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Research Article

Effects of Bed Height on Balance during Ingress and Egress from a Hospital Bed

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Abstract

Background: Patient falls from hospital beds are a major safety concern in hospitals, with bed ingress and egress alone responsible for most falls. Despite previous insights, no research has systematically assessed how bed height affects balance during ingress and egress. **Aims & Objectives:** Our study aimed to quantify individuals' balance during hospital bed ingress and egress at different heights by analyzing the components of ground reaction forces. **Methods:** Based on the experiment conducted in a previous study, ground reaction forces were collected from twenty-four healthy adults during ingress and egress from a hospital bed at different heights. Component force vectors for each foot were evaluated, and data was statistically analyzed using a two-factor Analysis of Variance (ANOVA) with follow-up post-hoc Tukey tests. **Results:** Significant imbalance was found in the medial-lateral direction for both feet at all bed heights during ingress and egress trials. A more balanced approach between the two feet was observed for the longitudinal direction, with mid-range heights demonstrating more optimal ground reaction forces. **Conclusion:** Our results revealed that individuals had better balance in the longitudinal direction for medium bed heights (51 to 66 cm) during ingress and egress. We provided further insights into the specific balance impairment during ingress and egress trials, indicating some left-right feet differences. In summary, medium bed heights (51 to 66 cm) resulted in the most stable balance with fewer differences between the right and left feet, suggesting that low and high bed heights may place patients at a higher risk of falling.

Keywords: Healthcare Ergonomics; Human Biomechanics; Patient Falls; Patient Well-Being; Fall Injury; Balance

Introduction

Inpatient falls are the most common adverse events in hospitals, with incidence rates between 2.4 and 9.1 per one thousand patient-days [1-3]. Annually, an estimated 700,000 to 1 million hospitalized patients experience falls [4]. These falls lead to extended hospital stays and increased healthcare costs for patients, hospitals, and insurers [5-7]. Patients with fall-related injuries stay in hospitals about eight days longer and incur approximately $13,000 more in costs compared to non-fallers [8,9]. Psychological impacts, such as fear and diminished confidence, also accompany fall-related injuries [10].

Patient falls in hospital and long-term care settings often involve interactions with hospital beds [11]. Falls during ingress (getting into bed using a stand-to-sit motion) and egress (getting out of bed using a sit-to-stand motion) have been a crucial safety concern for decades [12,13]. Studies indicate that bed ingress and egress alone may contribute up to 77% of total patient falls [14-17]. For instance, Hitcho et al., 2004 [18] analyzed approximately 200 cases of falls in hospital settings and found that around 10% (20 cases) occurred specifically during egress from a hospital bed.

Balance is a crucial factor in safely executing a sit-to-stand task without falling [19]. Research has shown that loss of balance is the primary cause of falls among elderly individuals, and preventing balance loss during bed ingress and egress can greatly reduce fall incidents [20]. In acute care hospital settings, the loss of balance due to unplanned and sudden egress from beds is the most common cause of falls [21]. This highlights the limitations of fall prevention strategies that focus solely on low bed heights. Effective fall prevention should address the biomechanical stability and balance of patients during bed ingress and egress. Additionally, optimizing hospital bed heights based on patient stability and balance may lead to better interventions for fall prevention.

Various studies have concluded that lowering hospital bed heights can reduce fall injuries, leading to this approach being widely promoted and adopted in healthcare settings [22-24]. The rationale is that a fall from a lower height would result in fewer injuries. However, this reasoning applies primarily to patients rolling out of bed rather than those ingressing or egressing the hospital bed. Lower hospital bed heights increase the likelihood of falls during ingress and egress, imposing significant ergonomic risks by forcing patients' knees and hips into biomechanically disadvantaged postures. Egressing from a lower bed height demands increased upper body motion, potentially compromising balance. Therefore, maintaining postural stability during bed egress is crucial, particularly as the body's center of mass shifts anteriorly [25]. Higher bed heights pose challenges during ingress, where patients rely on their hands or even jump into the bed, both compromising balance and increasing fall risks. Conversely, extremely low bed heights impose different biomechanical risks, exerting higher torque on knee and hip joints, critical for safe ingress [26].

Despite these insights, there remains a gap in the literature concerning the assessment of individuals' balance during ingress and egress from hospital beds at different heights. To our knowledge, no study has systematically evaluated the impact of varying hospital bed heights on patient balance during ingress and egress interactions. Therefore, our study aims to analyze individuals' balance as they ingress and egress from hospital beds of different heights by conducting a detailed evaluation of participants' ground reaction forces in these movements.

Methodology

Study Overview

Our study is based on prior research that investigated ground reaction forces during ingress and egress from hospital beds across different heights [25]. The study involved twenty-four healthy adults, focusing on bed heights ranging from 43 cm to 86 cm. Detailed information regarding the experimental apparatus, study participants, and setup specifics is comprehensively covered in the article by Usmani et al., 2023 [25].

Procedures

Healthy individuals participated in ingress and egress activities on a hospital bed set at varying heights. During these ingress/egress movements, participants positioned one foot on each of the adjacent force plates. All trials were conducted with participants facing away from the bed, and bed heights were randomized for each participant. For each bed height, participants first performed an ingress trial, which was considered complete once the subject was in a flat supine position on the hospital bed. Following ingress, subjects performed the egress trial at the same bed height. Each set of ingress and egress trials was performed twice. Bed heights ranged from 43 cm (17 inches) to 86 cm (34 inches), with adjustments made in increments of approximately 2.54 cm (1 inch). Upon completion of the study, participants received a compensation for their involvement.

Outcome Variables

Ground reaction forces in the anterior-posterior-A-P (x), medio-lateral-M-L (y), and longitudinal (z) directions were collected for each foot (left and right in participant perspective) using the force plates during all trials. Forces were measured in Newtons (N) for each foot in each direction, and their roles in the combined ground reaction force were evaluated.

Statistical Analysis

A two-factor Analysis of Variance (ANOVA) was employed to assess the effects of bed height and nature of trial (ingress/egress) for the components of ground reaction forces (in A-P, M-L, and longitudinal directions) for the right and left force plates, and the balance of individuals, quantified as the percentage contribution of each force component (left/right force plates) to the overall combined force (in the same direction), using Statistical Analysis System (SAS Institute, Cary, NC). Significant main and interaction effects were analysed further through post-hoc Tukey Studentized t-tests.

Results

Tables A1 and A2 in the Appendix summarize the Analysis of

Variance (ANOVA) findings. The main effect of bed height was significant for all components and resultant ground reaction forces except the resultant ground reaction force in the longitudinal (z) direction. However, the interaction effects of bed height by nature of trial (ingress/egress) were significant for components and resultant of ground reaction forces in the M-L and longitudinal directions.

	F(x) Left	F(y) Left	F(z) Left	F(x) Right	F(y) Right	F(z) Right	F(x) Resultant	F(y) Resultant	F(z) Resultant
HEIGHT	**<.0001**	**<.0001**	**0.004**	**<.0001**	**<.0001**	**0.02**	**<.0001**	**<.0001**	0.78
HEIGHT* INGRESS-EGRESS	0.69	**<.0001**	**<.0001**	0.48	**<.0001**	**<.0001**	0.41	**<.0001**	**<.0001**

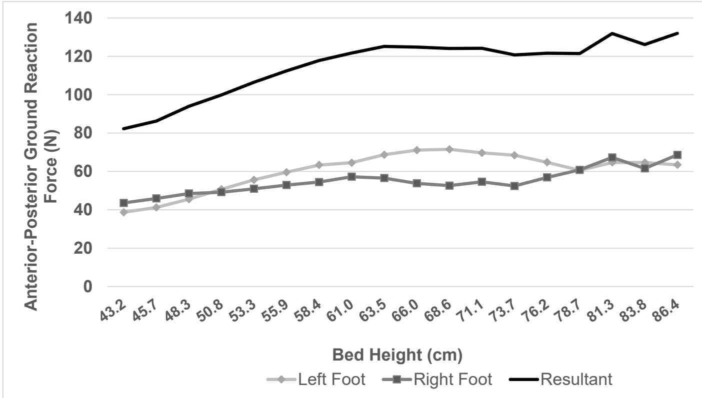
Table A1: Summary of Analysis of Variance Tests (p-value) for Forces (F(x/y/z) Left/Right: Ground Reaction Force (in x/y/z direction) on left/right force plate; F(x/y/z) Resultant: Resultant Ground Reaction Force (in x/y/z direction) on both force plates. Bold Values determine that the interaction between the two variables is significant (p-value<0.05).

	% F(x) Left	% F(y) Left	% F(z) Left
HEIGHT	**0.0003**	**<.0001**	**<.0001**
HEIGHT* INGRESS-EGRESS	0.12	**<.0001**	0.08

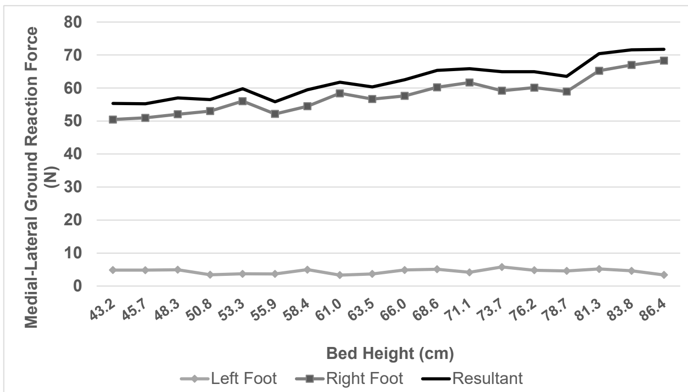
Table A2: Summary of Analysis of Variance Tests (p-value) for Percentage (%) of Forces (Percentage of Ground Reaction Force on the left force plate to the combined Ground Reaction Forces on both force plates, the right would be 100%-left). Bold Values determine the significance (p-value<0.05).

When the bed height ranged from 43 cm to 51 cm, both the left and right feet contributed equally to the combined ground reaction forces in the A-P direction. In the medium bed height range of 51 cm to 79 cm, the left foot exhibited greater A-P ground reaction forces compared to the right foot. At higher bed heights ranging from 80 cm to 86 cm, both feet contributed equally to A-P ground reaction forces. Figure 1a illustrates the trends in ground reaction forces from the left and right force plates, as well as the resultant ground reaction forces. In the M-L direction, the right foot predominantly contributed to the ground reaction forces, while the left foot's contribution was minimal (Figure 1b). For ground reaction forces in the longitudinal direction, a comparatively higher ground reaction force was observed for the right foot compared to the left foot when bed heights were either too low (43 cm to 62 cm) or too high (above 80 cm). Within the bed height range of 62 cm to 80 cm, both feet contributed equally to the ground reaction forces (Figure 1c).

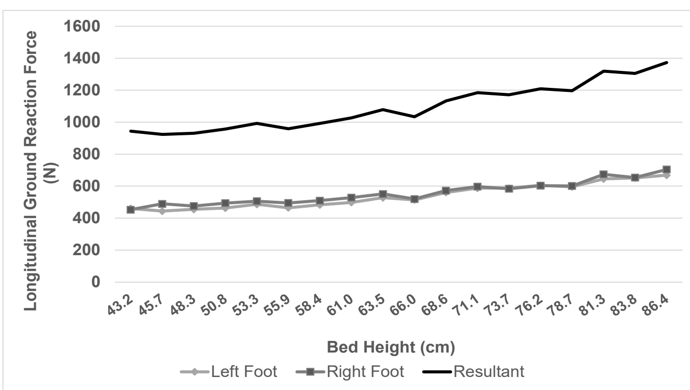
Following the significant interaction effects of bed height by nature of trial (ingress/egress) on each component of ground reaction forces in the medial-lateral and longitudinal directions, the left foot produced negligible ground reaction force across all bed heights in the medial-lateral direction. This indicates that the right foot alone contributed the majority of ground reaction force in the medial-lateral direction for both ingress and egress (Figure 2a). In the longitudinal axis, while the left and right feet contributed equally during egress, the trends for ingress showed that the left foot produced slightly less ground reaction force than the right foot at all bed heights, except when the height of the hospital bed was in the range of 66 to 69 cm. For these heights, the left and right feet had equal ground reaction forces during ingress trials as well (Figure 2b).



(a)

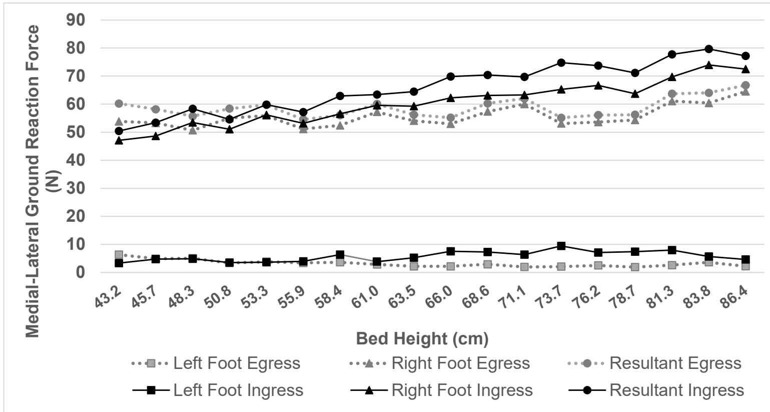


(b)

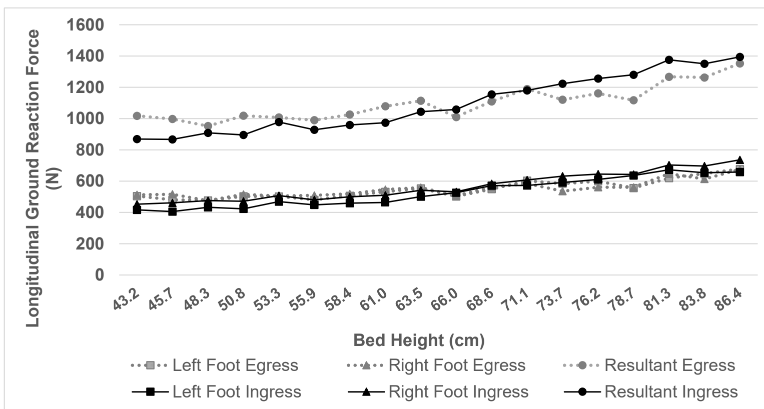


(c)

Figure 1: Variation of Ground Reaction Force (in Newton, N) in **(a)** Anterior-Posterior direction (Fx), **(b)** Medial-Lateral direction (Fy), and **(c)** longitudinal direction (Fz) with Bed Height (in cm); for left and right feet along with the resultant ground reaction forces on both force plates



(a)



(b)

Figure 2: Variation of Ground Reaction Force (in Newton, N) in **(a)** medial-lateral direction (Fy) and **(b)** longitudinal direction (Fz) with Bed Height (in cm); during ingress and egress for left and right force plates along with the resultant ground reaction force on both force plates

Percentage contributions of the left foot are evaluated and depicted in the results since the right foot would complement the left (e.g., 100% - left%). For the ground reaction force in the anterior/posterior axis, the contribution of the left foot ranged between 50% and 60% across all bed heights. In the medial-lateral axis, the left foot contributed less than 10% across all bed heights. However, in the longitudinal axis, both feet contributed almost equally at 50% (Figure 3).

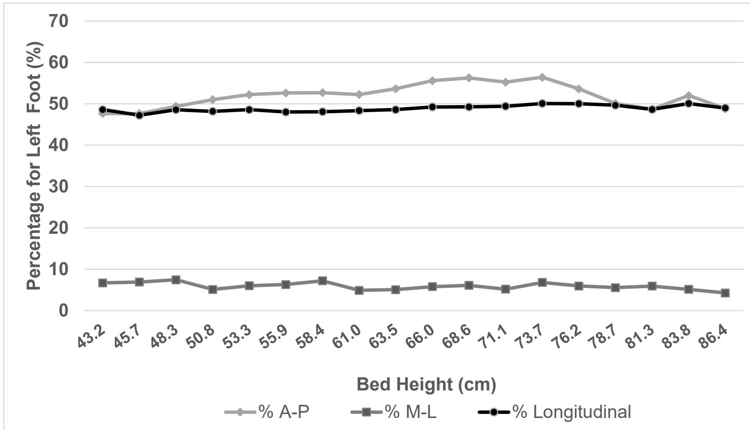


Figure 3: Variation of percentage (%) for left foot for Ground Reaction Forces in anterior-posterior direction (Fx), medial-lateral direction (Fy), and longitudinal direction (Fz) with different bed heights (in cm).

The interaction effect of bed height by trial type (ingress/egress) on the percentage of ground reaction force (in the medial-lateral direction) produced by the left foot was significant. During egress, the left foot contributed less than 10% to the resultant ground reaction force in the medial-lateral direction (medial/lateral axis) (Figure 4). Although the interaction effect of bed height by trial type was not significant for the percentage of ground reaction force produced by the left foot in the longitudinal direction or the anterior-posterior direction, the left foot contributed nearly 50% in the longitudinal direction across different bed heights. For the ground reaction force in anterior-posterior direction during egress, the left foot's contribution varied with height: it fluctuated around 50% for lower heights (43-58 cm), remained exactly 50% for medium heights (58-65 cm), and ranged from 56% to around 42% for higher heights (65-86 cm). During ingress, the left foot's contribution in the medial-lateral direction was consistently less than 10%, while it remained around 50% in the longitudinal direction across all heights. In the anterior-posterior direction, the left foot's contribution started below 50% for lower heights (43-51 cm), increased linearly to 61% at 69 cm bed height, and then decreased to around 50% at the highest bed height (86 cm).

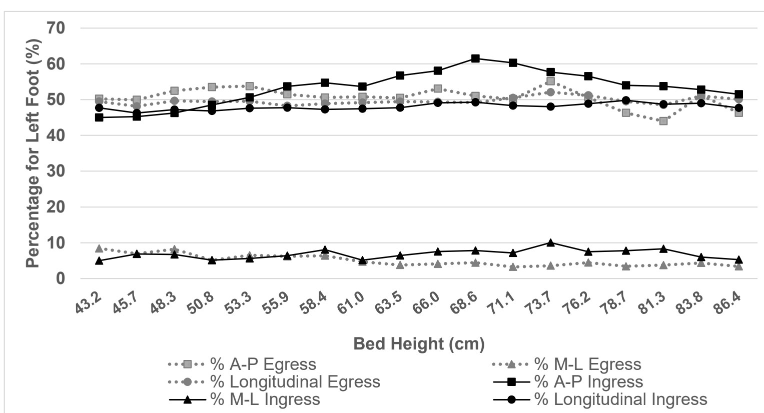


Figure 4: Variation of percentage (%) for left foot for Ground Reaction Forces in anterior-posterior direction (Fx), medial-lateral direction (Fy), and longitudinal direction (Fz) with different bed heights (in cm); during ingress and egress.

Discussion

Ingressing (getting into bed using a stand-to-sit motion) and egressing (getting out of bed using a sit-to-stand motion) from a hospital bed can be challenging and hazardous for patients, particularly those with gait impairments and weakened muscles. Although substantial evidence indicates that falls and injuries near the bedside remain a significant issue, the biomechanics of bed-related activities contributing to fall risk and other injuries have not been thoroughly examined. Previous studies have highlighted balance as a critical factor in successful sit-to-stand transitions without falling [27-29]. One study reported that loss of balance is the primary cause of falls in elderly patients, and that falls can be prevented if patients can maintain balance during ingress and egress from a bed [30]. Our study focused on specific factors impacting balance during ingress and egress from a hospital bed. We aimed to investigate how bed height influences balance concerning ground reaction forces and the contribution from each foot towards the resultant ground reaction force.

Our controlled laboratory study provided a quantitative assessment of balance during ingress and egress from a hospital bed by analyzing ground reaction forces in the anterior-posterior (x-direction), medial-lateral (y-direction), and longitudinal (z-direction) directions for each foot. Results showed pronounced asymmetry in medial-lateral forces at all the bed heights, highlighting varying balance requirements between the left and right feet. Minimal left foot contribution in the medial-lateral axis at all bed heights suggested a shift towards right-sided balance among participants. These findings are somewhat consistent with Christman et al., 2015 [31], who noted significant impacts on medial-lateral stance-off momentum during similar bed interactions. Distinct patterns in ground reaction forces along the anterior-posterior axis (x-direction) for the left and right feet were identified during ingress and egress from the bed. Participants favored their left side at medium bed heights (51-79 cm) and exhibited a more balanced stance at higher heights (79-86 cm) (Figure 3). One possible explanation for this observation is that the increased bed height may have prompted the subjects to pay greater attention to the movement, as they perceived higher bed heights to be more difficult and unstable [25]. The technique used by the participants may have also influenced the balance between the two feet (e.g., hopping out of the bed, swinging one leg more than the other one).

Moreover, our results indicated better balance in the longitudinal axis (z-direction) at medium bed heights (66-70 cm) during ingress and egress. However, no consistent relationship emerged between hospital bed height and medial-lateral balance loss. Despite previous research advocating lower bed heights for fall prevention [22-24], our findings did not support optimal balance at lower bed heights. A major reason for this contrast is that these studies mainly focused on falls due to patients rolling out of bed, rather than patients' interactions with the hospital bed. Consistent with other studies examining patient-bed interactions in falls [26, 32, 33] our study revealed that mid-range bed heights (51-66 cm) offered the best balance, with more even contributions from both feet to ground reaction forces in longitudinal (z-direction).

The findings of our study suggests that balance is most affected in the medial-lateral axis, with individuals at a higher risk of toppling towards the right side of their body. Evidence includes the consistently low contribution of the left force plate to total ground reaction force (less than 10%) in the medial-lateral direction across all bed heights (Figure 3). Additionally, during egress at medium bed heights, even distribution of ground reaction forces between both force plates in the longitudinal direction supports Usmani et al.'s, [25] claim that the optimal height for hospital beds lies within the medium range (51-66 cm). These results provide insight into specific areas of balance impairment during ingress and egress tasks, potentially guiding future interventions to reduce fall risk among individuals in hospital settings.

Limitations

Several potential limitations should be considered when interpreting the findings of this study. First, all participants were young and in good health, which may have provided more favorable conditions for balance. Patients in hospital or long-term care settings, who typically have poorer balance, may exhibit different patterns in ground reaction forces at various bed heights. Nevertheless, middle bed heights are generally expected to offer better postural balance conditions. Second, the participants egressed and ingressed the bed from the same side (right side) for all heights, which could have influenced the balance between the two feet. Third, the participants did not spend extended periods in bed before attempting egress, which could influence balance by affecting biomechanical, vestibular, proprioceptive, and physiological systems. Fourth, the study did not investigate how patients' body dimensions, such as height and weight (including obesity), may influence balance during ingress and egress from the bed. Future research should explore these factors to better understand their impact. Furthermore, environmental factors such as bed surface characteristics and conditions in the surrounding environment (e.g., presence of handrails, lighting, hospital socks with grips on bottom, floor types like carpeting or linoleum) could affect the ease and safety of bed ingress and egress. These factors were not systematically examined in this study but are likely to influence balance outcomes in real-world settings. Our study has laid foundational insights into balance responses during bed-related activities, but further investigation is necessary to comprehensively assess fall risk and optimize safety measures.

Conclusion

We analyzed the ground reaction forces generated by left and right feet during ingress and egress from a hospital bed, focusing on their contribution to the resultant ground reaction force. Our findings highlighted important challenges in maintaining balance at all bed heights in the medial-lateral (y-direction), with no discernible trend across different bed heights. However, individuals exhibited better balance in the longitudinal (z-direction) at medium bed heights (51 to 66 cm) during both ingress and egress from a hospital bed. This explains specific balance discrepancies between the left and right feet and emphasizes the critical role of bed height in affecting balance dynamics. Medium bed heights (51 to 66 cm) were associated with the most stable balance, demonstrating fewer disparities between the ground reaction forces of left and right feet (in longitudinal direction). In contrast, the lowest and highest bed heights posed increased balance issues for patients. Future research should focus on identifying optimal postures and whole-body mechanics that influence these ground reaction forces, aiming to enhance patient safety during bed-related activities.

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Ethical Considerations

Our research is based upon a cross-sectional controlled laboratory study (#2022–0016) that adhered to the principles outlined in the Declaration of Helsinki, and the protocol was approved by the Institutional Review Board at the University of Cincinnati, Cincinnati, OH, USA

Declaration of Competing Interest

All the authors declare that there is no conflict of interest regarding the publication of this article.

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