Research article

Motion is reduced in the unstable spine with the use of mechanical devices for bed transfers

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Context: Excessive spinal motion generated during multiple bed transfers of patients with unstable spine injuries may contribute to neurological deterioration.
Objective: To evaluate spinal motion in a cadaveric model of global spinal instability during hospital bed transfers using several commonly used techniques.
Design/participants: A motion analysis and evaluation of hospital bed transfer techniques in a cadaveric model of C5–C6 and T12–L2 global spinal instability.
Setting/outcome measures: Global instability at C5–C6 and T12–L2 was created. The motion in three planes was measured in both the cervical and lumbar spine during each bed transfer via electromagnetic motion detection devices. Comparisons between transfers performed using an air-assisted lateral transfer device, manual transfer, a rolling board, and a sliding board were made based on the maximum range of motion observed.
Results: Significantly less lateral bending at C5–C6 was observed in air-assisted device transfers when compared with the two other boards. Air-assisted device transfers produced significantly less axial rotation at T12–L2 than the rolling board, and manual transfers produced significantly less thoracolumbar rotation than both the rolling and sliding boards. No other significant differences were observed in cervical or lumbar motion. Motion versus time plots indicated that the log roll maneuvers performed during rolling board and sliding board transfers contributed most of the observed motion.
Conclusions: Each transfer technique produced substantial motion. Transfer techniques that do not include the logroll maneuver can significantly decrease some components of cervical and lumbar motion. Thus, some spinal motion can be reduced through selection of transfer technique.

Keywords: Spinal cord injuries, Transfer techniques, Logroll maneuver

Introduction

An estimated 11 000 cases of spinal cord injury (SCI) occur in the USA each year.[1] Because loss of a single neurologic level can lead to drastic differences in functional outcome in the patient with cervical SCI, it is important to prevent iatrogenic neurologic deterioration during the care of these patients. For this reason, spinal precautions and spinal immobilization are routinely used in the hospital care of patients with spinal injuries.

Recent studies have shown that up to 10% of patients with SCI experience neurologic deterioration after admission to the hospital.[2–6] In some of these cases, a causative factor such as application of an orthosis or prolonged hypotension was identified. But, in most studies the causes were either unknown or not reported. Hospital bed transfers are one link in the chain of events that can possibly lead to neurologic deterioration in the pre-operative patient with SCI by causing excessive spinal motion during transfer.

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It has previously been demonstrated that the commonly used log roll technique causes excessive motion in an unstable spine.[7] Pre-hospital patient transfer techniques that decrease spinal motion by avoiding use of the log roll technique have recently been reported.[8] However, little attention has been focused on in-hospital patient transfer methods. Given that patients who have sustained major trauma often need multiple diagnostic studies and therapeutic procedures that may necessitate multiple bed transfers, patient transfer techniques have the potential to worsen SCI by generating undue spinal motion. Therefore, it is worthwhile to test some commonly used transfer techniques in the setting of spinal instability. The purpose of this study was to evaluate and compare cervical and lumbar spine motion in a cadaveric model of spinal instability during in-hospital bed transfers using several common methods. We hypothesized that bed transfer techniques that utilized the log roll would cause greater spinal motion than those techniques that did not.

Methods

For this investigation, five cadavers were lightly embalmed per University of Rochester Medical Center protocol. In contrast to standard embalming, the light embalming protocol uses an embalming fluid (Hydrol B4, Hydrol Chemical Co., Landsdowne, PA, USA) designed to retain tissue elasticity. In addition, less total volume is infused into the cadaver. This resulted in a cadaver in which the stiffness of the joints and tissues was grossly similar to that of fresh cadavers, but with a longer period of use, allowing completion of the experimental protocol.

A global three-column disco-ligamentous instability at the C5–C6 level of the cervical spine was created via a posterior approach by disrupting the anterior and posterior disco-ligamentous structures and facet capsule. All soft tissue overlying the bodies of the lower cervical spine was resected so as not to restrict the movement of the sensors at the C5–C6 level. Instability at the T12–L2 level was created through an anterior approach by performing an L1 corpectomy and a posterior ligamentous release. An electromagnetic motion tracking device (Liberty, Polhemus Inc., Colchester, VT, USA) was used to measure the segmental motion generated between C5 and C6 as well as T12 and L2 during the execution of each transfer technique. The reliability and validity of this type of system in tracking cervical and lumbar spine motion have been well documented.[9–15] The system consists of one externally located transmitter that emits an electromagnetic field and several small receiver sensors with embedded orthogonal coils that detect the position and orientation of the sensor with respect to the transmitter. These small receiver sensors were mounted directly to the vertebral bodies using screws and cable ties. In the cervical spine, the sensors were placed on the anterior aspect of the vertebral body. In the lumbar spine, the sensors were placed on the lateral aspect of the vertebral body. The position and orientation data from each sensor were recorded on a computer for processing. The local reference frames of each sensor were aligned to the anatomical axes of the cadaver. The origin of the local reference frames was fixed on the anterior surface of the vertebral body, because without further disruption of soft tissue structures, it was not possible to access landmarks that would be necessary to define a mid-vertebral body point. The relative motion between C5 and C6 and T12 and L2 was determined by calculating the rigid body transformation matrix between the superior and inferior sensor. Kinematic data were sampled at a frequency of 240 Hz (four times per second).

Four patient transfer methods were studied; an air-assisted lateral transfer device (AirPal, Center Valley, PA, USA), manual transfer, a rolling board, and a sliding board. Each cadaver was fitted with a two-piece rigid cervical collar for all transfers (Vista®, Aspen Medical Products, Irvine, CA, USA). Transfers were executed by an experienced team of clinicians. The air-assisted lateral transfer device (AirPal) uses a powered air supply connected to a low-pressure inflatable mattress with a perforated undersurface (Fig. 1A). Once the mattress inflates, air escapes through the perforations to create a low-friction interface on which the mattress travels. Spinal motion recording was started at the time of inflation of a mattress already placed underneath the cadaver. The cadaver did not need to be log-rolled onto the device. Two research team members executed these transfers, with one stabilizing the cervical spine and the other pulling the mattress laterally.

Manual transfer involved four team members and a bed sheet already positioned underneath the cadaver. One researcher provided stabilization of the cervical spine while the remaining three members of the team were positioned about the sides and feet. The cadaver was lifted along with the bed sheet underneath and transferred laterally from one bed to the next in two steps. Recording was started just prior to lifting the patient.

The rolling board and sliding board are common transfer devices found in most hospitals and are readily available through medical supply companies.

Figure 1 Air-assisted lateral transfer device (AirPal; printed with permission from AirPal) (A), rolling board (B), and sliding board (C).

Four research team members were also needed for the rolling board technique. The rolling board (Fig. 1B) is a device consisting of four tubular aluminum rollers enveloped by a vinyl sleeve and resembles a short section of a conveyor belt. One team member maintained cervical spine stabilization; two were on each side of the cadaver, and one was at the feet. The cadaver was log-rolled to 45° and the rolling board was placed under the sheet on which the cadaver lay. The sheet was then pulled and the cadaver rolled across the rolling board onto the second bed. Another 45° log roll was then performed to remove the device from underneath the cadaver. Motion recording began just before the initial log roll. The final technique tested employed a sliding board. The sliding board (Fig. 1C) is a full-length polyethylene board that provides a low-friction surface on which a patient slides from one bed to another. The transfer technique used was similar to that of the rolling board, again with four team members.

Transfer procedures were performed in random order and were repeated three times on each cadaver. For each trial, angular and translational motion in each plane (sagittal, axial, and coronal) was calculated and the maximum range of motion was used for analysis. Separate analyses (analyses of variance with repeated measures) were completed for angular (flexion/extension, lateral bending, and axial rotation) and translational motions (anterior/posterior, medial/lateral, superior/inferior) to assess differences between the techniques; pairwise comparisons were made using Bonferroni adjustments for multiple comparisons. Data were analyzed using SPSS 15 (IBM, Chicago, IL, USA).

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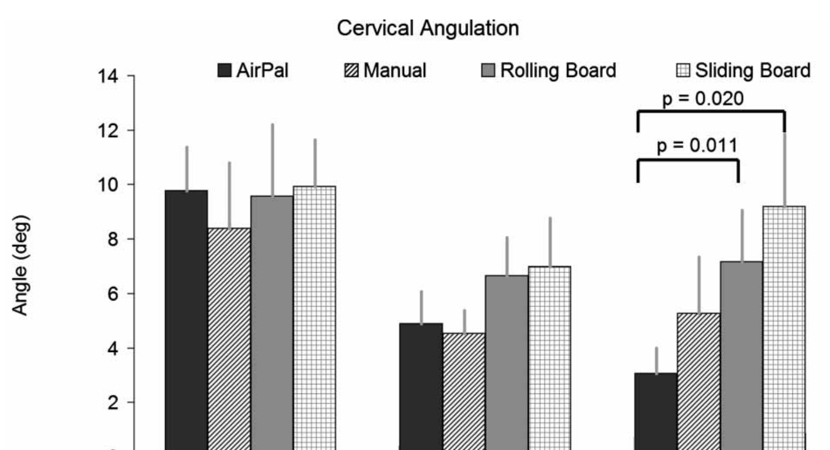
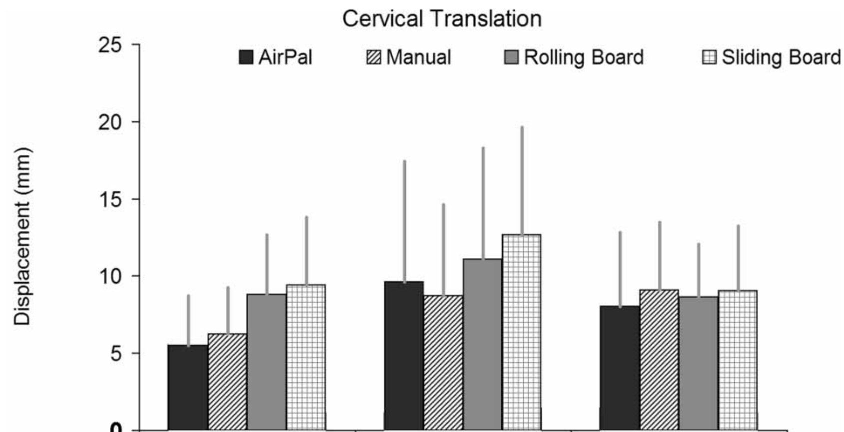
Results

The magnitude of cervical angulation was recorded with each technique. Transfers using the air-assisted device produced significantly less lateral bending than both rolling board and sliding board ($P = 0.011$ and 0.020, respectively; Fig. 2). No other significant differences



	Flexion/Extension	Axial Rotation	Lateral Bending
AirPal	9.8	4.9	3.0
Manual	8.4	4.5	5.3
Rolling Board	9.6	6.6	7.2
Sliding Board	9.9	7.0	9.2

Figure 2 Cervical angulation in three planes generated by bed transfers. Air-assisted device (AirPal) transfers generated significantly less lateral bending than rolling board and sliding board transfers.



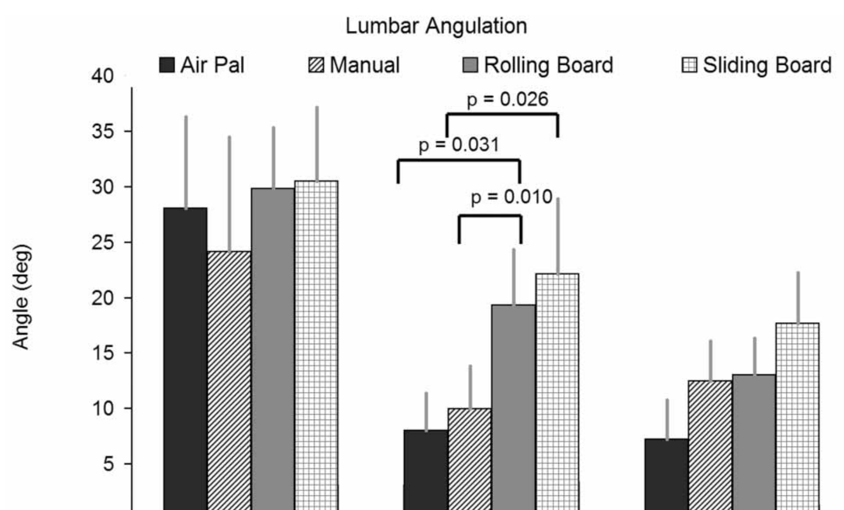
	Medial/Lateral Translation	Axial Translation	Anterior/Posterior Translation
AirPal	5.5	9.6	8.0
Manual	6.2	8.7	9.1
Rolling Board	8.8	11.1	8.6
Sliding Board	9.4	12.7	9.0

Figure 3 Cervical translation in three planes generated by bed transfers. There were no significant differences between techniques.

were observed in cervical angulation. No significant differences were found between the four techniques for cervical translation (Fig. 3).

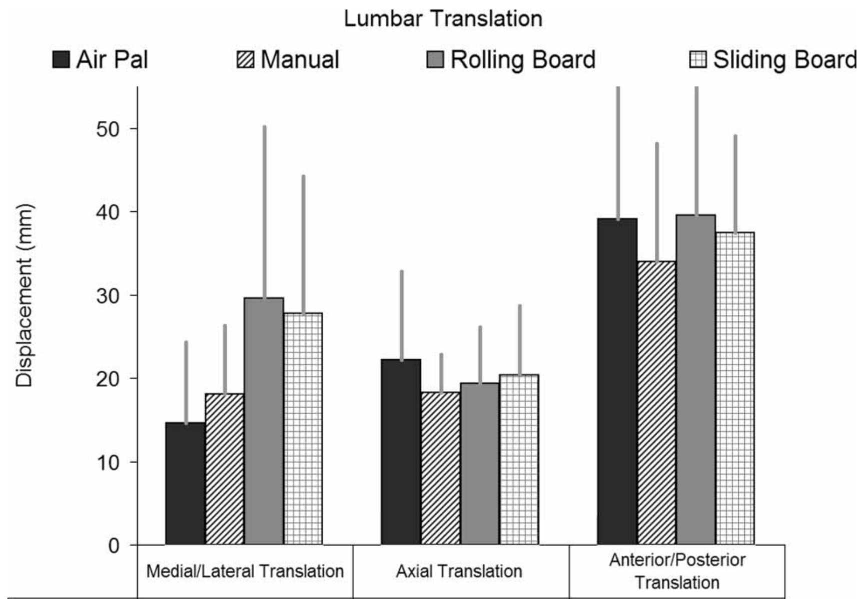
Transfers using the air-assisted device resulted in significantly less lumbar axial rotation than the rolling board ($P = 0.031$, Fig. 4) and approached significance when compared with the sliding board ($P = 0.056$). In addition, manual transfer produced significantly less axial rotation than both the rolling board and the sliding board ($P = 0.010$ and 0.026, respectively; Fig. 4). No other significant differences were observed between techniques in lumbar angulation. There were also no significant differences in lumbar translation between techniques (Fig. 5).

The cervical lateral bending angle versus time tracing in Fig. 6 demonstrate a large initial angulation for both the rolling board and sliding board transfers. This corresponded to the log roll that was needed to place the



	Flexion/Extension	Axial Rotation	Lateral Bending
Air Pal	28.0	8.0	7.2
Manual	24.1	10.0	12.4
Rolling Board	29.8	19.3	13.0
Sliding Board	30.4	22.1	17.7

Figure 4 Lumbar angulation in three planes generated by bed transfers. Air-assisted device (AirPal) transfers generated significantly less axial rotation than rolling board transfers and approached significance compared with sliding board transfers. Manual transfers generated significantly less axial rotation than both rolling board and sliding board transfers.



	Medial/Lateral Translation	Axial Translation	Anterior/Posterior Translation
Air Pal	14.6	22.2	39.0
Manual	18.1	18.2	34.0
Rolling Board	29.5	19.4	39.6
Sliding Board	27.8	20.4	37.5

Figure 5 **Lumbar translation in three planes generated by bed transfers. There were no significant differences between techniques.**

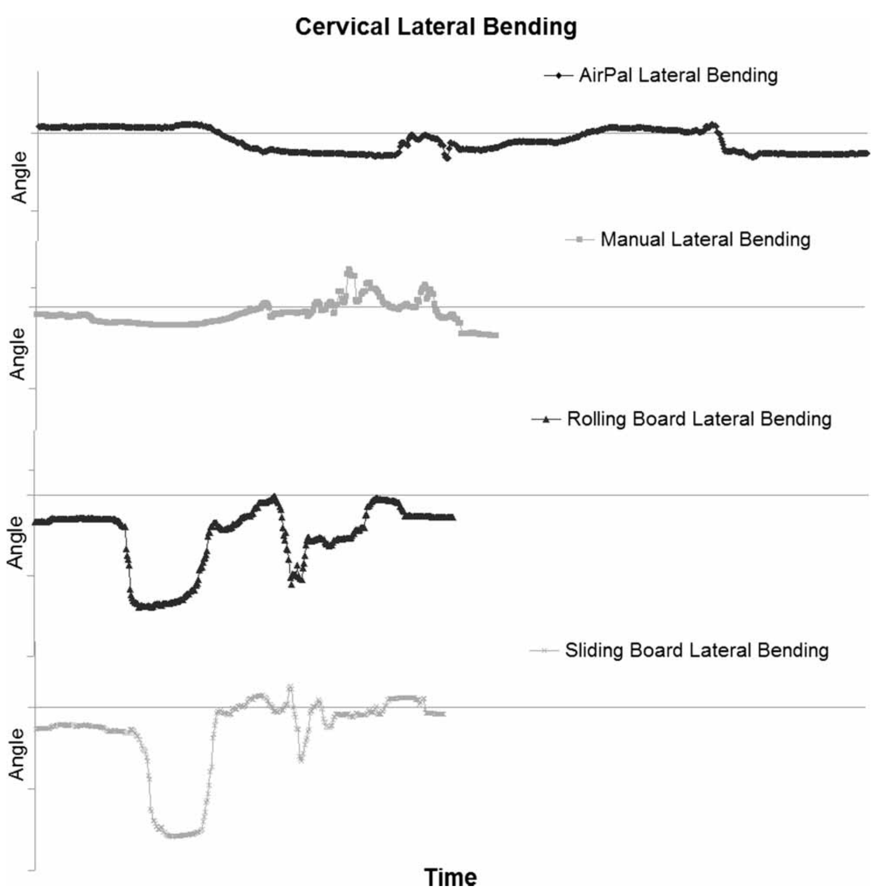


Figure 6 **Cervical lateral bending angle versus time tracings for bed transfers. The large change in angle seen initially in the rolling board and sliding board transfers correspond with the log roll maneuver required to place the cadaver onto the device.**

cadaver onto the transfer device. These data demonstrate the contribution of the log roll to the segmental motion observed. Similarly, the lumbar axial rotation angle versus time tracing shows large peaks in angulation that corresponded to the log roll maneuver performed to place and remove the cadaver from the device for the rolling board and sliding board transfers (Fig. 7).

Discussion

Much attention has been paid to diagnosis and treatment of vertebral column and spinal cord injuries, from the mechanisms of injury to definitive treatment. However, many intermediate steps in patient management are required prior to planning definitive treatment, and little research has been done to study these aspects of care, including bed transfers. When patients need multiple bed transfers for pre-operative diagnostic tests and therapeutic measures, there is potential for secondary neurologic injury due to excessive motion of the unstable spine. This and previous studies have shown that bed transfers can generate significant motion in unstable spine injuries.[16–19] Rechtine *et al.*[19] demonstrated 4–8 mm of cervical translation during a manual bed transfer in the same model of C5–C6 global instability. Our study produced similar magnitudes of cervical translation, from 5 to 13 mm. Horodyski *et al.*[18] demonstrated 6–11° of lumbar angulation for a six-person manual transfer in the same model of T12–L2 global instability. Our study generated 10–24° of lumbar angulation for a four-person manual transfer. In our experience, there is considerable variation from cadaver-to-cadaver even when the same protocols are followed, making comparisons to other studies somewhat difficult. These results however appear to be in line with previously reported studies.

The results of this study demonstrate that transfers using the air-assisted device resulted in 50% less cervical spine lateral bending motion compared with the rolling board and sliding board techniques. In addition, there was 50% less lumbar axial rotation with both air-assisted and manual transfer when compared with the rolling board and 50% less lumbar axial rotation with manual transfer when compared with the sliding board. Analysis of the angulation versus time graphs revealed that the high magnitudes of motion occurring

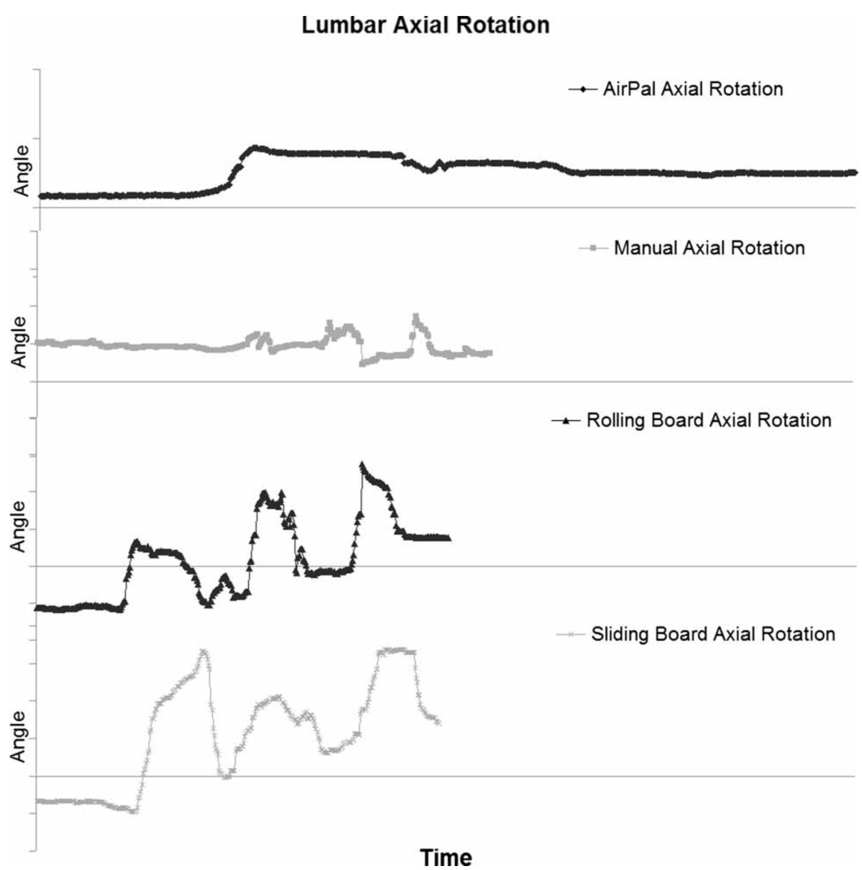


Figure 7 Lumbar axial rotation angle versus time tracings for bed transfers. The large peaks in angulation at the beginning and end of the rolling board and sliding board transfers correspond with the logroll maneuver required to place and remove the cadaver from the device.

with use of the rolling board and sliding board were due to the log rolls required at the beginning and end of each transfer. Cervical axial rotation, cervical medial–lateral translation, and lumbar medial–lateral translation, while not reaching statistical significance, did result in less motion in the techniques not requiring log rolls as compared with the techniques requiring the log roll. In the light of these observations, log roll maneuvers should be avoided whenever possible, as this additional spinal motion may lead to neurologic deterioration.

Even though there were no statistically significant differences between air-assisted and manual transfers, it should be noted that air-assisted transfers produced relatively smooth tracings on the angulation versus time graphs (Figs. 6 and 7). The high frequency variations seen on the tracings for manual transfers could be attributed to the fact that the four team members were suspending the cadaver over the bed during transfer, resulting in greater opportunities for variations in vertical position compared to the air-assisted device mattress, which essentially rested on top of the bed, limiting cadaver motion.

While these results indicate there are differences in motion between techniques, they also show that these techniques still cause a considerable amount of spinal motion. For example, there was little difference in the magnitudes of lumbar flexion-extension for all transfer techniques, with values ranging from 24 to 30°. Also, no technique caused less than 34 mm of anterior–posterior translation in the unstable lumbar segment. Thus, the differences between various transfer techniques presented here may not be clinically relevant because significant motion still occurs in the remaining planes despite reductions in motion in a single plane.

Another observation that should be noted is that use of the air-assisted device required only two trained personnel, while the other techniques required four. In our study, transfer personnel were experienced clinicians who were used to working with each other. In the clinical setting, this is usually not the case, leading to potentially more variability in these transfer methods. Also, products similar to the air-assisted device have been shown to decrease the amount of force needed to transfer the patient.[20] There may be secondary benefits to hospital staff in using such assistive devices in terms of reduced risk of injury to staff by eliminating the need to physically lift or roll the patient for each transfer.

These results parallel those reported by Horodyski *et al.*[18] who demonstrated that a mechanical transfer device produced less spinal motion than a traditional transfer method. In this study, a motorized lateral patient transfer device that could pull a cadaver across two beds without lifting was compared with a manual transfer in which six trained personnel lifted a cadaver from one bed to another. The same global lumbar spinal instability model as in this study was used, and their results showed that the mechanical device produced less spinal motion in all three planes compared with the manual transfer. Unfortunately, this device has been discontinued.

The strengths of this study include the fact that our motion capture method provides continuous recording, as opposed to static radiographs or images. Continuous recording allowed us to perform a detailed analysis of the entire transfer process. This motion recording system can be used in the future to fine-tune transfer techniques in order to minimize spinal motion. Still, this study has several limitations. From a practical standpoint, the air-assisted device mattress must be placed under the patient upon initial transfer from backboard to emergency room stretcher for this method to be effective. Otherwise, an additional transfer maneuver would be needed to place the patient on the device. We have previously compared methods for removing spine-injured patients from the spine board.[21] However, once resting on this device, the patient does not need to be removed from it until surgery, as it was designed to remain under the patient between transfers. In contrast, the sliding board and rolling board cannot be left underneath the patient, necessitating their removal after transfers. Another limitation arises from the fact that this is a cadaver study. The effects of muscle control in a conscious patient cannot be assessed in a cadaver model. This study thus simulates the clinical scenario in which an unconscious patient is undergoing bed transfer. In addition, while the magnitudes of angulation and translation were recorded, the effects of these changes on the size of the spinal canal were not measured, as they were in other models of spinal instability.[22,23] As such, the direct effects on the spinal cord and nerve roots could not be measured. However, these results still demonstrate that there are significant differences in spinal motion between transfer techniques, and future work can be directed toward measuring the direct effects on the spinal cord resulting from bed transfers.

Conclusion

In summary, studies have shown that neurologic deterioration of patients with SCI can occur in the early phases of hospital care prior to definitive treatment. Currently used bed transfer techniques all cause considerable motion in a cadaveric model of cervical and lumbar

spinal instability, which can lead to neurologic deterioration. While eliminating the log roll maneuver can reduce some components of cervical and lumbar spine motion during bed transfers, considerable angulation and translation still occurs. More work in developing motion-limiting bed transfer techniques is needed.

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