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Association between high-heeled shoes of varied heel height and bladder neck elevation in women: An exploratory study

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Abstract

Objectives: To evaluate the relationship between high-heeled shoes of varied heel height and bladder neck elevation in women.

Methods: A cross-sectional, exploratory design was applied. Twenty-three continent 18-49-year-old women performed pelvic floor muscle (PFM) contractions while standing in high-heeled shoes of varied heel height. Transabdominal ultrasound was used to evaluate bladder neck elevation in ventral-cranial direction from the resting position during maximum voluntary contraction (MVC) of pelvic floor muscles.

Results: Significantly greater bladder neck elevation was demonstrated in neutral ankle position compared to the two- (0.27 [95% CI 0.14 to 0.39] $p < 0.001$) and three-inch high-heeled conditions (0.37 [95% CI 0.21 to 0.53]) $p < 0.001$). A non-significant association was found between lumbopelvic angle and bladder neck elevation in the ankle dorsiflexion and the two- and three-inch high-heeled conditions.

Conclusion: Significantly lower bladder neck elevation in high-heeled conditions indicates that pelvic floor muscle contraction to elevate bladder neck might not be as strong while wearing high-heel shoes as it is while standing bare feet. Further studies with larger sample size are required to evaluate the possible relationship between varied heel height, bladder neck elevation and urinary incontinence in women.

Key words: ankle position; high heels; lumbar lordosis; pelvic floor muscle; pelvic tilt.

Trial registration: Australian New Zealand Clinical Trials Registry (ACTRN12617001463369).

Introduction

Pelvic floor muscle (PFM) laxity can result in hypermobility of bladder neck [1, 2]. Correct positioning of the bladder neck is crucial for equal transmission of increasing intra-abdominal pressure to the bladder and urethra [1-3]. Increases in intra-abdominal pressure that occur during strenuous activities (strenuous exercise, sneezing, coughing or laughing) are transmitted to urethra and can enhance urethral closure, provided the bladder neck position is above the pelvic floor [1, 3, 4]. However, if the pelvic floor is higher than the bladder neck position, greater pressure is transmitted to the bladder than to the urethra, reducing the urethral closure and continence status [1, 3].

Bladder neck position at rest and during voluntary contraction in upright position in various populations (nulliparous, primiparous, pregnant, continent and incontinent women) is described in literature [1, 2, 5-10]. Miller et al [5] found that bladder neck position is dorsal-caudal (backwards and downwards) at rest in women with urinary incontinence, relative to their continent counterparts [1]. Several studies showed that bladder neck position during voluntary PFM contraction was elevated in ventral-cranial direction [1, 6-8, 10]. Meyer et al showed that the bladder neck position in upright position was lower in incontinent and postpartum women compared to nulliparous continent and parous women [10]. Despite changes in bladder neck position in upright position, to the best of our knowledge, no studies have investigated bladder neck position at rest and during maximum voluntary contraction (MVC) of PFM in women while standing in high-heeled shoes.

Use of high-heeled footwear began more than 1000 years ago and resulted in the development of changes in gait, posture and the kinematics and kinetics of the spine, pelvis, hip, knees, and ankle [11, 12]. 37% to 69% of women are reported to use high-heeled shoes daily [11, 13, 14]. 59% of them wear these high-heeled shoes continuously for about 1-8 hours/day [15, 16] and most women wearing high-heeled shoes with heel height more than 5 cm [17, 18]. In a survey of 1056 Chinese women in Hong Kong in 2010, 226 (24%) women always wore high-heeled shoes and 453 (42.9%) women wore them on some days of the week [19].

Previous studies have reported that high-heeled shoes force ankles into plantar flexion [14, 20, 21]; obvious increases in plantar flexion during high-heel wearing was identified in several studies [14, 21-23]. Research evidence has found significant associations between ankle positions (neutral, dorsiflexion and plantar flexion) and PFM activity in women [24-26]. To date, there are three published articles describing the findings from research evaluating the influence of ankle position on resting and maximum voluntary contraction (MVC) of PFMs [24-26]. One of these was performed using women with stress urinary incontinence (SUI), and found lower MVC in PFMs during ankle plantar flexion, relative to neutral ankle position and dorsiflexion in standing [24]. A second study also use women with SUI, and found lower MVC in PFMs during posterior pelvic tilt created by passive plantar flexion (platform set at 15° under heels), relative to anterior pelvic tilt created by passive dorsiflexion (platform set at 15° under forefoot) [26]. However, a third study using continent women found greater MVC in PFMs during ankle plantar and dorsiflexion, relative to a neutral ankle position [25]. Although the results to date are somewhat contradictory, as a group these studies indicate that ankle position influence PFM activity.

Ankle positions are proposed to influence PFM activity via their effect on lumbar lordosis and pelvic inclination (lumbopelvic posture) [24-27]. Hypo-lordosis and related posterior tilt of pelvis created by dorsiflexion is proposed to cause the sacrum to move in an anterior and inferior direction and pubis in a posterior and superior direction, drawing closer the attachments of the pubococcygeus muscle (key PFM), resulting in shortening of the PFM and elevating the urethral support [24, 26, 27]. However, in hyperlordosis, the reverse of this is thought to occur, causing a stretching of the muscle and decrease in urethral support [24-26]. Induced hyper-and hypolordosis have been also found to affect vaginal closure pressure [27]. Significantly lower intra-vaginal pressure measured using vaginal manometry was identified in induced hyperlordotic posture compared to hypolordoctic posture in standing and during increases in intra-abdominal pressure (coughing, lifting heavy load) [26]. Given these findings, we hypothesize that high-heeled shoes with heel height of 5-8 cm inducing 20-29° of plantar flexion will reduce PFM activity resulting in decreased bladder neck elevation in women.

Given these considerations, to our knowledge, no studies have evaluated the association between high-heeled shoes of varied heel height and bladder neck mobility in women. This study will, therefore, investigate:

(1) The influence of high-heeled shoes of varied heel height (two-and-three inches heel height) on bladder neck elevation in ventral-cranial direction from the resting position during MVC of PFMs; and to compare the bladder neck elevation in high-heeled conditions with neutral ankle position.

(2) The association between lumbopelvic angle and bladder neck elevation during MVC of PFMs in high-heeled and induced dorsiflexion conditions.

Methods

This study was a preliminary, prospective, cross-sectional observational design evaluating the influence of high-heeled shoes on bladder neck elevation in women. This study was conducted between October 2017 and December 2017. The study was approved by the institutional review board (HSEARS20171016003).

Participants

Study participants included non-pregnant 18-49-year-old women without any type of urinary incontinence. Women with previous pelvic surgeries, recent childbirth (< 3 months), diabetes, smoking history, chronic lung diseases, neurological problems, and urinary tract infection were excluded from the study.

Outcome measures

Bladder neck elevation in ventral-cranial direction from the resting position during MVC of the PFMs was measured using transabdominal ultrasound (TAS; GE Healthcare/Logiq TAS system). All the study participants were assessed for bladder neck elevation with a full bladder in standing by the same examiner. The ultrasound-scanning probe was placed vertically in the midsagittal plane at the supra-pubic region (see Fig. 1c). A marker was placed at the position of the bladder neck at rest (see Fig. 1a) and displacement from resting position during voluntary PFM contraction (see Fig. 1b) was measured in millimeters. Prior to testing, the study participants were briefed on the importance of having full bladder for TAS. They were requested to void 1-hour prior to testing and then drink 500 ml of water and not urinate until after the end of test [7]. Prior to measurements with TAS, the physiotherapist made women to perform preliminary contractions to ensure correct contraction of the PFMs. Measurement of PFM activity with TAS was conducted by a physiotherapist with expertise in TAS and assisted by another physiotherapist with specialist experience in women's health.

The psychometrically valid and reliable spinal mouse (Idiag, Fehraltdorf, Switzerland) was used to measure lumbar lordosis and pelvic inclination (tilt) [28, 29]. Measurements with the spinal mouse were performed by the principal investigator (PK). For each high-heel condition and dorsiflexion, the position of the lumbar spine (T12 to S1) [30] and the position of the sacrum and hips were recorded. For lumbar angles, negative values corresponded to lumbar lordosis (see Fig. 1d). With regard to pelvic inclination, 0° represented a neutral pelvis (no tilt). Hence, a greater angle indicated an anterior pelvic tilt and a lower angle/negative value indicated a posterior pelvic tilt [29] .

Procedure

Written informed consent was obtained from all interested women. Measurement of bladder neck elevation with TAS was performed while standing with four different ankle positions: (1) neutral ankle position (i.e., bare feet); (2) ankles in dorsiflexion (see Figure 2a); (3) high-heeled shoes with a heel height of 5.08 cm (2 inches; see Figure 2b); and (4) high-heeled shoes with a heel height of 7.62 cm (3 inches; see Figure 2c). Prior to measurements during the high-heel conditions, women wore the two-and-three inches high-heeled shoes for 30 minutes each in order for postural adjustments to occur. A five minute rest period was provided between the two high-heeled conditions. Both high-heeled shoes (2 and 3 inches) were provided by the research team. A five-minute rest period was allowed between measurements in the consecutive ankle conditions.

Data analysis

Descriptive statistics were computed for the sociodemographic data to describe the sample. Within-group data of TAS imaging of bladder neck elevation during MVC of PFMs across four conditions were compared using one-way repeated measures analysis of variance (ANOVA). Post-hoc analysis was performed using Bonferroni correction. Bonferroni correction was preferred over other post-hoc tests such as Sidak and Tukey, as it is robust in terms of power and control of the Type I (incorrectly rejecting a true null hypothesis) error rate. Bivariate (Pearsons's) correlation analysis was used to measure the strength of the association between lumbopelvic angle and induced dorsiflexion and two-and-three inches high-heeled conditions. Considering bladder neck elevation in neutral ankle position as reference, the difference between the reference and induced dorsiflexion and high-heeled conditions (two-and-three inches) were correlated with lumbopelvic angle in the respective ankle conditions. Statistical significance was established at $\alpha = 0.05$.

Results

Twenty-five women volunteered to be in the study; two women declined participation. The remaining twenty-three women were included in the study. Participant sociodemographic information is reported in Supplementary Table 1. The mean age of participants was 30.6 years (SD = 12.3). The study participants represented a variety of ethnic groups. Fifty-two percent (12/23) of the participants reported that they were occasional users of high-heeled shoes, wearing high-heeled shoes on an average of 2 days a week, for 6 hours each day.

The mean differences in bladder neck elevation during MVC of PFMs, between various ankle conditions are reported in Table 1. As can be seen, significantly greater bladder neck elevation during MVC of PFMs was found in neutral ankle position compared to two inches (0.27 [95% CI 0.14 to 0.39] $p < 0.001$) and three inches high-heeled conditions (0.37 [95% CI 0.21 to 0.53]) $p < 0.001$). Significantly greater bladder neck elevation during MVC of PFMs was also demonstrated in neutral ankle position compared to ankle dorsiflexion (0.25 [95% CI 0.12 to

0.38]) $p = 0.02$). There was no significant difference in bladder neck elevation between ankle dorsiflexion and two (-0.1 [95% CI -0.18 to 0.14] $p = 0.83$) or three inches (-0.12 [95% CI -0.25 0.12] $p = 0.07$) high-heeled conditions.

The mean scores of lumbopelvic angle in standing with neutral ankle position, induced dorsiflexion and high-heeled (two-and three inches) conditions are reported in Table 2. The correlation coefficients for the association between lumbopelvic angle and the aforementioned three ankle conditions are presented in Supplementary Table 2. Pearson's correlation coefficient analysis found weak and nonsignificant associations between lumbopelvic angle and the aforementioned ankle conditions.

Discussion

This preliminary exploratory study sought to (1) investigate the effect of high-heeled shoes of two-and-three inches heel height on bladder neck elevation during MVC of PFMs; (2) compare the bladder neck elevation in high-heeled conditions with neutral ankle position; and (3) evaluate the associations between lumbopelvic angle and high-heeled shoes (two-and-three inches) and induced dorsiflexion. The results demonstrated significantly greater bladder neck elevation during MVC of PFMs in standing with neutral ankle position, relative to standing with two-and-three inches high-heeled shoes. Significantly greater bladder neck elevation during MVC of PFMs was also identified when participants were standing in a neutral ankle position, relative to induced ankle dorsiflexion while standing. However, no significant difference in bladder neck elevation was identified between induced ankle dorsiflexion and the two or three inches high-heeled conditions. Correlation coefficient analysis revealed no significant associations between lumbopelvic angle and two-and-three inches high-heeled conditions or induced ankle dorsiflexion.

Being one of the major components of the supportive structure of the stress continence control system, the activity of the PFMs is crucial to maintaining continence and urethral support during increases in intra-abdominal pressure during activities such as coughing, sneezing, and lifting. It is understood that the normal function of the urethral support system requires contraction of the PFMs (primarily levator ani), which provides support for urethra [31]. Previous clinical studies [24, 26] and the systematic review [32] by the current research team found greatest MVC of PFMs in neutral ankle position, relative to the plantar flexion condition. Study findings herein indicate that pelvic floor muscle contraction to elevate bladder neck might not be as strong while wearing high-heel shoes as it is while standing bare feet..

The current study did not identify a specific pattern of lumbar lordosis or pelvic tilt in plantar flexion (i.e., high-heeled conditions) or induced dorsiflexion. Although the mean scores of lumbopelvic angle was indicative of an increase in lumbar lordosis, our study found no statistically significant associations between lumbopelvic angle and high-heeled conditions or induced dorsiflexion. It is possible that the lack of significance in the associations examined could have been due to (1) the spinal mouse being been less sensitive to minute changes in lumbopelvic angle across the three ankle conditions, (2) the relatively small size of the study sample, or (3) the rest period between each ankle condition being insufficient to allow for realignment of the spine.

This study is the first to investigate the relationship between high-heeled shoes of varied height on bladder neck elevation in women. Of importance is the use of the reliable and valid TAS for measurement of bladder neck elevation [33]. In addition, the displacement of bladder with a correct PFM contraction is easy to identify and distinguish from incorrect PFM contraction with TAS [33]. This study does have some limitations which should be considered when evaluating the findings. The order of ankle positions in which bladder neck elevation was evaluated was not randomized. It is possible that women may have learned to perform correct PFM contraction in subsequent ankle positions. Also, the sample size was relatively low, which limits power for detecting potentially real associations among the study variables in the population. Finally, the generalizability of results is limited by the population characteristics of the study; specifically, the majority of the participants in this study were non-smokers, highly educated, and young. Future researchers in this area would do well to address these limitations by (1) randomly assigning the order of the different ankle positions, (2) using larger sample sizes, and (3) recruiting study participants that are more representative of the population.

Conclusions

Despite the study's limitations, the findings provide new and important results with respect to the potential impact of different ankle positions on bladder neck elevation. Specifically, the findings indicate that when standing, the bladder neck elevation during MVC of the PFMs is significantly greater during neutral ankle positions, relative to two-and-three inches high-heeled shoes and induced dorsiflexion. Significantly lower bladder neck elevation in high-heeled conditions indicates that pelvic floor muscle contraction to elevate bladder neck might not be as strong while wearing high-heel shoes as it is while standing bare feet. Further studies with larger sample size are required to further explore the relationship between varied heel height and bladder neck elevation in various populations (such as pregnant, postpartum, multiparous and nulliparous women).

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Table 1. Sociodemographic characteristics of participants.

Characteristics	***n* = 23**
Age (years), mean (*SD*)	30.6 *(12.3)*
Ethnicity n *(%)*	
Chinese	13 *(57)*
Indian	2 *(9)*
Mexican	1 *(4)*
Korean	5 *(22)*
European	1 *(4)*
Philipino	1 *(4)*
Marital status n *(%)*	5 *(20)*
Parity n *(%)*	5 *(20)*
High heel users	
Regular n *(%)*	1 *(4)*
Occasional n *(%)*	12 *(52)*
Non-users n *(%)*	10 *(44)*

Table 2. Mean differences in bladder neck elevation in different ankle conditions.

Ankle positions	**Paired Differences (n = 23)**		
	Mean (SD)	**95% Confidence Interval**	***p***
Neutral ankle – 2" High-heel	0.27 (0.28)	0.14 to 0.39	< 0.001*
Neutral ankle – 3 " High-heel	0.37 (0.36)	0.21 to 0.53	< 0.001*
Neutral ankle – Induced ankle DF	0.25 (0.29)	0.12 to 0.38	< 0.001*
2" High-heel – Induced ankle DF	-0.01 (0.37)	-0.18 to 0.14	0.832
3 " High-heel – Induced ankle DF	-0.12 (0.30)	-0.25 to 0.01	0.073

*: significant *P* value; Note: DF = Dorsiflexion.

Table 3. Mean scores of bladder neck elevation and lumbopelvic angle across the ankle conditions.

Ankle position	MVC Mean (SD)	Lumbar lordosis Mean (SD)	Pelvic tilt Mean (SD)
Neutral Ankle	1.07 (0.52)	-17.28 (18.76)	21.85 (5.72)
Induced Dorsiflexion	0.82 (0.43)	-26.07 (5.28)	21.78 (4.07)
Two inches high-heeled shoes	0.81 (0.57)	-24.57 (0.67)	22.07 (5.82)
Three inches high-heeled shoes	0.69 (0.37)	-22.35 (6.22)	19.21 (4.06)

Table 4. Zero-order Pearson correlation coefficients between lumbopelvic angle and the difference between MVC reference value, and corresponding values of induced ankle dorsiflexion, and two-and-three inches high-heeled conditions.

Ankle condition	**MVC (Ankle neutral -DF) *r* (p-value)**	**MVC (Ankle neutral - two inches high-heeled condition) *r* (p-value)**	**MVC (Ankle neutral – three inches high-heeled condition) *r* (p-value)**
LL in DF	-0.21 (0.46)	NR	NR
LL in two inches high-heeled shoes	NR	0.03 (0.89)	NR
LL in three inches high-heeled shoes	NR	NR	-0.41 (0.15)
PT in DF	0.41 (0.15)	NR	NR
PT in two inches high-heeled shoes	NR	0.11 (0.72)	NR
PT in three inches high-heeled shoes	NR	NR	0.37 (0.20)

Note: DF= Dorsiflexion; LL = Lumbar Lordosis; MVC = Maximum Voluntary Contraction; PT = Pelvic Tilt; NR = Correlation not relevant to study objective.

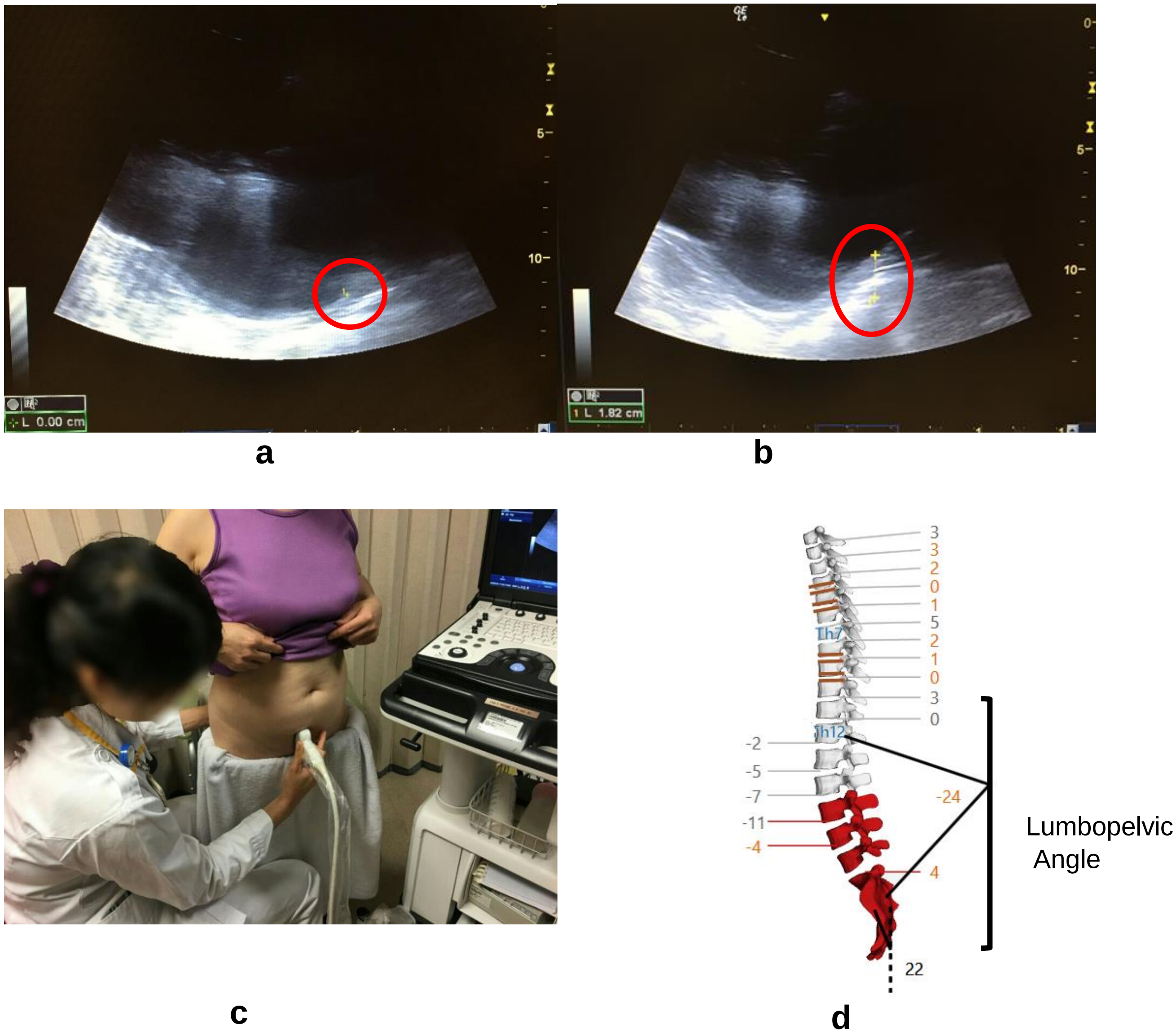

Figure 1. Bladder neck mobility at (a) rest (b) maximum voluntary contraction (c) Ultrasound probe placement and measurement (d) spinal mouse recordings of lumbopelvic angle

a b c

Figure 2. Assessment of bladder neck mobility using transabdominal ultrasound (a) during induced dorsiflexion, (b) while wearing two inches high-heeled shoes, and (c) while wearing three inches high-heeled shoes.