual diagnostics, with no evidence of major violations. To further examine these relationships while accounting for potential confounding factors, we performed multiple linear regression through three models. In each model, we entered heel height as the primary independent variable and included body mass index (BMI) and cumulative heel exposure (time × frequency of wearing high-heeled shoes: hours per day × days per week) as covariates. We included plantar flexor flexibility as an additional predictor in the hip flexibility model, while the lumbar curvature model incorporated both plantar and hip flexibility. To investigate potential indirect pathways linking heel height, lower-limb flexibility, and lumbar curvature, we conducted mediation analysis using nonparametric bootstrap resampling. Specifically, we tested whether plantar flexor flexibility mediated the relationship between heel height and hip flexor flexibility, and whether hip flexor flexibility mediated the relationship between heel height and lumbar curvature. We estimated indirect effects using 5,000 bootstrap simulations to generate bias-corrected confidence intervals, defining statistical significance by the absence of zero within the 95% confidence interval.

Results

A total of 40 female participants were recruited for the study. Table 1 presents a detailed description of the demographic and physical characteristics of the study sample. Participants reported wearing high-heeled shoes for 7.3±1.8 hours per day, 6.1±0.5 days per week, with a mean heel height of 7.1±2.6 cm (Table 1).

Table 1 Demographic characteristics of the study participants

	Mean±S.D.
Participant characteristics	
Age (year)	30.8±6.3
Weight (kg.)	52.4±6.5
Height (cm.)	161.5±4.0
BMI (kg/sq.m.)	20.1±2.2
Shoe usage	
Heel height (cm.)	7.1±2.6
Time of wearing high-heeled shoes (days)	216.0±25.6
Frequency of wearing high-heeled shoes (days/week)	6.1±0.5
Time of wearing high-heeled shoes (hours/day)	7.3±1.8
Outcome variables	
Plantar flexor flexibility (degree)	40.5±6.1
Hip flexor flexibility (degree)	0.4±7.3
Lumbar curvature (cm)	3.9±1.5

S.D.=standard deviation, BMI=body mass index

The correlation analysis showed a significant correlation between heel height and plantar flexor flexibility (r=−0.358, p-value=0.023, Table 2 and Figure 2A). A significant correlation was also observed between plantar flexor flexibility and hip flexor flexibility (r=0.32, p-value=0.044, Table 2 and Figure 2B). Additionally, hip flexor flexibility was significantly correlated with lumbar curvature (r=0.362, p-value=0.022, Table 2 and Figure 2C).

In multiple regression analyses controlling for BMI and cumulative heel exposure (Table 3), heel height was not significantly associated with plantar flexor flexibility (p-value=0.116). Plantar flexor flexibility remained a significant predictor of hip flexor flexibility (β=0.47, p-value=0.021, Table 3). In the lumbar curvature model, BMI (β = 0.21, p-value=0.034) and cumulative heel exposure (β=−0.05, p-value=0.015) were significant predictors, whereas heel height, plantar flexibility, and hip flexibility were not (Table 3).

The mediation analysis indicated that plantar flexor flexibility did not significantly mediate the relationship between heel height and hip flexor flexibility (ACME=−0.29, 95% CI [−0.99, 0.06], p-value=0.106). However, the direct effect of heel height on hip flexor flexibility remained significant (ADE=0.84, p-value=0.045). Similarly, hip flexor flexibility did not significantly mediate the association between heel height and lumbar curvature (ACME=0.03, 95% CI [−0.03, 0.14], p-value=0.344). Overall, heel height was not significantly associated with lumbar curvature in the adjusted analyses.

Discussion

This study examined the relationships between heel height, lower-limb flexibility, and spinal alignment in female retail workers. Increased heel height was significantly associated with reduced plantar flexor flexibility. Additionally, plantar flexor flexibility was positively correlated with hip flexor flexibility, which in turn was associated with

Table 2 Correlation coefficients between heel height, flexibility, and lumbar curvature

Variables	Heel height	Plantar flexor flexibility	Hip flexor flexibility	Lumbar curvature
Heel height	1			
Plantar flexor flexibility	−0.358* [−0.66, −0.05]	1		
Hip flexor flexibility	0.133 [−0.19, 0.43]	0.320* [0.01, 0.57]	1	
Lumbar curvature	0.022 [−0.29, 0.33]	0.246 [−0.07, 0.52]	0.362* [0.06, 0.60]	1

Values are presented as correlation coefficients (r) with corresponding 95% confidence intervals in brackets. *indicates statistical significance (p-value<0.05).

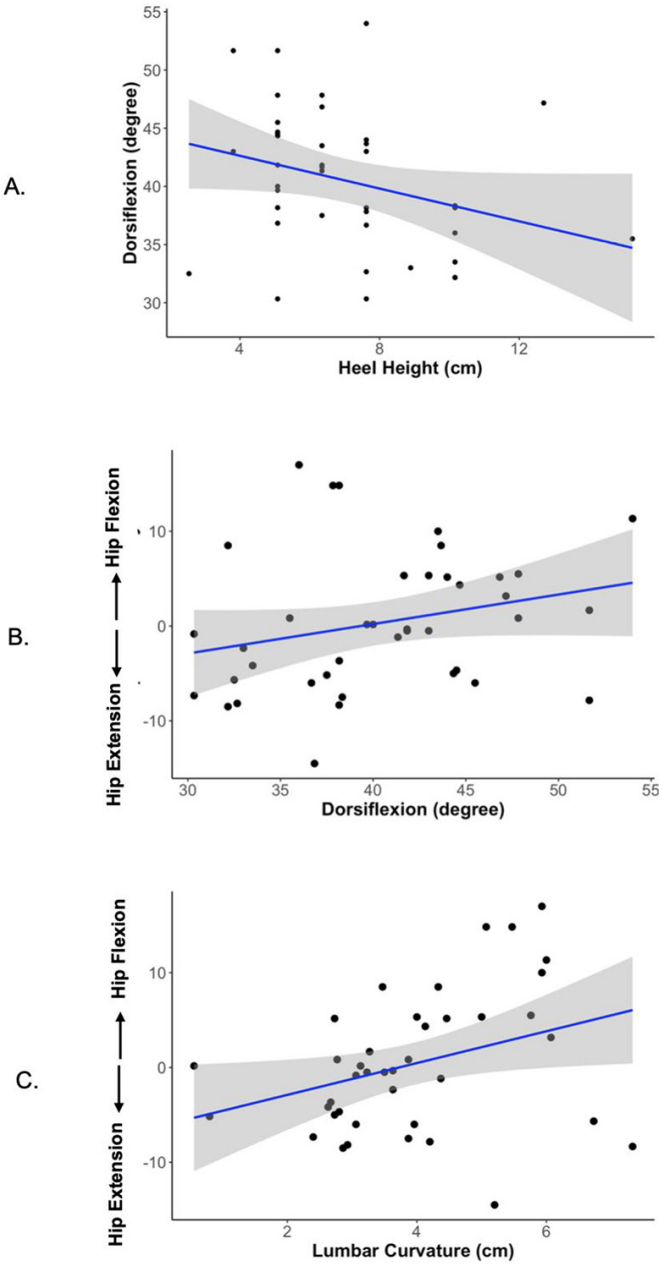

Figure 2 Scatter plots illustrating the pairwise correlations between heel height, lower-limb flexibility, and lumbar curvature. A. Correlation between heel height (cm) and plantar flexor flexibility, represented by ankle dorsiflexion range of motion (ROM). B. Correlation between plantar flexor flexibility and hip flexor flexibility. C. Correlation between hip flexor flexibility and lumbar curvature (cm). Remarks: In panels B and C, hip flexor flexibility was recorded as the hip flexion angle during the Modified Thomas Test, where positive values indicate hip flexion and negative values indicate hip extension. Ankle dorsiflexion ROM was used to represent plantar flexor flexibility. Solid lines represent the linear regression fit, and shaded areas indicate the 95% confidence intervals

Table 3 Multiple regression analyses predicting plantar flexibility, hip flexibility, and lumbar curvature

Outcome variable	Predictor	β	SE	p-value
Plantar flexor flexibility	Heel height	−0.61	0.38	0.116
BMI		0.05	0.43	0.904
Cumulative heel exposure		0.10	0.08	0.240
Hip flexor flexibility	Plantar flexor flexibility	0.47	0.19	0.021*
Heel height		0.84	0.46	0.073
BMI		0.45	0.49	0.372
Cumulative heel exposure		−0.13	0.09	0.188
Lumbar curvature	Hip flexor flexibility	0.04	0.03	0.281
Plantar flexor flexibility		0.06	0.04	0.148
Heel height		0.02	0.09	0.822
BMI		0.21	0.09	0.034*
Cumulative heel exposure		−0.05	0.02	0.015*

Values are presented as standardized regression coefficients (β), standard errors (SE), and p-values. * indicates statistical significance (p-value<0.05). Models were adjusted for body mass index (BMI) and cumulative heel exposure.

Table 4 Mediation analysis testing whether plantar and hip flexibility mediated the relationship between heel height and lumbar curvature

Pathway	Mediation effect	Estimate	95% CI	p-value
heel height → plantar flexor flexibility → hip flexor flexibility	ACME	−0.29	−0.99 to 0.06	0.106
	ADE	0.84	0.02 to 2.15	0.045*
	Total Effect	0.56	−0.36 to 1.65	0.219
	Proportion mediated	0.51	−8.04 to 5.70	0.318
heel height → hip flexor flexibility → lumbar curvature	ACME	0.03	−0.03 to 0.14	0.344
	ADE	0.02	−0.16 to 0.26	0.849
	Total Effect	0.05	−0.12 to 0.30	0.598
	Proportion mediated	0.59	−4.96 to 5.76	0.702

Values are presented as estimates with 95% confidence intervals (CI) and p-values. ACME=average causal mediation effect, ADE=average direct effect. Indirect effects were estimated using nonparametric bootstrap resampling. *indicates statistical significance (p-value<0.05).

increased lumbar curvature. However, the magnitudes of these correlations were low, indicating weak associations. This suggests that heel height is not a strong independent determinant of plantar flexor flexibility, hip flexor flexibility, or lumbar curvature. This interpretation is supported by the regression analyses: after adjusting for BMI and cumulative heel exposure, heel height was no longer a significant predictor of plantar flexor flexibility, whereas plantar flexor flexibility remained associated with hip flexor flexibility. In the lumbar curvature model, BMI and cumulative heel exposure were significant predictors, whereas heel height and flexibility variables were not. Moreover, mediation analyses further indicated that neither plantar flexor flexibility nor hip flexor flexibility significantly mediated the relationships between heel height and lumbar curvature. These findings suggest that although pairwise correlations exist within the lower-limb kinetic chain, heel height alone may not be the primary determinant of lower-limb flexibility or lumbar posture when cumulative exposure and anthropometric factors are considered.

The relationship between heel height and plantar flexor flexibility aligns with previous studies that have

documented adaptive shortening of the gastrocnemius and soleus muscles, along with increased Achilles tendon stiffness in habitual high-heel users[3,4,14]. A possible explanation is that prolonged high-heel use positions the foot in a sustained plantar-flexed posture, with higher heels producing greater angles of plantar flexion. Over time, this fixed position can lead to adaptive shortening of the gastrocnemius and soleus muscles. A previous study showed that structural adaptations, including reduced gastrocnemius length and increased tendon stiffness, typically occur in individuals who wear high-heeled shoes at least 3 days per week for a minimum of 6 months[8]. In the present study, participants met this exposure threshold, as they reported regular high-heel use of at least 6 days per week for a minimum of 6 months. However, variability in career duration among retail workers may have influenced the degree of muscle–tendon adaptation observed. Additionally, regular users of high heels experience greater and more rapid strain in the gastrocnemius muscle fascicles compared to barefoot walkers, even with restricted ankle motion[3,14], potentially increasing the risk of strain-related injuries. High-heeled footwear also promotes a more plantar-flexed and supinated foot posture, which alters weight distribution and limits ankle mobility[15,16]. These biomechanical constraints may explain the lower limb overuse syndromes in regular high-heel users. However, this relationship was no longer statistically significant after controlling for BMI and cumulative heel exposure in the multiple regression analysis. This finding suggests that the initial correlation may partly reflect the influence of additional factors related to body composition or long-term footwear habits rather than heel height alone.

The significant association between plantar flexor and hip flexor flexibility observed in both pairwise and adjusted analyses suggests a functional linkage between distal and proximal muscle groups along the kinetic chain. A reduction in plantar flexor extensibility may result in compensatory recruitment or increased tension in proximal musculature, including the hip flexors. This finding aligns with the theory of myofascial continuity, which proposes that fascial and muscular structures are interconnected, allowing tension or restriction in one region to influence mobility and alignment elsewhere[17,18]. In addition, anterior pelvic tilt may contribute to this relationship. Increased anterior pelvic tilt is associated with adaptive shortening of the hip flexors and altered lumbopelvic alignment[7,19], which may influence distal muscle function through kinetic chain interactions. Such coordinated adaptations may emerge over time as the body attempts to maintain upright posture and gait efficiency in the context of altered foot and ankle mechanics caused by high-heeled footwear. However, mediation analysis indicated that plantar flexor flexibility did not significantly mediate the relationship between heel height and hip flexor flexibility. Instead, heel height demonstrated a significant direct effect on hip flexor flexibility, suggesting that its effects are not solely explained by distal flexibility. This aligns with previous studies in which wearing high heels altered whole-body posture, including pelvic orientation and trunk alignment, which may directly influence hip joint positioning and flexibility[6,7].

The significant association between hip flexor flexibility and lumbar curvature provides further evidence of biomechanical coupling between muscle length and spinal alignment. Shortened hip flexors, particularly the iliopsoas, exert an anterior pull on the pelvis, promoting anterior pelvic tilt and increasing lumbar curvature[20,21]. While this alignment pattern is commonly observed in individuals who regularly wear high heels and is thought to increase compressive loading of the lumbar spine[22,23], neither plantar nor hip flexibility significantly predicted lumbar curvature in our adjusted regression models. Instead, BMI and cumulative heel exposure emerged as the primary significant predictors. These findings are consistent with a recent study, suggesting that the cumulative mechanical loading and gradual postural adaptations associated with

long-term wear[24] may exert a more profound influence on spinal morphology than the immediate heel height or isolated muscle flexibility. The mediation analyses further supported this interpretation. Plantar flexor flexibility did not significantly mediate the relationship between heel height and hip flexor flexibility, and hip flexibility did not mediate the relationship between heel height and lumbar curvature. These results indicate that although flexibility relationships exist within the lower-limb kinetic chain, the influence of heel height on more proximal structures may not operate through a simple linear pathway. The present findings suggest that musculoskeletal adaptations associated with habitual high-heel use may be multifactorial. Rather than heel height alone, cumulative exposure to high heels and individual anthropometric characteristics may play more substantial roles in determining lower-limb flexibility and lumbar posture.

Our findings provide a foundation for developing more comprehensive health and footwear guidelines. Current recommendations typically focus on limiting heel height.[25,26] However, they often overlook the roles of muscular flexibility, cumulative exposure, and spinal alignment. Based on our results, updated guidelines should adopt a more integrative approach. First, limiting continuous periods of high-heel use is essential to reduce cumulative musculoskeletal strain. Maintaining a healthy BMI may also be important, as increased BMI was associated with greater lumbar curvature and may contribute to higher spinal loading during high-heel use. In addition, regular flexibility training targeting the plantar flexors and hip flexors should be encouraged to help maintain muscular balance and prevent adaptive shortening, which has been linked to postural changes.[17,21] Footwear recommendations should also prioritize moderate heel heights, cushioned soles, and supportive designs that promote more even weight distribution[27,28]. For individuals new to wearing high heels, a gradual adaptation process and alternating between different footwear styles throughout the day may help minimize discomfort and reduce injury risk. Furthermore, from an occupational health perspective, employers, especially those in professions with formal dress codes, should consider implementing policies that allow more comfortable footwear options, scheduled rest breaks, or the use of orthotic insoles. These workplace strategies may help mitigate musculoskeletal risks while still maintaining a professional appearance. Notably, the guidelines proposed in this study differ from existing ones by emphasizing the importance of lower-limb flexibility and spinal alignment, offering a more holistic and proactive framework for promoting long-term musculoskeletal health among high-heel users.

Limitations

There were several limitations in our study. First, the sample size was relatively small and restricted to a single urban area in Southern Thailand, which may limit statistical power and generalizability. The study achieved approximately 60% power to detect a medium effect size (r=0.35), increasing the risk of Type II error. Future multi-center studies with larger samples are needed to confirm these findings. Second, although BMI and cumulative heel exposure were accounted for, unmeasured confounders (e.g., physical activity and stretching habits) may have contributed to residual confounding. Third, the cross-sectional design precludes causal or temporal inference regarding the relationships between high-heel use, lower-limb flexibility, and spinal alignment. Longitudinal studies are needed to determine whether prolonged high-heel use leads to progressive musculoskeletal adaptations over time. Fourth, the absence of a control group with limited or no high-heel exposure restricts direct comparisons and limits interpretation of the observed associations. Fifth, the observed effect sizes were modest, indicating relatively weak associations that should be interpreted with caution. Sixth, all the measurements were performed by

a single assessor. Therefore, inter-rater reliability was not established. Finally, lumbar curvature was assessed using a non-invasive linear measure of curvature depth. Although this method has demonstrated acceptable reliability,[13] the absence of a defined minimal, clinically important difference limits any clinical interpretation, and findings should therefore be considered in terms of relative associations rather than absolute thresholds.

Conclusion

This study examined the relationships between high-heeled shoe use, lower-limb flexibility, and spinal alignment in female retail workers. Although initial correlations suggested associations along the lower-limb kinetic chain, adjusted analyses indicated that heel height alone was not a significant predictor of plantar flexor flexibility or lumbar curvature. Instead, cumulative heel exposure and BMI were more strongly associated with lumbar alignment. Mediation analyses further showed that plantar and hip flexor flexibility did not explain the relationships between heel height and proximal musculoskeletal outcomes. These findings suggest that cumulative exposure and anthropometric factors may play a greater role than heel height alone in musculoskeletal adaptations among regular high-heel users. Our findings support the need for more comprehensive footwear and occupational health guidelines that incorporate strategies for managing cumulative exposure, maintaining flexibility, and supporting postural alignment. Further research with larger and more diverse populations and longitudinal designs is needed to clarify the causal relationships and evaluate preventive interventions.

Ethics approval and consent to participate

The study received ethical approval from the Research Ethics Committee of the Faculty of Medicine, Prince of Songkla University (REC 57-317-11-2). All participants provided written informed consent prior to enrolment.

Consent for publication

Not applicable.

References

1. Hong WH, Lee YH, Chen HC, Pei YC, Wu CY. Influence of heel height and shoe insert on comfort perception and biomechanical performance of young female adults during walking. Foot Ankle Int 2005;26:1042-8.
2. Morris PH, White J, Morrison ER, Fisher K. High heels as supernormal stimuli: How wearing high heels affects judgements of female attractiveness. Evol Hum Behav 2013; 34:176-81.
3. Cronin NJ, Barrett RS, Carty CP. Long-term use of high-heeled shoes alters the neuromechanics of human walking. J Appl Physiol (1985) 2012;112:1054-8.
4. Csapo R, Maganaris CN, Seynnes OR, Narici MV. On muscle, tendon and high heels. J Exp Biol 2010;213:2582-8.
5. Mika A, Oleksy Ł, Mika P, Marchewka A, Clark BC. The influence of heel height on lower extremity kinematics and leg muscle activity during gait in young and middle-aged women. Gait Posture 2012;35:677-80.
6. Mika A, Clark BC, Oleksy Ł. The influence of high and low heeled shoes on EMG timing characteristics of the lumbar and hip extensor complex during trunk forward flexion and return task. Man Ther 2013;18:506-11.
7. Schroeder J, Hollander K. Effects of high-heeled footwear on static and dynamic pelvis position and lumbar lordosis in experienced younger and middle-aged women. Gait Posture 2018;59:53-7.
8. Kim Y, Lim JM, Yoon B. Changes in ankle range of motion and muscle strength in habitual wearers of high-heeled shoes. Foot Ankle Int 2013;34:414-9.
9. Li Z, Hu M, Zhang L, et al. High-heeled shoes increase motion of the talocrural joint while limiting the subtalar joint. Gait Posture 2025;118:100-7.
10. Shang J, Chen L, Zhang S, et al. Influence of high-heeled shoe parameters on biomechanical performance of young female adults during stair ascent motion. Gait Posture 2020;81:159-65.
11. Almansoof HS, Nuhmani S, Muaidi Q. Correlation of ankle dorsiflexion range of motion with lower-limb kinetic chain function and hop test performance in healthy male recreational athletes. PeerJ 2023;11:e14877.

12. Eimiller K, Stoddard E, Janes B, Smith M, Vincek A. Reliability of goniometric techniques for measuring hip flexor length using the modified thomas test. Int J Sports Phys Ther 2024; 19:997–1002.
13. Prowse A, Aslaksen B, Kierkegaard M, Furness J, Gerdhem P, Abbott A. Reliability and concurrent validity of postural asymmetry measurement in adolescent idiopathic scoliosis. World J Orthop 2017;8:68–76.
14. Cronin NJ. The effects of high heeled shoes on female gait: A review. J Electromyography Kinesiology 2014;24:258–63.
15. Speksnijder CM, vd Munckhof RJH, Moonen SAFCM, Walenkamp GHIM. The higher the heel the higher the forefoot-pressure in ten healthy women. The Foot 2005;15:17–21.
16. Ko PH, Hsiao TY, Kang JH, Wang TG, Shau YW, Wang CL. Relationship between plantar pressure and soft tissue strain under metatarsal heads with different heel heights. Foot Ankle Int 2009;30:1111–6.
17. Myers TW. Anatomy trains : myofascial meridians for manual and movement therapists. Edinburgh: Churchill Livingstone; 2001.
18. Wilke J, Krause F, Vogt L, Banzer W. What is evidence-based about myofascial chains: a systematic review. Arch Phys Med Rehabil 2016;97:454–61.
19. Preece SJ, Tan YF, Alghamdi TDA, Arnall FA. Comparison of pelvic tilt before and after hip flexor stretching in healthy adults. J Manipulative Physiol Ther 2021;44:289–94.
20. Kendall FP. Muscles : testing and function with posture and pain. 5th ed. Baltimore: Lippincott Williams & Wilkins; 2005.
21. Neumann DA. Kinesiology of the musculoskeletal system: foundations for physical rehabilitation. St. Louis: Mosby, Inc.; 2002.
22. Joshi G, Pathak H, Bagade VK, Naidu S. The effect of heel height on balance, lumbar lordosis and core muscle strength among young healthy indian females. Int J Health Sci Res 2024;14:135–42.
23. Younas AS, Tanveer F, Sharif F, Waseem I, Mahmood W, Ahmad A. Association of low back pain with the use of high heel in ladies: a systematic review (2014–2020). Anaesthesia, Pain & Intensive Care 2023;27:681–8.
24. Irsyam I, Ketaren A, Putra R, Tendean S, Budisantoso A. Contributing factors to musculoskeletal disorders in women who routinely use high heels. Bali Med J 2022;11:711–4.
25. Barnish MS, Barnish J. High-heeled shoes and musculoskeletal injuries: a narrative systematic review. BMJ Open 2016;6: e010053.
26. Kerrigan DC, Johansson JL, Bryant MG, Boxer JA, Della Croce U, Riley PO. Moderate-heeled shoes and knee joint torques relevant to the development and progression of knee osteoarthritis. Arch Phys Med Rehabil 2005;86:871–5.
27. Hong WH, Lee YH, Lin YH, Tang SF, Chen HC. Effect of shoe heel height and total-contact insert on muscle loading and foot stability while walking. Foot Ankle Int 2013;34:273–81.
28. Yung-Hui L, Wei-Hsien H. Effects of shoe inserts and heel height on foot pressure, impact force, and perceived comfort during walking. Appl Ergon 2005;36:355–62.