Original Study

A Simulation Study of the Factors Influencing the Risk of Intraoperative Slipping

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Abstract

This simulation study seeks to quantify the risk of intraoperative slipping associated with the use of Trendelenburg during minimally invasive gynecologic surgery. We found that heavier patients are more likely to slip and that the choice of antislip material had a significant impact on the propensity to slide in the lithotomy position.

Background: To identify the impact of weight, table surface, and table type on slipping in a simulation of minimally invasive gynecologic surgery. **Methods:** A mannequin was placed into increasing Trendelenburg until a slip was observed; the table angle at the time of the event was measured (slip angle). The influence of mannequin position (supine vs. lithotomy), weight, table surface, and model was evaluated. A linear regression model was used to analyze the data. **Results:** Mannequin weight, bed surface, and bed type all significantly impacted the slip angles. In general, higher mannequin weights tolerated significantly more Trendelenburg before slipping in the supine position but less in lithotomy compared to lower weights. In lithotomy, the disposable sheet and gelpad performed worse than the bean bag, egg crate foam, and bedsheet. There was no difference in slipping because of bed surface in the supine model. The Skytron operating table performed significantly better than the Steris operating table when tested with the bedsheet. **Conclusion:** Operative position, patient weight, and bed surface together influence the slipping propensity. In lithotomy, heavier patients were more prone to slipping while the inverse was true in supine. The egg crate foam, bean bag, and bedsheet were the best antislip surfaces. Operating room table choice can mitigate slippage.

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Introduction

Laparoscopic surgery has become increasingly important in the drive to reduce patient morbidity. The introduction of robotic surgery has only served to accelerate this trend by allowing more complex surgeries to be performed using a minimally invasive technique. A key requirement of any minimally invasive gynecologic procedure is adequate visualization of the pelvis. This necessitates moving the bowel into the upper abdomen which is facilitated by placing patients in the Trendelenburg position. Steep Trendelenburg in the range of 30°-40° has historically been referenced as necessary for adequate visualization, but modern studies have found 16°-28° to be adequate.[1,2] Increasing levels of patient obesity, which often require a greater degree of Trendelenburg, are not fully addressed in these studies.

The question of how much Trendelenburg can safely be used before a patient slips down the table has not been well studied. The potential morbidity associated with patient movement on the operating room (OR) table is not insignificant and includes dislodged airways, cervical spine hyperextension, and neurologic injury.[3,4] Of additional concern for robotically treated patients is the possibility of intra-abdominal injury or tearing of skin incisions by fixed robotic instruments if the patient moves on the table.[5]

We aim to identify the bed material on which the greatest amount of Trendelenburg can be safely achieved as modified by other factors such as patient weight and bed type.

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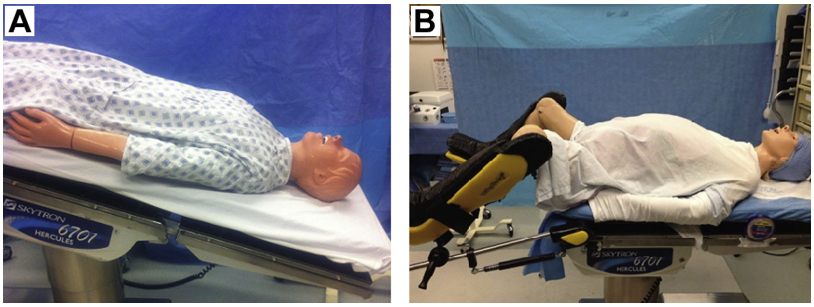
Figure 1 Mannequins Set Up for Testing in (A) Supine and (B) Lithotomy Position. Long Way Down



Methods

Institutional review board exclusion was granted. The experimental models used in this study were designed to replicate the conditions experienced by patients during laparoscopic surgery.

Mannequins similar in height to an average female were obtained to function as human surrogates. Specifically, in the supine model, a WMD/CBRNE/DECON full-body trainer mannequin (Simulaid, Saugerties, NY) was used. A Noelle Maternal Birthing simulator S551 (Gaumard, Miami, FL) was used for the lithotomy model because of greater range of motion in the hips allowing for better placement in Allen stirrups and its ability to hold a greater amount of weight than the Simulaid mannequin (Figure 1).[6] The portion of the mannequin in contact with the bed surface was made of a combination of rubberized silicone and polyvinylchloride. The coefficient of friction is variable dependent on a variety of surface interactions, and the manufacturer does not have the information for their propriety materials. Given the tackiness and texture of the material, baby powder, which lowers the coefficient of friction, was used on the mannequin's surface to help it better approximate human skin.[7-9] The mannequins were then positioned in either supine or lithotomy position with their arms tucked. When in lithotomy, the mannequin's legs were placed in Yellowfin Elite Stirrups (Allen, Acton, MA).

A variety of mannequin weights were tested. A starting weight of 100 lbs was increased in 50-lbs increments to a maximum of 250 lbs in the supine and 300 lbs in the lithotomy model because this mannequin was able to hold more weight without being damaged. The weight was evenly distributed across the mannequin's torso (hips to shoulders) and arms to limit the effect of weight being concentrated toward the pelvis or shoulders as a source of error.

The OR table was covered with the selected surface. The bedsheet served as our baseline surface as this best represented a typical OR set up. The other surfaces tested, except for the disposable sheet which was used in isolation, were laid on top of the bedsheet. The egg crate foam was further secured to the sheet with tape. In the case of the bean bag, which is the only surface tested that did not lie flat on the bed, the mannequin was cradled in the bean bag and suction was applied to lock it in place. The addition of egg crate foam or a gelpad to the bedsheet was selected for testing as they are 2 common approaches to limit slipping currently used clinically. Two additional surfaces, a bean bag and a disposable bedsheet (Microtek Disposable sheet Model #ABTSLSCF; Microtek Medical, Columbus, MS), were also evaluated in the lithotomy model as our hospital recently introduced a slick disposable sheet in the OR that anecdotally increased slipping.

Two OR tables were used in our testing. An AMSCO 3085 SP (Steris, Mentor, OH) and a 6701 Hercules (Skytron, Grand Rapids, MI) were both used in the supine testing and only the Skytron in the lithotomy testing. The maximum amount of Trendelenburg available on Steris and Skytron beds were 25° and 30°, respectively.

To replicate a sliding event, the angle of Trendelenburg was increased until the mannequin was noted to slip. A slip was defined as any movement of the mannequin down the slope toward the head of the table. The slip angle was defined as the angle of the bed from the horizontal when slipping was first observed and was measured using a Swanson angle finder attached to the OR table and repeated in triplicate. All measurements were performed by the same examiner to limit variability. For each combination of treatment conditions, the average slip angle from three consecutive runs was analyzed.

Linear regression models were used to analyze the effect of bed surface, weight, and bed type. Model-based estimates of treatment-level differences were computed, and P values were obtained. All analyses were performed using SAS 9.3 (Cary, NC). Significance tests were evaluated using a type I error rate of 0.05.

Results

Supine Model

The slip angle for each surface is presented in Table 1. An analysis of the effect of mannequin weight and bed surface (Table 2)

Table 1 The Effect of Bed Surface and Mannequin Weight on Slip Angle in the Supine Position

Weight Comparisons (lbs)	Mannequin Slip Angle (Degrees)		
	Bedsheet	Egg Crate Foam	Gelpad
100	23.0	23.7	24.3
150	21.3	23.3	21.7
200	22.7	22.7	21.7
250	28.7	25.0	23.7

Table 2 Effect of Mannequin Weight and Bed Surface on the Risk of Slipping in Supine Derived From a Multivariate Model

Comparison by Weight and Bed Surface	Condition More Resistant to Slipping (Difference of Slip Angle in Degrees)	*P* Value
Weight (lbs)		
Overall	NA	.09
100 vs. 150	100 lbs (1.57)	.27
100 vs. 200	100 lbs (1.30)	.35
100 vs. 250	250 lbs (2.13)	.15
150 vs. 200	200 lbs (0.27)	.84
150 vs. 250	250 lbs (3.70)	.027
200 vs. 250	250 lbs (3.43)	.036
Bed Surface		
Overall	NA	.62
Bedsheet vs. egg crate foam	Bedsheet (0.25)	.83
Bedsheet vs. gelpad	Bedsheet (1.08)	.37
Egg crate foam vs. gelpad	Egg crate foam (0.83)	.48

Abbreviation: NA = not applicable.

revealed no significant overall effect for either variable although there was a trend to significance with weight ($P = .09$). This remained true in the subset analysis for the bed surface, but there was a difference in weight comparisons of 150 and 200 lbs to 250 lbs. In these comparisons, the 250-lbs mannequin required more Trendelenburg to slip than the lighter weights.

The mannequin was significantly less likely to slip on the Skytron vs. the Steris OR table taking an additional 6.5° to induce a slip on the bedsheet ($P = .007$). There was a trend toward weight leading to a decreased risk of slipping ($P = .053$). Although weight was not a significant factor in slipping overall, the subgroup analysis showed the mannequin at 250 lbs was less likely to slip than at 100 ($P = .021$), 150 ($P = .021$), and 200 lbs ($P = .054$).

Lithotomy Model

The mannequin was evaluated on five bed surfaces (Tables 3 and 4). Looking at all bed surfaces, weight significantly influenced the risk of slipping. In particular, the mannequin was more resistant to sliding at lower weights (eg, 100 and 150 lbs). Bed surface was also found to have a significant impact on slipping. The bed surfaces split into 2 groups based on their propensity to slip. The bean bag, egg crate foam, and bedsheet made up the slipping resistant group and were found to have equivalent performance to each other. The nonresistant group consisted of the gelpad and the disposable sheet which also had equivalent slipping risk.

Discussion

Patient safety remains the top consideration in the OR. The continued trend toward minimally invasive techniques in gynecologic surgery has increased the number of patients placed in steeper Trendelenburg to achieve adequate visualization and thus subsequently increased the potential number of patients at risk of slipping on the OR table. When a slipping event actually occurs, it is likely a multifactorial event. In this study, the impact of several factors (weight, position, bed surface, and operating table type) that were hypothesized to influence the amount of mannequin movement on the operating table was evaluated.

Weight influenced the risk of slipping in our model, but its overall effect is modulated by both the bed surface and the patient positioning. The supine model demonstrated a trend that lighter mannequins were more prone to slipping, which became significant at the higher weights tested, whereas the lithotomy model showed that lighter patients were less likely to slip. Although a direct comparison cannot be made between the supine and lithotomy models, it is notable that the 2 positions are acting contradictorily which could be a result of the decreased surface area in contact with the table when in lithotomy or the effect of Allen stirrups on the

Table 3 Slip Angle by Mannequin Weight and Bed Surface in the Lithotomy Position

Weight of Mannequin (lbs)	Mannequin Slip Angle (Degrees)				
	Bedsheet	Egg Crate Foam	Gelpad	Bean Bag	Disposable Sheet
100	27	30.3	18.3	31.0	19.3
150	27.3	28.3	17.7	31.0	16.7
200	17.7	20.0	12.7	21.4	10.7
250	21.3	20.3	13.0	20.7	16.3
300	17.7	22.3	20.7	20	15.3

Table 4 Effect of Mannequin Weight and Bed Surface on the Risk of Slipping in Lithotomy Derived From a Multivariate Model

Comparison by Weight and Bed Surface	Condition More Resistant to Slipping (Difference of Slip Angle in Degrees)	*P* Value
Weight (lbs)		
Overall	NA	<.001
100 vs. 150	100 lbs (0.98)	.56
100 vs. 200	100 lbs (8.68)	<.001
100 vs. 250	100 lbs (6.86)	<.001
100 vs. 300	100 lbs (5.98)	.002
150 vs. 200	150 lbs (7.70)	<.001
150 vs. 250	150 lbs (5.88)	.003
150 vs. 300	150 lbs (5.00)	.008
200 vs. 250	250 lbs (1.82)	.28
200 vs. 300	300 lbs (2.70)	.12
250 vs. 300	300 lbs (0.88)	.60
Bed Surface		
Overall	NA	<.001
Bean bag vs. bedsheet	Bean bag (2.62)	.13
Bean bag vs. disposable sheet	Bean bag (9.16)	<.001
Bean bag vs. egg crate foam	Bean bag (0.58)	.73
Bean bag vs. gelpad	Bean bag (8.34)	<.001
Bedsheet vs. disposable sheet	Bedsheet (6.54)	.001
Bedsheet vs. egg crate foam	Egg crate foam (2.04)	.23
Bedsheet vs. gelpad	Bedsheet (5.72)	.003
Disposable sheet vs. egg crate foam	Egg crate foam (8.58)	<.001
Disposable sheet vs. gelpad	Gelpad (0.82)	.62
Egg crate foam vs. gelpad	Egg crate foam (7.76)	<.001

Abbreviation: NA = not applicable.

propensity to slip. Further testing to make a direct comparison between the supine and lithotomy position will be needed to determine how each influences slipping and to perhaps identify how to modify this risk. However, the finding that greater patient weight predisposes to slipping in lithotomy has real-world relevance as obesity rates are an ever increasing problem, and these patients often require more Trendelenburg for adequate visualization.

There is one series reported in abstract form that evaluated the effect of bed surface (no antislip, egg crate foam, egg crate foam plus chest strap, and padded shoulder braces) on the distance slipped in Trendelenburg. Twenty volunteers in lithotomy position were placed in Trendelenburg, and the distance from several anatomic land marks were measured. There was no difference in the amount of slippage between the surfaces at the anterior superior iliac spine, umbilicus, and head, but the slippage at the acromion was significantly less with the shoulder braces.[10] However, its small size and lack of complete manuscript limit the utility of this study. Additionally, shoulder blocks have been associated with brachial plexus injuries making them a less than ideal antislip method.[4]

In our study, bed surface made no difference in slipping risk for the supine model. However, in lithotomy, the bean bag, egg create foam, and bedsheet were found to be equally superior to the disposable sheet and the gelpad. The best explanation of the disposable sheet's propensity to slip is the slick nature of the synthetic cloth's weave leading to less friction between the mannequin and the operating table. As for the gelpad, it was the least malleable of the surfaces tested, and it was noted at the time of testing that the mannequin did not sink into the gel and the other surfaces. We feel that instead of allowing the mannequin to sink in the operating table's cushions, which would increase surface area contact, the gelpad spreads out the mannequin's weight allowing it to avoid getting caught up in any dips within the table surface. On the basis of these findings, the bean bag, egg crate foam, or bedsheet would all be equally good choices of antislip material.

Interestingly, the OR table choice was noted to mitigate the risk of slipping when only a bedsheet was used. Because of differences between brands such in foam cushion density and the gap size between the cushion supports, each type of table will have a different propensity for slipping. In this trial, the Skytron bed had softer cushions and wider gaps than the Steris bed. We hypothesize these differences allowed the mannequin to sink in better and translated into less risk of slipping at almost every weight tested.

This study has several important strengths. First, there is limited variability between test runs as the same mannequin can be used repeatedly. Our model can also be easily adapted to look at other variables that may affect slip angle. Finally, to our knowledge, this is the first study that attempts to assess how certain characteristics influence the angle of Trendelenburg at which slipping occurs. The limitations of this study are that the mannequin does not perfectly replicate a human. For example, the weight could only be added to the torso and arms of the mannequin, whereas in real women, the weight distribution is highly variable.

In conclusion, this study presented two model systems with the ability to assess the impact of various factors on when patients in Trendelenburg position slip without putting patients or human volunteers at risk of injury. The egg crate foam, bean bag, and bedsheet were found to be the surfaces most resistant to slipping and therefore would be recommended bed surfaces for patients undergoing laparoscopic surgery. The gelpad and disposable sheet should be avoided when the lithotomy position and Trendelenburg are used. Special attention should be paid to obese patients as they are at particularly high risk when in lithotomy position. Further studies to directly compare lithotomy to supine position, look at the impact of weight distribution on slipping risk, and ultimately validate our findings using human subjects will be needed in the future to allow new strategies to be developed to limit the risk of intraoperative slipping.

Clinical Practice Points

- Intraoperative slipping is both a patient safety issue and an important factor in determining if a procedure can be performed using minimally invasive techniques.
- The literature on this topic is limited, so further investigation is needed. In this study, we identified that heavier patients are more prone to slipping in lithotomy position.
- This can be mitigated using antislip surfaces with an egg crate foam, a bean bag, or a bedsheet performing the best in our testing.
- Additionally, the type of operating table was also found to significantly impact the risk of sliding.
- Current trends point to an increasingly obese population and minimally invasive surgery is rapidly becoming the modality of choice for both oncologic and benign gynecologic surgery. Therefore, an ever greater number of patients will be at high risk of sliding due not only to their weight but also from the steeper Trendelenburg needed to provide adequate pelvic visualization.
- The findings of this study will help clinicians with preoperative patient selection to limit the number of conversions to an open procedure and the risk of patient injury.

Disclosure

The authors have stated that they have no conflicts of interest.

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