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Stopping the Slide

How Hospital Bed Design Can Minimize Active and Passive Patient Migration

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Patient migration, or the amount of movement toward the foot of the bed, has been shown to significantly vary because of the mechanical design differences in hospital beds. Previously, the amount of migration was measured immediately following head-of-bed articulation in healthy subjects. This study not only evaluates how much migration occurs immediately after head-of-bed articulation but also measures additional migration during a standard 2-hour repositioning period in subjects with limited mobility. **Key words:** *hospital beds*, *movement*, *patient positioning*, *pressure ulcer*, *shear*

IT IS WELL KNOWN that patients commonly migrate toward the foot of the bed, requiring frequent repositioning. However, the reasons why patients move and the consequences of that movement are not well understood. There are at least 2 contributors to patient migration: bed design and the effect of gravity over time. During head-of-bed (HOB) elevation, the head section of the bed may mechanically push patients down the bed as much as 10.6 cm or as little as 1.5 cm depending on bed design.[1] The additional migration that may occur because of gravity over time has not been studied.

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WHY DOES MIGRATION MATTER TO PATIENTS?

Whether patient migration occurs because of bed design or gravity, there are consequences for both patients and caregivers. Patients may experience increased shear and friction forces and a reduction in therapeutic torso angle.[2] Caregivers may be required to reposition patients up in bed frequently, a patient handling maneuver that has been shown to cause musculoskeletal disorders.[3,4]

Although pressure ulcer etiology is multifactorial in nature, shear forces caused by HOB elevation were defined as one of the primary causes of pressure ulcers as early as 1958 by Reichel.[5] This initial work identified that elevation of the HOB contributed to pressure ulcers in paraplegic patients and suggested that paraplegic patients be positioned as much as possible at 0° HOB elevation, and if the patient required HOB elevation, the number of times the HOB was raised was minimized. Pieper[6] highlighted the etiology associated with this elevation, stating that when the HOB was elevated, the body moved toward the foot of the bed while the resistance generated by the bed surface holds the body in place. This resistance of movement toward the foot of the bed results in potentially large friction forces between the patient's skin and the bed surface with shear occurring at deeper fascial levels of the tissue, leading to the stretching and angulation of blood vessels reducing perfusion.[6]

Oomens and associates[7] reviewed the etiology of suspected deep tissue injuries recently and evaluated ischemia, pressure, and shear as pressure ulcer risk factors. This study indicated that there were 2 basic pathways to cell death and subsequent deep tissue injury. The first mechanism highlighted the impact of ischemia, which changed aerobic metabolism to anaerobic. There was a buildup of waste products and a change in pH, which led to cell death. The other more rapid pathway of cell death was due to direct deformation of tissues, leading to cellular membrane failure and cytoskeletal changes. In a clinical setting, these pathways for cellular damage are likely to be additive.

Cox[8] reported that additional intrinsic pressure ulcer risk factors exist in intensive care unit (ICU) patients. These patient risk factors are related to poor blood flow to peripheral tissues, decreased oxygenation, poor nutrition, and reduced ability to remove metabolic waste. Given these risk factors, ICU patients may be extremely vulnerable to pressure ulcer formation. Hospital beds used in pressure ulcer high-risk environments need to minimize patient migration, thereby reducing shear-based risk factors.

Maintaining patients in a semi-recumbent position is required for prevention of ventilator-associated conditions and enteral feeding protocols. However, as patients migrate, their torso elevation flattens. Wiggermann and associates[2] studied the relationship of migration to torso angle and found that if subjects had a 10-cm movement at 45° HOB, they lost 13.0° of torso angle, and 9.1° with the same distance at 30° HOB.

WHY DOES MIGRATION MATTER TO CAREGIVERS?

Patient migration has been one of the primary reasons that caregivers are required to perform "pull up in bed" maneuvers to maintain proper patient torso angle. These maneuvers have been shown to place strain on the spinal column of caregivers[3,4] at levels of force that induce back injuries.[9] Therefore, minimizing patient migration may be beneficial not only to patients but also to their caregivers.

WHAT IS BEING DONE TO MITIGATE MIGRATION?

Bed manufacturers have developed different designs of HOB pivot joints (the mechanical design that allows the head section to move up and down relative to the seat section of the bed) with the intent of preventing patient migration. However, limited data exists to directly compare the efficacy of those designs. This article describes the second of a 2-part series of experiments aimed at comparing 4 ICU bed designs to evaluate patient migration using a technique called Motion Capture that objectively measures movement. This technique captures video of the specific movement to be studied. This video was then analyzed to determine how much a strategically placed body marker displaced in 3-dimensional space. Motion capture has been popularized by the film industry to accurately depict human and animal movements in animated movies or movies with computer graphics. This technique has previously been applied to the clinical environment to study patient movements and safe patient handling maneuvers.[10]

In a previous study of patient migration, Davis and Kotowski[1] measured active migration, cumulative movement, and perception of discomfort in healthy subjects. Active migration is the movement during HOB elevation, whereas cumulative movement is the total distance traveled when the patient is elevated at the desired HOB angle and then lowered again to a flat position. In this study, subjects were placed in 4 ICU beds in the flat position and underwent repeated HOB elevations at 30° and 45°. The beds were returned to the flat position after reaching the desired HOB angle after each articulation. This study also quantified the torso compression, which corresponds to the change in distance between the shoulders and trochanter, representing the amount of "balling up" of the patient by the bed articulation. In the previous study, trochanter active migration was as much as 10.6 cm (and as low as 1.5 cm) when the bed was in the highest position at 45° HOB. By the time the bed returned to flat, the trochanter had moved as much as 20.5 cm (cumulative movement) and as little as 7.4 cm depending on the HOB pivot design. Torso compression was impacted by bed design. The ankle active migration and cumulative movement distances were similar. Beds that had more complex HOB articulation designs had less active migration and cumulative movement, and patients rated the beds more comfortable.

Study objectives

The aim of this study was to analyze patient active and passive migration of individuals with mobility levels representative of the ICU patient population. Active migration was measured during initial HOB elevation and then passive migration was measured over a 2-hour period, assessing the "gravity over time" component. Thus, the primary objective of this study was to measure how much active and passive migration occurs in 4 ICU beds with different HOB pivots in patients who are unable to independently reposition themselves. Secondary objectives included assessing (1) how torso angle was affected by migration distance and (2) perceptions of perceived sliding and discomfort during HOB articulations and overall perception of comfort for each of the beds.

METHODS

Subjects

Patients with limited ability to independently reposition themselves, as determined by a Modified Barthel Index, were included in the study if they were willing to sign informed consent and had a stable medical condition that did not require ongoing acute care interventions. Patients in the study suffered from one of the following conditions: stroke, amyotrophic lateral sclerosis, multiple sclerosis, spina bifida, or spinal cord injury with paralysis. To be included, patients had to have a Modified Barthel Index subscore for repositioning of 12 or less for chair-to-bed transfer and 12 or less for ambulation.[11] The Modified Barthel Index was developed by Shah and is a common tool used to score the ability of patients suffering stroke to care for themselves.[12]

Patients were excluded from participation if they were unable to travel to the study site, could not understand verbal instructions in the English language, had an existing pressure ulcer located on the supine aspect of the body, weighed more than 195 kg/ 429 lb (lowest maximum weight capacity of all beds tested), or were unable or unwilling to remain in bed for a total of 4 hours per day (2 uninterrupted 2-hour sessions divided by a break, length selected by the patient) for 2 different days (a total of 8 hours in bed). All subjects read and signed an institutional review board–approved consent form before beginning data collection.

Procedure

Each subject was positioned in all 4 beds in a randomized, predetermined, counterbalanced order. The participant was aligned to the appropriate anatomic location on each bed by the designated manufacturer indicators for proper patient positioning (eg, trochanter aligned with indicator on bed) in a supine position. The bed was placed in a flat (0° HOB) position, and the first motion capture recording was completed. The HOB was then elevated to 45°, and marker coordinates were recorded immediately. Marker coordinate recordings were then taken every 5 minutes for 2 hours. Upon completion of the 2-hour period, subjective assessments of sliding and comfort were undertaken. On average, a 10- to 15-minute break was taken by the subject before moving to the second bed where the same assessment schedule was completed. Two beds were completed on a single day, with subjects returning for a second day of data collection. If the subject was not able to ingress or egress into the beds, a mobile lift was used to position the patient.

Bed descriptions

Four different bed types were evaluated:

1. Bed A (Hill-Rom Progressa with StayIn-Place) was designed to have the head pivot slide backward simultaneously as the head section extends when the HOB is raised.
2. Bed B (Hill-Rom Progressa without Stay-InPlace) had the head pivot sliding with no lengthening of the head section during the raising of the HOB.
3. Bed C (Linet Multicare) had a simple stationary head pivot in which the HOB section pivots around when articulated upward.
4. Bed D (Stryker InTouch) had 2 hinge points for the head pivot where the HOB pivots about one up until 20° and then pivots about the other pivot joint beyond that elevation.

A previous publication by Davis and Kotowski[1] has provided additional information about the beds.

Outcome measures

Outcome measures included active and passive migration, or the distance moved relative to the start time (flat supine position) at each time period; torso compression; and subjective measures relating to perceived discomfort and sliding.

Active and passive migration was calculated by assessing the distance moved relative to the starting position of the trochanter and ankle motion capture markers. This movement was electronically captured by video that documented the movement of the body as compared with stable motion capture markers placed on the corresponding bed frame. Positive migration values indicated a movement toward the foot of the bed, and negative values indicated movement upward toward HOB.

Torso compression measured the maximum decrease in distance between the shoulder and trochanter markers during the articulation. The trochanter-shoulder baseline was assessed when the participant was flat on the bed prior to the raising of HOB to 45°. Torso compression provides an objective assessment of the level of scrunching or balling up of the participant.

Perception of sliding was assessed by the question "How much sliding did you feel you had during the last 2 hours?" which was answered using an integer scale with 0 (none) to 10 (sliding several inches).

Perception of discomfort was assessed by the question: "Do you have any discomfort anywhere in your body?" which was answered by using an integer scale of 0 (no discomfort) to 10 (most unbearable pain imaginable). If any discomfort was specified, the specific body region was recorded.

Motion capture technique

Movement of the patient relative to the bed was measured using a 6-camera, passive optical motion capture system (Motion Analysis Corporation, Santa Rosa, California). The system quantifies the precise position of 13 retroreflective markers (7 on the body and 6 on the bed frame in 3-dimensional space). All data were collected at a sampling rate of 10 Hz, digitized, and analyzed using Cortex software. Net migration and torso compression outcome measures were calculated and analyzed using a custom MATLAB routine (MATLAB R2015b; The MathWorks, Inc, Natick, Massachusetts). Retroreflective body markers were positioned on bony landmarks using standardized locating procedures for the body (right side) locations and on the bed frame. A detailed description of marker placement and technique has been reported in Kotowski et al.[10] The trochanter marker was located lateral to the center of the greater trochanter. Trochanter migration was measured relative to the thigh section of the bed as defined by the pivot at the HOB and thigh sections and the pivot of the thigh and foot sections. The ankle marker was located on the lateral malleolus of the fibula with movement relative to the foot section of the bed, as defined by markers on the pivot for thigh and foot sections and at the end of the bed. The retroreflective markers were 1.3 cm in diameter and attached to appropriate spots on the body using hypoallergenic double-sided adhesive circular washers.

Statistical analyses

Descriptive statistics (means and standard deviations) were computed for all outcome variables as a function of bed type and time interval. A repeated-measures analysis of variance was completed on each dependent variable to identify whether there were significant effects of bed type and time intervals. Post hoc analyses in the form of Tukey standardized Honest difference tests were conducted to identify the source of the differences between beds. A Kruskal-Wallis 1-way analysis of variance by ranks procedure was used to determine significant differences for the discomfort and sliding variables. Follow-up post hoc comparisons were computed for significant effects in the form of a Wilcoxon signed rank test with a Bonferroni correction. The significance level for this study was $\alpha = .05$.

RESULTS

Participants

The study participants consisted of 16 females and 4 males who all had clinical diagnoses that reduced their mobility level. Overall, participants had very limited ability to move independently in bed. While the participants were predominantly female, the population was typical of an older patient population with average (SD) age, height, and weight for females being 55.2 (7.7) years, 163.2 (7.2) cm, and 88.6 (24.4) kg and for males being 54.2 (17.0) years, 182.5 (4.1) cm, and 113.6 (27.4) kg, respectively. The average (SD) Modified Barthel Index subscores for transfer and ambulation for females were 7.8 (3.0) and 5.9 (4.8) and for males were 2.9 (3.8) and 4.0 (4.6), respectively.

Active and passive migration

Beds A and B had significantly less active migration than beds C and D. Active migration of the trochanter for bed A was 3.6 cm and for bed B was 5.8 cm, which both were statistically different when compared with bed C (13.2 cm) and bed D (13.8 cm) immediately after HOB elevation ($P < .05$) (Table). Ankle active migration was also significantly less for beds A and B (5.1 and 5.7 cm, respectively) than for beds C and D (10.2 and 12.0 cm, respectively).

During the passive migration period, the trochanter and ankle migration was lower for bed A (1.4 cm/3.7 cm trochanter/ankle), bed B (1.7 cm/3.1 cm), and D (2.2 cm/2.1 cm) than for bed C, with the highest passive migration at 6.4 cm trochanter/6.9 cm ankle ($P < .05$). The trajectory for passive migration is demonstrated in Figure 1, which shows an ongoing migration for bed C whereas the other beds show more of a flat trajectory post–HOB elevation.

Figure 2 provides the relative results of the active and passive migration. For all the beds, the majority of the trochanter and ankle migration occurred during the active phase (>58%). However, bed D had the greatest percentage of migration in the active phase relative to the passive phase (>85% for trochanter and ankle).

Torso compression was greatest for bed B and lowest for bed D. The torso compression remained relatively steady throughout the

Table. Mean (SD) of Migration at HOB Elevation and End of 2-Hour Period and Subjective Perceptions[a]

Time Period	Outcome	Bed A	Bed B	Bed C	Bed D
Right after HOB elevation	Trochanter active migration, cm	3.6 (0.6) *(C, D)*	5.8 (1.0) *(C, D)*	13.2 (1.3) *(A, B)*	13.8 (1.1) *(A, B)*
Right after HOB elevation	Ankle passive migration, cm	5.1 (0.9) *(C, D)*	5.7 (0.7) *(C, D)*	10.2 (1.0) *(A, B)*	12.0 (1.0) *(A, B)*
At 2 h	Trochanter active migration, cm	5.0 (0.8) *(C, D)*	7.5 (1.4) *(C, D)*	19.6 (1.7) *(A, B)*	16.0 (1.4) *(A, B)*
At 2 h	Ankle passive migration, cm	8.8 (1.9) *(C, D)*	8.8 (1.3) *(C, D)*	17.1 (1.7) *(A, B)*	14.1 (1.2) *(A, B)*
At 2 h	Rating of sliding 1-10 (0 = none, 10 = sliding many inches)	2.4 (0.4) *(C)*	2.0 (0.3) *(C, D)*	6.3 (0.6) *(A, B, D)*	3.7 (0.7) *(B, C)*
At 2 h	Rating of discomfort 1-10 (0 = none, 10 = unbearable pain)	2.2 (0.4) *(D)*	2.3 (0.4) *(D)*	5.8 (0.6) *(A, B, D)*	3.1 (0.5) *(C)*

Abbreviation: HOB, head of bed.
[a] *Italicized letters* indicate the value is significantly different from the value of the bed designated, for example, *(C, D)* in first cell indicates bed A is significantly different from beds C and D.

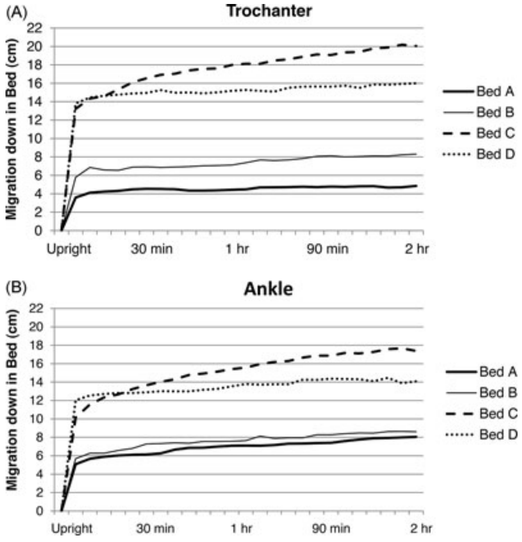

Figure 1. Mean migration for (A) trochanter and (B) ankle as a function of bed type and time interval over the 2-hour assessment period.

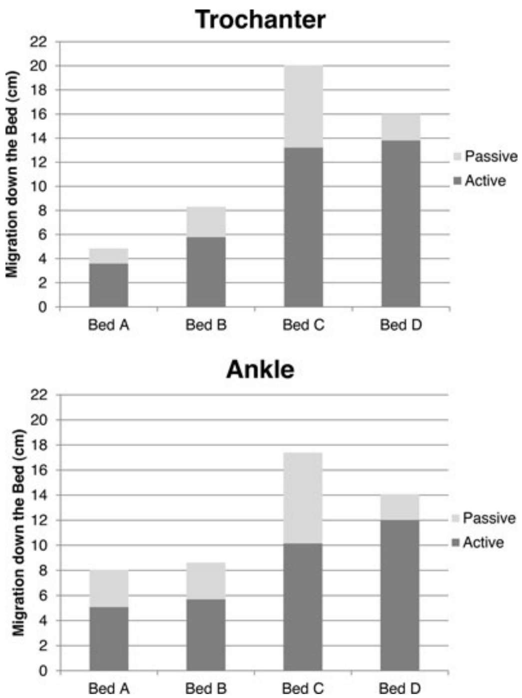

Figure 2. Relative distribution of migration for (A) trochanter and (B) ankle during the active and passive phases of the 2-hour assessment.

2-hour passive phase, although there was a slight trend of increased torso compression in the second hour for beds A, B, and D.

The perceptions of sliding and discomfort that were recorded at the end of the passive phase (2-hour period) had similar trends as the net migration at the end of the passive phase (Table). Bed C was significantly higher for perceived sliding at 6.3 on a 10-point scale than beds A and B, which had the lowest values at 2.4 and 2.0, respectively ($P < .05$). There was no difference between beds A, B, and D for perceived sliding. The trend was similar for discomfort, with more discomfort for bed C and the least for beds A and B (5.8 vs ~2.2; $P < .05$).

DISCUSSION

The distance moved during a single 45° HOB elevation was significantly affected by bed type and ranged from 3.6 cm (bed A) to 13.8 cm (bed D). When observing patients over a 2-hour period, the total migration distances ranged from 5.0 cm (bed A) to 19.6 cm (bed C).

The amount of "active" migration (initial movement due to the HOB raising) that these functionally compromised subjects experienced was slightly higher than in our previous work with healthy volunteers[1] (Figure 3). Beds A and B had migrations of 1.5 and 3.3, respectively, in healthy volunteers at 45°

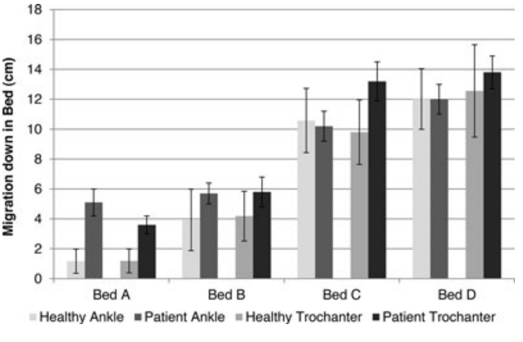

Figure 3. Migration during active migration for the upright position for healthy volunteers (phase 1) and patients (phase 2).

HOB elevation, and the current subjects with compromised mobility experienced 3.6- and 5.8-cm migration in beds A and B, respectively. Migration for beds C and D was 9.9 and 10.6 cm for healthy subjects at 45° as compared with 13.2 and 13.8 cm, respectively, for these compromised subjects.[1] The perception of sliding was also greater for this compromised population than for the healthy volunteer population. Although the relative differences between bed types were similar, these findings suggest that patients may actually migrate more when their ability to independently reposition is compromised.

For all bed types, most patient migration occurred during the "active" phase due to HOB elevation, rather than the "passive" phase due to gravitational forces. This makes sense due to the large friction forces existing between the patient and the bed surface. Differences in HOB articulation were the primary factor in patient migration, not the final angle at which the HOB occurred. Active migration at the trochanter ranged from 68% to 86% of the total distance moved. At the ankle, ranges were between 58% and 85%.

The differences between beds for torso compression were significant but not large in magnitude. These data may have been affected by the impact of anatomic changes due to primary disease states that have occurred in this patient population.

The clinical ramifications of patient migration include increased shear within the patient's soft tissues. When a patient slides down the bed, the buildup of shear forces within the tissues due to friction between the bed mattress increases, potentially resulting in tissue breakdown leading to the development of pressure ulcers.[5,6,13] By minimizing patient migration, there is a likely reduction in sustained shear and friction, which may reduce pressure ulcer risk.

Patient migration also reduces the elevation of the patient torso; Wiggermann and associates[2] provided evidence that when patients move down the bed, there is a corresponding magnitude of torso angle reduction. Maintaining an upright anatomic position is important for the prevention of aspiration in ventilated subjects and those receiving enteral nutrition. These findings suggest that if not properly managed, patient migration may increase the risk of hospital-acquired pneumonia and ventilator-associated conditions.

In addition to the negative consequences for the patient, migration presents risks to caregivers. Patients who migrate toward the foot of the bed must be repositioned up in the bed. Repositioning patients in the bed is one of the most risky tasks that caregivers perform.[3,4] Therefore, by reducing overall patient migration, the numbers of occurrence for pull up in bed maneuvers may also be reduced. Supplemental Digital Content Table (available at: http://links.lww.com/JNCQ/A275) provides a summary of key clinical implications.

Extremely limited evidence is available to compare how different beds perform with respect to patient migration. It is incumbent on caregivers to evaluate beds in the absence of objective data. The aim of this study was to provide some evidence supporting objective decisions regarding HOB articulation designs, with the goal of reducing pressure ulcer risk factors and risks of caregiver injury. ICU beds that most effectively limited patient migration were those with complex HOB pivot designs. Patient migration also may be tested by assessing the distance moved during a normal 45° HOB elevation by marking patient initial and final positions; however, those results would need to be correlated with the results of this study. It is the recommendation of the authors that this is one component of an objective assessment process during the bed purchasing process and selection.

Limitations

To obtain the high level of accuracy provided by motion capture equipment, it was necessary to perform this study in a laboratory setting. In addition, it would not be practical or ethical to transfer hospital patients between beds and ask caregivers not reposition patients over a 2-hour period. However, this study is the first of its kind to use participants with diagnoses that result in immobility and are representative of hospital patients. Although patient migration is likely to contribute to adverse events such as pressure ulcers and caregiver musculoskeletal injuries, these direct relationships have not been quantified. Future studies need to measure the friction between the patient and the bed surface along with patient migration to understand the true impact.

CONCLUSIONS

Significant differences in patient migration occurred among the bed types that were studied, with migration primarily attributed to the initial HOB elevation (active migration) rather than gravity over time (passive migration). Beds with complex HOB pivot joints had the least amount of both active and passive migration. Subjects stated they perceived more sliding and discomfort in beds that had more migration. Migration may cause increased risk of pressure ulcers, limit torso angle, and cause caregivers to have to reposition patients more frequently.

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