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Helmet and Shoulder Pad Removal in Football Players With Unstable Cervical Spine Injuries

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Football, one of the country's most popular team sports, is associated with the largest overall number of sports-related, catastrophic, cervical spine injuries in the United States (Mueller, 2007). Patient handling can be hindered by the protective sports equipment worn by the athlete. Improper stabilization of these patients can exacerbate neurologic injury. Because of the lack of consensus on the best method for equipment removal, a study was performed comparing three techniques: full body levitation, upper torso tilt, and log roll. These techniques were performed on an intact and lesioned cervical spine cadaveric model simulating conditions in the emergency department. The levitation technique was found to produce motion in the anterior and right lateral directions. The tilt technique resulted in motions in the posterior left lateral directions, and the log roll technique generated motions in the right lateral direction and had the largest amount of increased instability when comparing the intact and lesioned specimen. These findings suggest that each method of equipment removal displays unique weaknesses that the practitioner should take into account, possibly on a patient-by-patient basis.

Keywords: sports medicine, neck injury, trauma

Football continues to be one of the most popular team sports in the United States, with more than 1.8 million participants in 2006 (Mueller, 2007). Although spinal cord injury is uncommon in football, the large number of participants has resulted in the sport being associated with the largest overall number of sports-related, catastrophic, cervical spine injuries in the United States (Mueller, 2007). Catastrophic cervical spine injury is defined as any structural deformation of the cervical spinal column linked with actual or potential damage to the spinal cord (Banerjee et al., 2004). Improper stabilization of these patients, therefore, could precipitate or worsen neurologic injury. The evaluation and management of football players suspected of having suffered catastrophic cervical spine injuries is difficult owing to the protective equipment worn during participation, and proper handling techniques are required to minimize neurologic sequelae and expedite treatment.

Previous authors have demonstrated that maintaining spinal immobilization during removal of the football helmet and shoulder pads is difficult and requires training, practice, and a team of qualified personnel (Donaldson et al., 1998; Gastel et al., 1998; Metz et al., 1998; Palumbo et al., 1996). The helmet and shoulder pads, when left in place, hold the spine in a neutral position and provide some additional stability (Waninger, 1998). Based on these findings, the recommendation regarding equipment removal from both the NCAA and the Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete is that the helmet and shoulder pads should only be removed after radiographs have been obtained (Kleiner, 2003). However, this equipment can prohibit visualization of the cervical spine (Davidson et al., 2001; Laprade et al., 2000; Swenson et al.,. 1997; Veenema et al., 2002; Waninger et al., 2004). Therefore, the helmet and shoulder pads will need to be removed to provide radiographic clearance and, in patients identified with catastrophic spine injury, before treatment.

Current methods of helmet and shoulder pad removal demonstrate unnecessary amounts of movement and an ideal technique has not yet been described nor have different methods been compared (Donaldson et al., 1998). The purpose of this study is to simulate a catastrophic C5-C6 cervical spine injury and evaluate force and motion across the unstable segment while performing three different methods of equipment removal.

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Methods

Six fresh frozen cadaveric vertebral specimens from C2 to T2 were used. Each specimen was dissected down to the osteoligamentous structures. The C2 and T2 vertebrae were then embedded into poly(methyl methacrylate) (PMMA). Polhemus FASTRAK transducers (Polhemus, Colchester, VT) were fastened using carbon fiber rods inserted and cemented into the C5 and C6 bodies. The cadaveric specimen was inserted into the base of a weighted model head and then into a fixture on a weighted anthropomorphic torso superior to a Denton six-axis load cell (Model 4386 R.A. Denton Inc., Rochester Hills, MI). Although the torso extended down to the tailbone, the addition of legs was determined to have a negligible effect on neck motion owing to their weight being offset by additional lifting personnel and then only during the levitation procedure. Since the torso incorporated shoulders down to the insertion of the deltoid arms were also omitted, and in-vivo trials showed that they were naturally tucked in by the lifters during the procedures. The appropriate weight of the head (13 lbs) and torso (100 lbs) was obtained by using Hatze's (1980) average segment densities and based on a defensive back football player. An NFL-issue Riddell helmet with mask removed and NCAA-issue Riddell shoulder pads were then fit onto the head and torso respectively. The patient construct was placed supine on a narrow table to simulate being in a hospital gurney on a backboard (Figure 1).

Three techniques were compared for equipment removal: levitation, tilt, and log roll. The techniques were performed by a team of physicians and research personnel who received technique instruction from emergency room and sports medicine physicians. The first step for all techniques was to untie the shoulder pads and unsnap the earpieces with a tongue depressor while a person above the patient stabilized the head.

Levitation

A person was stationed by the right shoulder of the construct and stabilized the spine with their hands on either side of the jaw and fingers wrapped around the construct's nuchal line. Their forearms were placed on the chest of the construct, under the shoulder pads, to provide additional stability and a tactile reference to the torso. With at least four assistants, the construct was lifted straight up completely off the table, taking care to keep the construct's head and torso horizontal. The helmet was then removed by the person at the top of the table with slight forward rotation of the helmet. The helmet should not be spread apart by the ear holes as this maneuver only serves to tighten the helmet on the forehead and occiput. The shoulder pads were then removed and the head and torso was lowered back on to the table.

Tilt

A person was stationed on the right side of the construct with one hand on the front of the jaw and the other hand posteriorly on the nuchal line. Three additional assistants were used to tilt the construct to about 50 deg at the waist, similar to the motion of a "sit-up." The person at the head of the bed then removed the helmet in a similar manner to the one used in the levitation technique. The shoulder pads are then removed. The person at the top of the bed again grasped both sides of the construct's head and assisted in stabilizing the neck as the construct's shoulders were lowered back to the table.

Figure 1 — Setup of specimen model placed supine on a narrow table to simulate a hospital gurney backboard.

Log Roll

A person stationed at the base of the neck stabilized the spine with their hands on either side of the jaw with fingers wrapped around the construct's nuchal line. The forearms were placed on the chest of the construct under the shoulder pads to provide additional stability. The helmet was then removed by the person at the head of the bed in the same manner as was used in the levitation and tilt techniques. The stabilization of the head was then passed to the individual at the head of the bed who placed their hands on either side of the occiput with their fingers wrapped around the nuchal line. Care was taken to ensure that hyperextension of the neck does not occur during this transition. Using four assistants, the construct was log-rolled to the right side and the shoulder pads were removed. Following removal of the shoulder pads, the construct was rolled supine and their head and shoulders were allowed to rest on the table.

The Polhemus FASTRAK system was used to record dynamic, real time six-degree-of-freedom motion at the anterior edge of the endplates of the C5-C6 disc. A matrix transformation was used to transform the reference frame of the Polhemus data from the transducers on the carbon rods to the fiducial points at the midsagittal anterioinferior point of the C5 vertebral body and midsagittal anterosuperior point of the C6 veterbral body on either side of the C5-C6 disc. The Denton six-axis load cell was used to measure axial and shear forces along with moments during all three methods of equipment removal. Each method was repeated three times for all specimens (Table 1). The technique order of helmet and shoulder pad removal was randomized for each specimen. Once each intact specimen had been tested, a catastrophic cervical spine injury was created at C5-C6 by sectioning the interspinous ligament, posterior longitudinal ligament, facet capsules, and posterior one-third of the annulus. This is a typical lesion present in the literature (Donaldson et al., 1998; Palumbo et al., 1996) as well as being indicative of the common flexion-distraction injury seen in high-impact sports (Banerjee et al., 2004). Each specimen was again tested using all three methods of equipment removal with three trials of each technique.

In the analysis of the results, the examined metric for each combination of specimen, method of equipment removal, and specimen stability (intact or lesioned) were averaged for the three trials. Metrics evaluated were the peak translation for the local C5-C6 region, peak shear, and peak moment in the transverse plane. Peak translation was the largest amount of displacement between fiducial points in a transverse plane constructed relative to the torso. A general linear model using within-subjects repeated measures analysis of variance was used to compare the three methods (SPSS version 10). If, after this ANOVA comparison, the group passed the $\alpha < .05$ criterion, pairwise comparisons were made using Fisher's least significant difference test at a threshold of $\alpha = 0.05$.

Results

Peak Translation

Peak local distraction was defined as the transverse plane translation between the C5 and C6 vertebral bodies. For intact specimens, ANOVA statistical significance was demonstrated for peak translations between the three techniques for posterior, right lateral, and left lateral distraction. A significant pairwise effect was seen between the posterior peak translation and the right peak translation of the tilt procedure compared with the other methods. A significant effect was also seen between the left peak translation of the levitation procedure compared with the other methods. This procedure demonstrated a trend toward increased anterior translation compared with the other methods and a larger sample size ($n = 9$, $\beta = 0.8$) would have demonstrated a statistical difference for the size of the effect observed in this study (Table 2; Figure 2).

For lesioned specimens, ANOVA statistical significance was demonstrated for anterior peak translations, although no method had a significant effect in the pairwise analysis (Table 2). A larger sample size ($n = 13$, $\beta = 0.8$) would have demonstrated a statistical difference for the size of the effect observed in this study (Figure 3).

Peak Shear Force

Shear was defined as the transverse plane shear forces produced between the head and base of the neck. Comparing peak shear between the intact and lesioned trials

Table 1 Testing Matrix Depicting Randomized Testing Protocol for Each Specimen

	S040327	s040342	c060112	c060350	c060357	c606430
Intact						
First	Logroll	Tilt	Levitate	Tilt	Levitate	Logroll
Second	Levitate	Logroll	Tilt	Levitate	Logroll	Tilt
Third	Tilt	Levitate	Logroll	Logroll	Tilt	Levitate
Lesion						
First	Levitate	Logroll	Tilt	Logroll	Levitate	Tilt
Second	Tilt	Levitate	Logroll	Tilt	Logroll	Levitate
Third	Logroll	Tilt	Levitate	Levitate	Tilt	Logroll

Table 2 Means, Standard Deviations, and *P* Values (Two Tailed) for Peak Anteroposterior and Lateral C5-C6 Distraction

Peak Distraction	Levitation-Roll	Levitation-Tilt	Roll-Tilt
Anterior Distraction [mm] Intact	ANOVA (P = 0.064, α = 0.05, *n* = 9 @ β = 0.8) L = 1.77 ± 0.68, *R* = 1.52 ± 0.31, T = 1.27 ± 0.27		
Posterior Distraction [mm] Intact	L = 0.10 ± 0.06, *R* = .10 ± 0.05, P = 0.98, α = 0.05	L = 0.10 ± 0.06, T = 0.38 ± 0.20, P = 0.024*, α = 0.05,	*R* = .10 ± 0.05, T = 0.38 ± 0.20, P = 0.031*, α = 0.05,
Right Distraction [mm] Intact	L = 0.53 ± 0.20, *R* = .61 ± 0.22, P = 0.53, α = 0.05	L = 0.53 ± 0.20, T = 0.13 ± 0.04, P = 0.005*, α = 0.05,	*R* = .61 ± 0.22, T = 0.13 ± 0.04, P = 0.003*, α = 0.05
Left Distraction [mm] Intact	L = 0.23 ± 0.09, *R* = .50 ± 0.25, P = 0.017*, α = 0.05,	L = 0.23 ± 0.09, T = 0.81 ± 0.44, P = 0.016*, α = 0.05,	*R* = .50 ± 0.25, T = 0.81 ± 0.44, P = 0.08, α = 0.05, (*n* = 13 @ β = 0.8)
Anterior Distraction [mm] Lesion	L = 2.31 ± 0.78, *R* = 1.98 ± 0.91, P = 0.053, α = 0.05, (*n* = 12 @ β = 0.8)	L = 2.31 ± 0.78, T = 1.81 ± 0.71, P = 0.06, α = 0.05, (*n* = 13 @ β = 0.8)	*R* = 1.98 ± 0.91, T = 1.81 ± 0.71, P = 0.297, α = 0.05,
Posterior Distraction [mm] Lesion	ANOVA (P = 0.21, α = 0.05) L = 0.17 ± 0.12, *R* = .42 ± 0.45, T = 0.43 ± 0.22		
Right Distraction [mm] Lesion	ANOVA (P = 0.055, α = 0.05, *n* = 9 @ β = 0.8) L = 0.58 ± 0.29, *R* = .87 ± 0.48, T = 0.37 ± 0.16		
Left Distraction [mm] Lesion	ANOVA (P = 0.129, α = 0.05) L = 0.35 ± 0.18, *R* = .82 ± 0.56, T = 0.77 ± 0.79		

Note. *Denotes significance. The *n* value denotes samples needed to obtain given significance α and power β, given the size of effect observed in this study.

for all transverse plane directions and methods displayed no statistical difference (α = 0.05).

For intact specimens, all directions of peak shear force in the transverse plane displayed ANOVA statistical significance. For pairwise comparisons, a significant effect was seen between the anterior and right lateral shear of the levitation procedure compared with the other methods. A significant effect was also seen between the posterior, right, and left lateral shear of the tilt procedure compared with the other methods. Finally, a significant effect was seen between the right lateral shear of the roll procedure compared with the other methods (Table 3; Figure 4).

For lesioned specimens, all directions of peak shear force in the transverse plane displayed ANOVA statistical significance except for left peak shear. For pairwise comparisons, a significant effect was seen between the anterior and right lateral shear of the levitation procedure compared with the other methods. A significant effect was also seen between the posterior and right lateral shear of the tilt procedure compared with the other methods. Finally, a significant effect was seen between the right lateral shear of the roll procedure compared with the other methods (Table 3; Figure 5).

Peak Moment

Moments were defined with the anteroposterior moment about the axis running medial-lateral, and the lateral moment being about the axis running anteroposterior in the transverse plane. These moments were produced between the head and base of the neck. Comparing peak moments between the intact and lesioned trials for all transverse plane directions and methods displayed no statistical difference (α = 0.05).

For intact specimens, all directions of peak moment in the transverse plane displayed ANOVA statistical significance. For pairwise comparisons, a significant effect was seen between the anterior and right lateral moment of the levitation procedure compared with the other methods. A significant effect was also seen between the posterior, right, and left lateral moment of the tilt procedure compared with the other methods. Finally, a significant effect was seen between the right lateral moment of the roll procedure compared with the other methods (Table 4; Figure 6).

For lesioned specimens, all directions of peak moment in the transverse plane displayed ANOVA statistical significance except for left peak moment. For pairwise comparisons, a significant effect was seen between the anterior and right lateral moment of the levitation procedure compared with the other methods. A significant effect was also seen between the posterior and right lateral moment of the tilt procedure compared with the other methods. Finally, a significant effect was seen between the right lateral moment of the roll procedure compared with the other methods (Table 4; Figure 7).

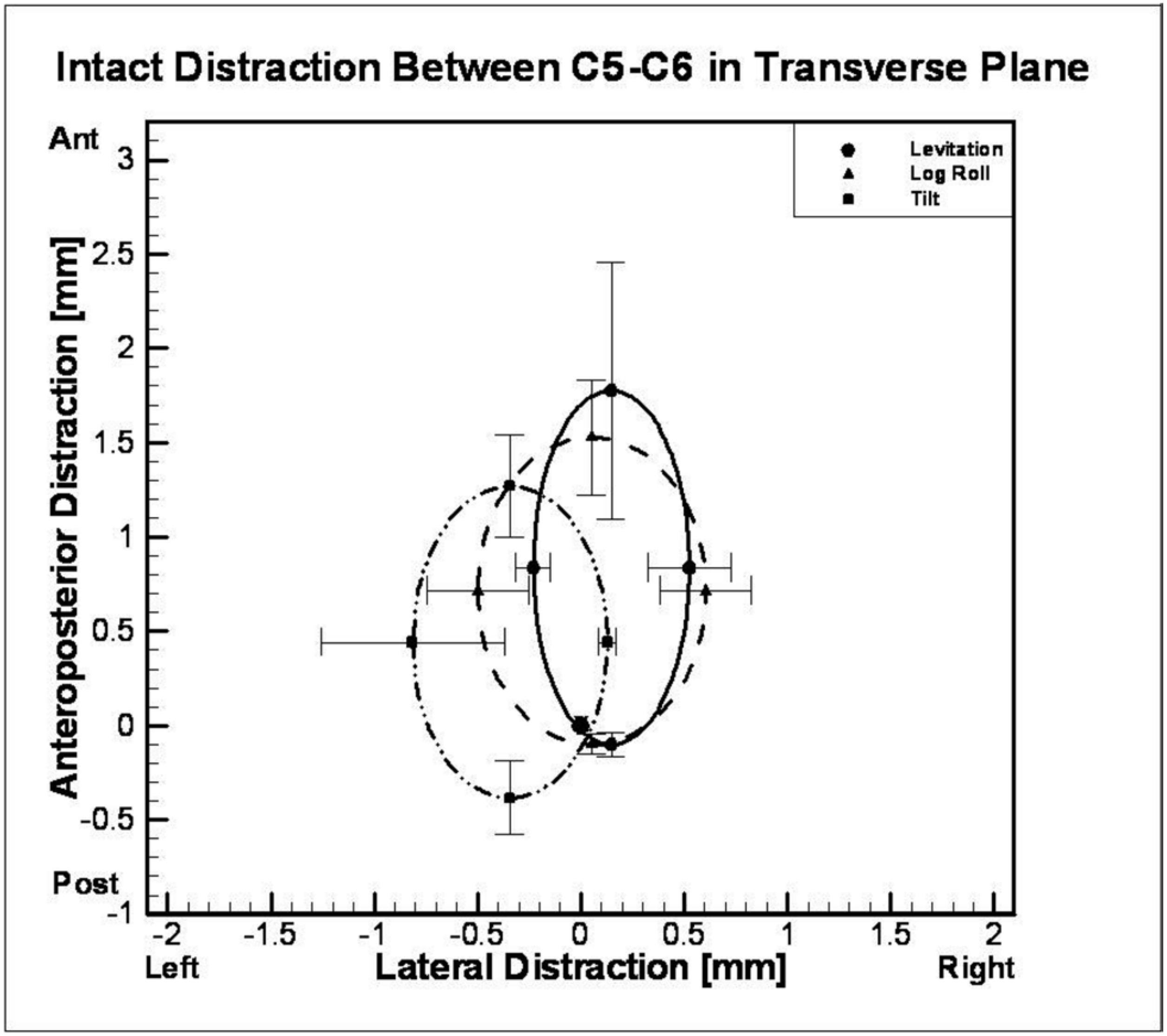

Figure 2 — Peak distractions between the C5-C6 level in the transverse plane for intact specimens.

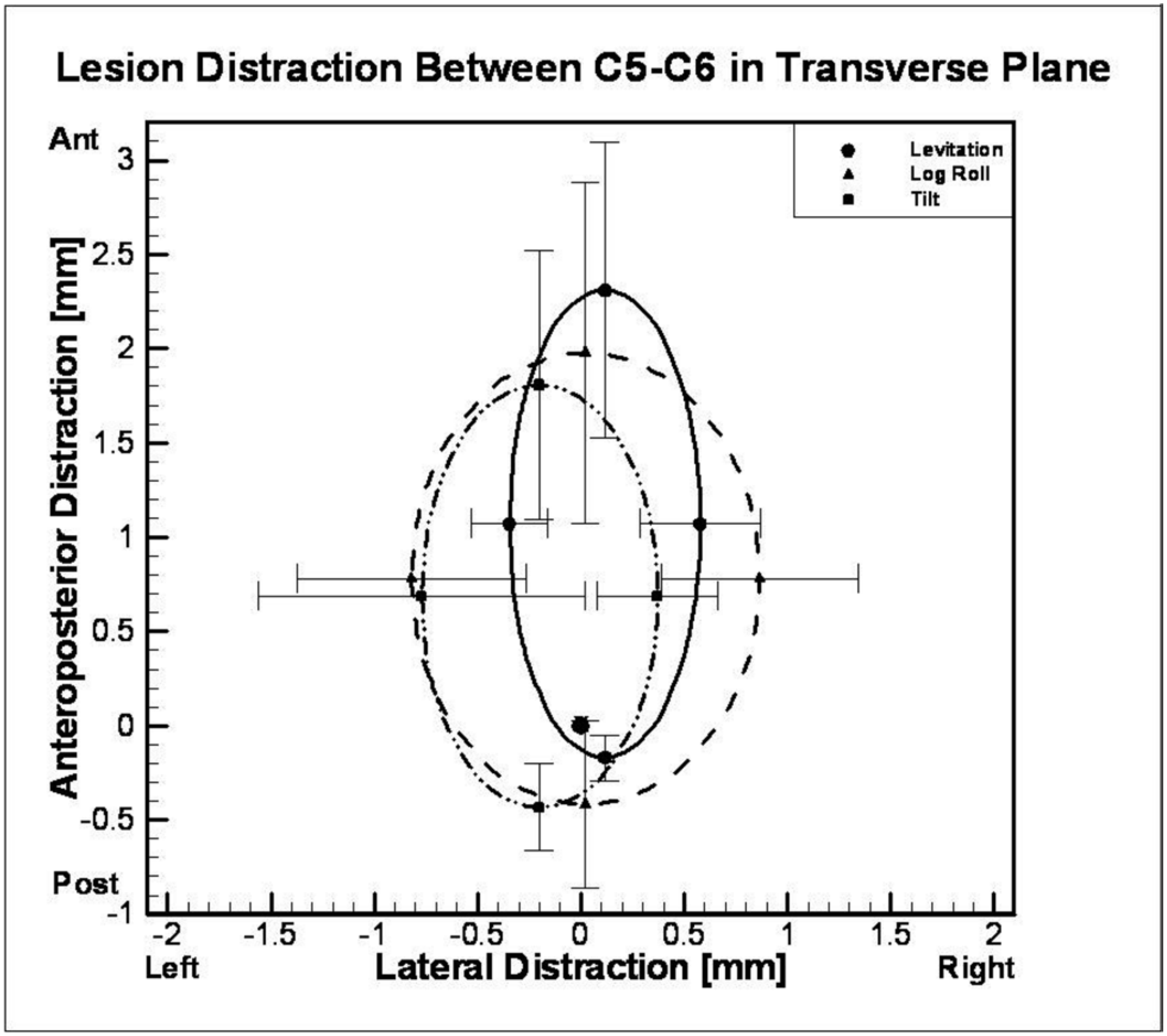

Figure 3 — Peak distractions between the C5-C6 level in the transverse plane for lesioned specimens. The lesion produced an increased instability most prominent during the roll procedure, as well as represented throughout by increased standard deviations for each direction.

Table 3 Means, Standard Deviations, and *P* Values (Two Tailed) for Anteroposterior and Lateral Shear

Peak Shear	Levitation-Roll	Levitation-Tilt	Roll-Tilt
Anterior Peak Shear [N] Intact	L = 49.1 ± 4.67, *R* = 35.4 ± 4.43, P = 0.01*, α = 0.05,	L = 49.1 ± 4.67, T = 32.6 ± 6.51, P = 0.01*, α = 0.05,	*R* = 35.4 ± 4.43, T = 32.6 ± 6.51, P = 0.180, α = 0. 05
Posterior Peak Shear [N] Intact	L = 4.30 ± 1.70, *R* = 5.68 ± 2.30, P = 0.31, α = 0.05	L = 4.30 ± 1.70, T = 20.9 ± 11.9, P = 0.019*, α = 0.05,	*R* = 5.68 ± 2.30, T = 20.9 ± 11.9, P = 0.026*, α = 0. 05
Right Lateral Peak Shear [N] Intact	L = 13.8 ± 4.15, *R* = 23.9 ± 2.91, P = 0.003*, α = 0.05	L = 13.8 ± 4.15, T = 6.78 ± 1.99, P = 0.005*, α = 0.05	*R* = 23.9 ± 2.91, T = 6.78 ± 1.99, P = 0.000004*, α = 0.05
Left Lateral Peak Shear [N] Intact	L = 8.46 ± 3.07, *R* = 7.39 ± 1.57, P = 0.211, α = 0.05	L = 8.46 ± 3.07, T = 14.4 ± 3.06, P = 0.031*, α = 0.05	*R* = 7.39 ± 1.57, T = 14.4 ± 3.06, P = 0.013*, α = 0.05
Anterior Peak Shear [N] Lesion	L = 48.9 ± 7.01, *R* = 33.0 ± 5.22, P = 0.005*, α = 0.05	L = 48.9 ± 7.01, T = 31.9 ± 4.75, P = 0.001*, α = 0.05	*R* = 33.0 ± 5.22, T = 31.9 ± 4.75, P = 0.755, α = 0. 05
Posterior Peak Shear [N] Lesion	L = 5.92 ± 1.86, *R* = 4.92 ± 2.13, P = 0.200, α = 0.05	L = 5.92 ± 1.86, T = 18.6 ± 9.52, P = 0.034*, α = 0.05,	*R* = 4.92 ± 2.13, T = 18.6 ± 9.52, P = 0.02*, α = 0. 05
Right Lateral Peak Shear [N] Lesion	L = 13.4 ± 2.04, *R* = 24.3 ± 4.00, P = 0.002*, α = 0.05	L = 13.4 ± 2.04, T = 8.07 ± 4.47, P = 0.013*, α = 0.05,	*R* = 24.3 ± 4.00, T = 8.07 ± 4.47, P = 0.001*, α = 0.05
Left Lateral Peak Shear [N] Lesion	ANOVA (P = 0.221 α = 0.05), L = 8.58 ± 2.33, *R* = 8.72 ± 4.38, T = 12.6 ± 6.80		

Note. *Denotes significance.

Discussion

The players most likely to sustain a catastrophic cervical spine injury in football are defensive backs (Boden et al., 2006) and the most common mechanism for sustaining this injury is flexion and axial loading that occurs during spear tackling (Torg et al., 1979; 1990; 1991; 2002). During a spear tackle, the neck is flexed to 30 degrees and the cervical spine is a straight column. If an axial force is applied to the head, the paravertebral musculature is no longer effective at dissipating this force, and the vertebral column fails in a flexion mode. In football players, paralysis in association with this injury often occurs in the subaxial spine, likely as a result of the relative narrowing of the spinal canal at these levels (Parke, 1988; Torg et al., 1991).

Equipment removal in the athlete with an unstable cervical spine is a complex procedure and it is unknown how much translation is safe before neurologic injury is precipitated or worsened. Any amount of abnormal intervertebral motion may cause damage, and in the subaxial spine (C3-C7), even small amounts of segmental elongation or deformation are not well tolerated (De Lorenzo et al., 1996; Lennarson et al., 2000). The ideal technique, though likely unattainable, would therefore result in no motion. The removal methods performed in this experiment were designed to simulate the conditions and care an actual construct would receive in the emergency room by a trained group of caregivers. When each method was compared before and after lesion, there was no statistical difference for shear or moment (α = 0.05, two tailed), denoting that the methods were performed reproducibly (Figures 4, 5, 6, and 7). Each of the tested methods also involved the removal of the helmet and shoulder pads simultaneously to diminish the chance of abnormal alignment that may occur with helmet removal alone (Donaldson et al., 1998; Palumbo et al., 1996; Swenson et al., 1997; Prinsen et al., 1995; Segan et al., 1993). The observed magnitude of the displacements, forces, and moments were not large (compared with failure data) and thus not indicative of injury. Although it is unknown how much translation is safe before neurologic injury is precipitated, none of the tested techniques of equipment removal exceeded White et al.'s (1975) radiographic criteria of more than 3.5 mm of translation to define an unacceptable amount of motion. However, none of the three techniques investigated were able to completely minimize motion and analysis of the local, C5-C6 region produced significant increases in the lesioned distractions as well as marked increases in variability (Figures 2 and 3). Each of the tested methods had its shortcomings, and personnel involved in the care of football players must be aware of the limitations of the technique they choose to employ.

The levitation technique has a tendency for anterior motion, seen by this technique having the largest local anterior displacement, shear, and moment as compared with the other techniques. The levitation technique is

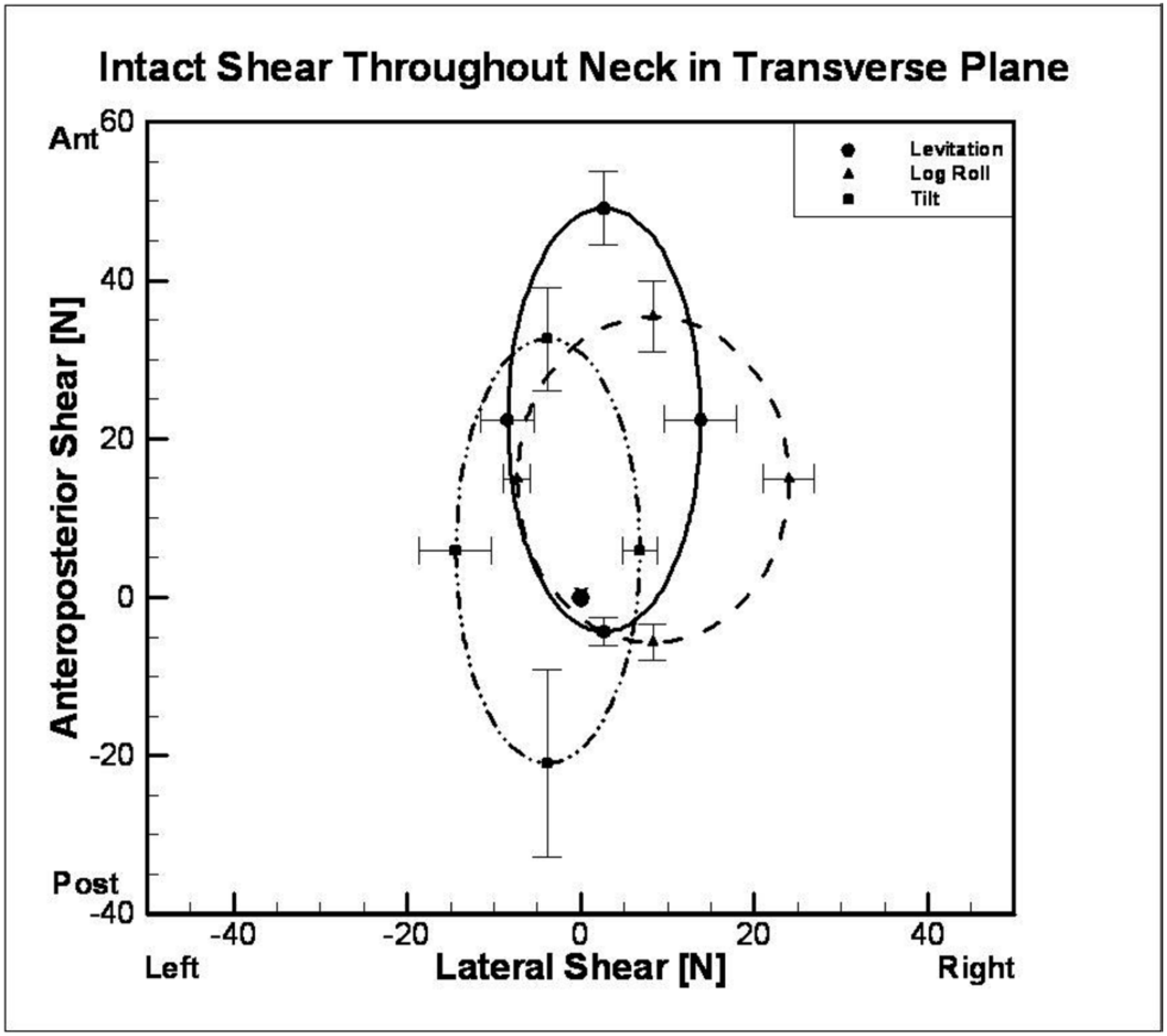

Figure 4 — Peak shear across the neck in the transverse plane for intact specimens.

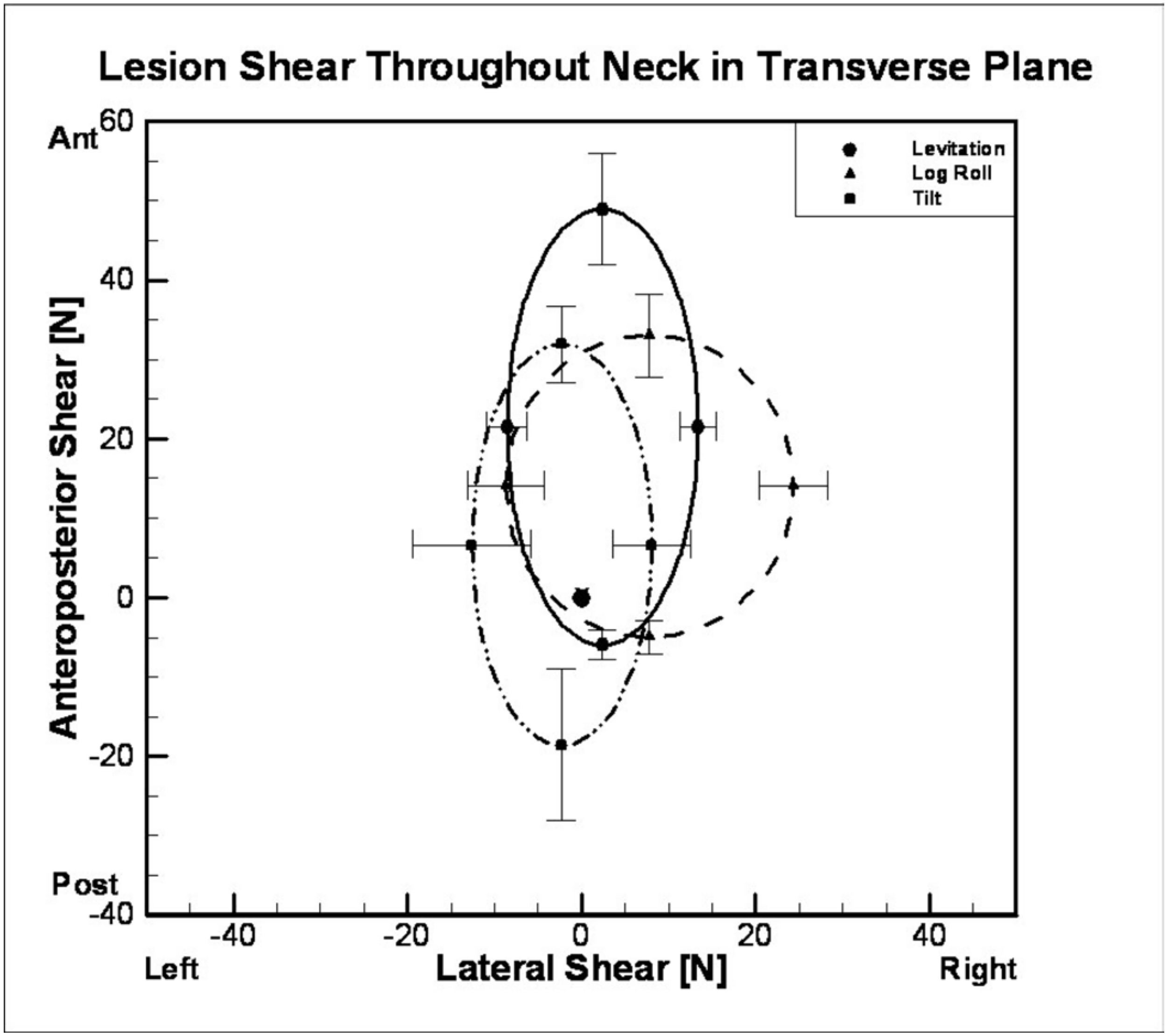

Figure 5 — Peak shear across the neck in the transverse plane for lesioned specimens. The similarity to the intact shear shows that the procedures were repeatable.

Table 4 Means, Standard Deviations, and *P* Values (Two Tailed) for Anteroposterior and Lateral Moment Peaks

Peak Moment	Levitation-Roll	Levitation-Tilt	Roll-Tilt
Anterior Moment [N-mm] Intact	L = 6919 ± 1110, *R* = 5172 ± 811, P = 0.019*, α = 0.05	L = 6919 ± 1110, T = 5034 ± 1073, P = 0.023*, α = 0.05	*R* = 5172 ± 811, T = 5034 ± 1073, P = 0.501, α = 0.05
Posterior Moment [N-mm] Intact	L = 839 ± 471, *R* = 1061 ± 612, P = 0.57, α = 0.05	L = 839 ± 471 T = 4247 ± 2521, P = 0.022*, α = 0.05	*R* = 1061 ± 612, T = 4247 ± 2521, P = 0.019*, α = 0.05
Right Moment [N-mm] Intact	L = 2093 ± 466, *R* = 2925 ± 321, P = 0.008*, α = 0.05	L = 2093 ± 466, T = 1024 ± 283, P = 0.0002*, α = 0.05	*R* = 2925 ± 321, T = 1024 ± 283, P = 000001*, α = 0.05
Left Moment [N-mm] Intact	L = 1233 ± 569, *R* = 1271 ± 375, P = 0.768, α = 0.05	L = 1233 ± 569, T = 2506 ± 999, P = 0.022*, α = 0.05,	*R* = 1271 ± 375, T = 2506 ± 999, P = 0.012*, α = 0. 05,
Anterior Moment [N-mm] Lesion	L = 6953 ± 1315, *R* = 5000 ± 834, P = 0.012*, α = 0.05,	L = 6953 ± 1315, T = 5121 ± 1179, P = 0.002*, α = 0.05	*R* = 5000 ± 834, T = 5121 ± 1179, P = 0.823, α = 0.05
Posterior Moment [N-mm] Lesion	L = 893 ± 296, *R* = 719 ± 343, P = 0.306, α = 0.05	L = 893 ± 296, T = 3612 ± 1940, P = 0.024*, α = 0.05	*R* = 719 ± 343, T = 3612 ± 1940, P = 0.019*, α = 0.05
Right Moment [N-mm] Lesion	L = 1878 ± 272, *R* = 2768 ± 572, P = 0.035*, α = 0.05,	L = 1878 ± 272, T = 1007 ± 646, P = 0.027*, α = 0.05,	*R* = 2768 ± 572, T = 1007 ± 646, P = 0.004*, α = 0. 05,
Left Moment [N-mm] Lesion	ANOVA (P = 0.105, α = 0.05) L = 1210 ± 512, *R* = 1439 ± 670, T = 2366 ± 1250		

Note. *Denotes significance.

also associated with right distractions, shears, and moments that are larger than the tilt procedure but smaller than the log roll procedure. This method displayed a trend of a doubled or greater standard deviation in left lateral displacements between intact and lesioned specimens (Figures 2 and 3). These findings raise the possibility that the forces on the cervical spine when performing this technique may therefore result in unwanted anterior or right lateral translation and increased variability in the left lateral directions for an unstable cervical spine.

The etiology of these forces likely stems from the person stabilizing the head during the lifting phase of the levitation procedure. The stabilization was done from the right side with their arms and back bent and their forearms resting on the chest of the model. To stabilize the head and themselves during the lifting of the construct the person must straighten their back, pulling to the model's right, which may explain the increased shear force and moment to the right lateral side observed with this technique. In addition, having the forearms resting on the chest of the construct to assist with head stabilization during the levitation procedure may result in the increased anterior shear and moment. As the construct is levitated, the person stabilizing the head tends to flex their biceps to compensate for the weight of the head and to assist in levitating the construct. This results in a lever action against the torso, pulling the head anteriorly causing flexion of the cervical spine. It is possible that this anteriorly directed force may be diminished if the person stabilizing the neck does not make an effort to assist in the levitation of the construct and instead concentrate on maintaining a constant degree of elbow flexion throughout the lifting procedure.

The tilt technique is currently recommended by NATA (Kleiner, 2003). Donaldson et al. (1998) performed a study using fluoroscopic imaging on C5-C6 injuries utilizing a similar technique of equipment removal. The tilt technique produces posterior motion, evidenced by the largest posterior displacement, shear, and moment as compared with the other techniques. The tilt technique is also associated with left distractions, shears, and moments that are also larger than the other procedures. This method displayed a trend of a doubled or greater standard deviation in right lateral and anterior displacements between intact and lesioned specimens (Figures 2 and 3). These findings raise the possibility that the forces on the cervical spine when performing this technique may therefore result in unwanted posterior or left lateral translation and increased variability in right lateral and anterior directions for an unstable cervical spine.

These motions may occur because the person stabilizing the head during the tilt procedure does so without having a tactile reference to the torso while holding the head and neck. The posterior shear may result from the person stabilizing the head having to “catch-up” with those persons tilting the torso, and therefore not lifting

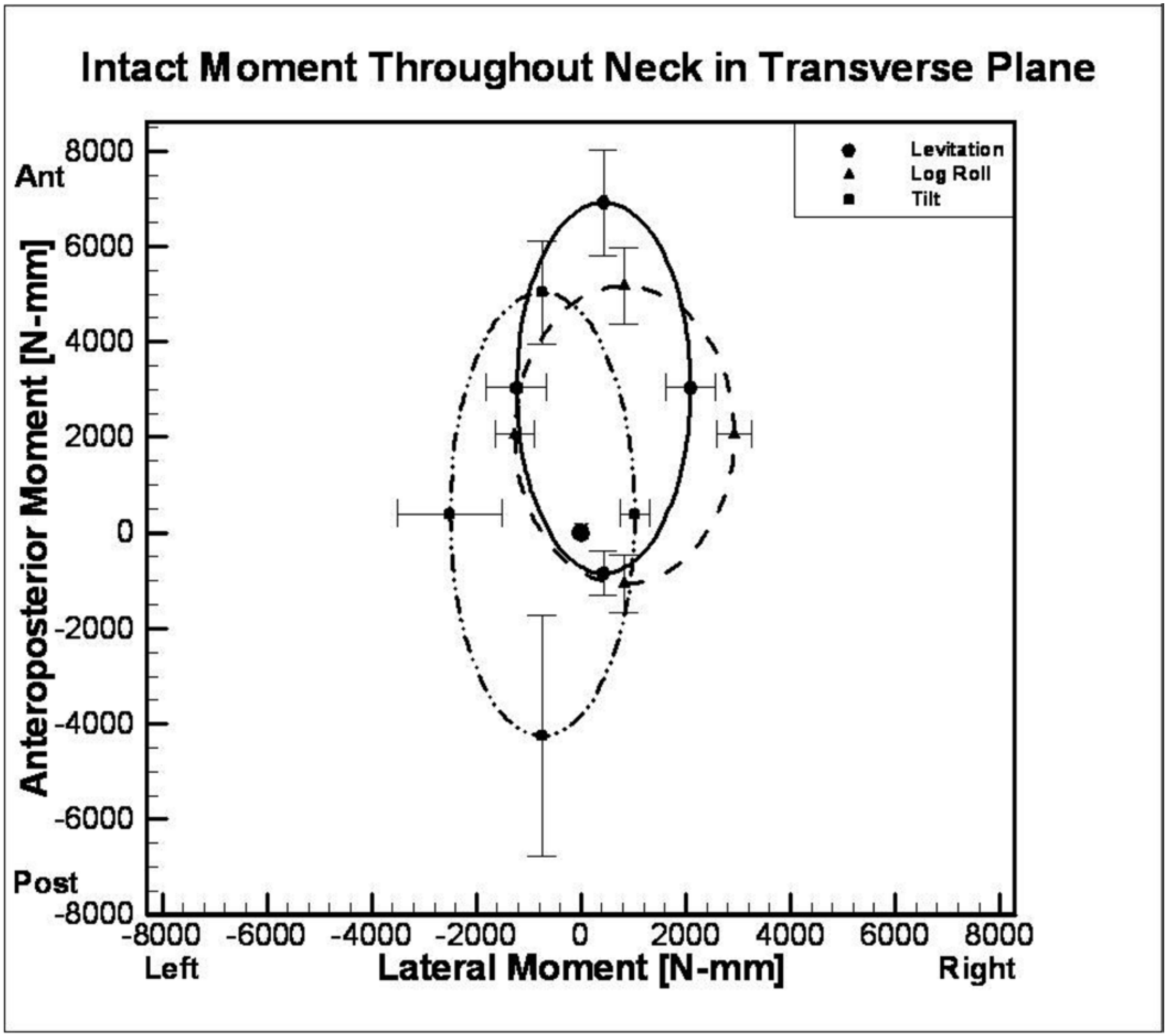

Figure 6 — Peak moment across the neck in the transverse plane for intact specimens.

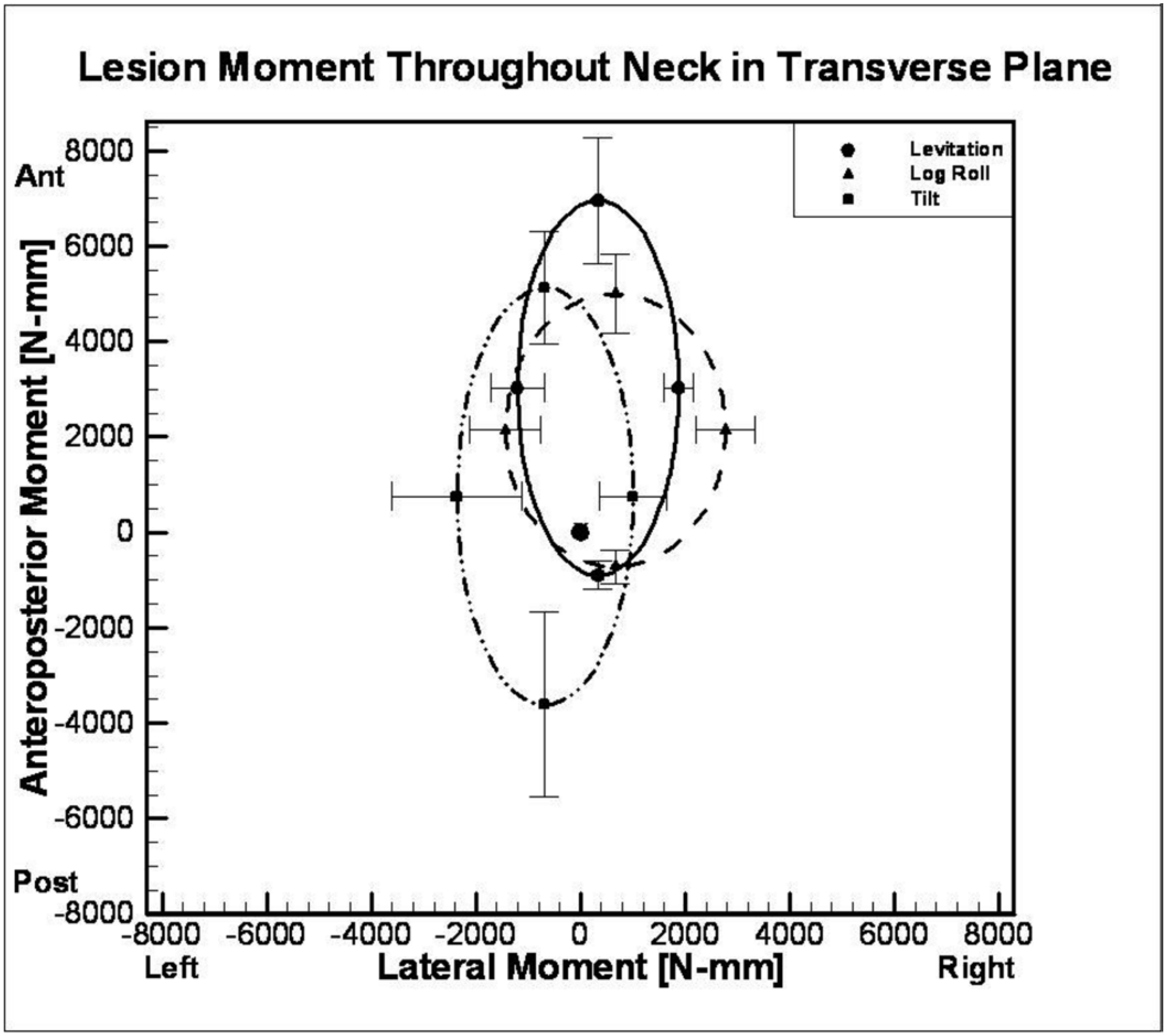

Figure 7 — Peak moment across the neck in the transverse plane for lesioned specimens. The similarity to the intact moment shows that the procedures were repeatable.

enough initially to offset gravity. The left lateral motion may stem from the person's tendency (stationed on the right) to extend and lock their arms (pushing to the left) as they flex their muscles to hold the weight of the head at a distance from their body. Both these effects may be diminished if the person stabilizing the head moves as close as possible and braces themselves by placing their elbows on the torso, allowing them to move in concert with the patient. As with the levitation procedure, care must be taken not to assist with tilting the patient, which may result in an increased anterior force.

The log roll technique produced the largest right lateral displacement, shear, and moment. This method displayed a trend of a doubled or greater standard deviation in both right and left lateral and anteroposterior displacements between intact and lesioned specimens (Figures 2 and 3). These findings raise the possibility that the forces on the cervical spine when performing this technique may therefore result in unwanted right lateral translation and increased variability in all transverse plane directions on an unstable cervical spine.

In the roll procedure, the specimen was tilted to the right side, therefore changing the direction of the head's weight vector from posterior in the supine position to right lateral when the specimen was tilted on the side. Because the person stabilizing the head stands superior to the specimen, and has no tactile reference to the torso, the changed force vector could cause a right lateral shear. The lack of tactile reference combined with the position of the person stabilizing the head could also be responsible for increased movement of an unstable spine in the transverse plane. The person stabilizing would have to change technique entirely to achieve a tactile reference. With this method the construct is not lifted so the likelihood of an increased anterior shear force is minimal. The trend of increased transverse plane movement variability in the lesioned specimen denotes that this method may be unwieldy for a severely unstable cervical spine.

Our study has a number of limitations. Previous authors evaluating the effects of equipment removal on the cervical spine have used radiographs or video fluoroscopy (Donaldson et al., 1998; Gastel et al., 1998; Metz et al., 1998; Palumbo et al., 1996; Meyer & Daniel, 1985) and have analyzed axial distraction for only helmet removal or resting spine alignment with various equipment attached, to which our results are not directly comparable. The Polhemus FASTRAK measurement system, however, has been demonstrated as a reliable and valid method for measuring cervical spine motion (Kleiner, 2003) and in combination with a Denton load cell we are able to obtain more information on the forces acting on the injured cervical segment than with radiographs or fluoroscopy. This would provide another assessment of intervertebral motion, and future studies should consider this when evaluating their method of recording data. The study is cadaveric in nature and results obtained in vitro may not completely correlate to those in vivo. In particular, musculature may or may not be active and the muscles also may passively provide resistance, though the muscles would not be extended out of their neutral zone in these procedures. In addition, the study was limited to the current number of specimens; however, statistically significant data were obtained. With additional specimen samples, many of the trends observed could be found to be statistically significant.

Although the results did not demonstrate an excessive amount of displacement, a closer look at the forces acting on the injured segment provides some insight into the advantages and disadvantages of each method. The levitation method of equipment removal resulted in a significant anterior shear force and moment, as well as a moderate right lateral shear force and moment. The tilt method resulted in a significant posterior shear force and moment, which in turn produced a significant posterior displacement. The log roll technique resulted in a significant right lateral shear force and moment. By examining the trends of increased variability of methods between intact and lesioned specimens, it was observed that the translational standard deviation was more than doubled in all lateral and anteroposterior directions for the log roll procedure. The levitation procedure doubled translational standard deviation in left lateral displacement, and the tilt procedure did so in right lateral and anterior displacement. Comparing these variabilities, it appears as though the log roll method becomes erratic with a lesioned, instable specimen (Figures 2 and 3). It would seem that the levitation method would be the most stable candidate based on its centered and minimum amount of distraction, shear, and moment, particularly if the anterior lifting tendency is eliminated.

Our model simulated the most common damage mechanism, a flexion axial load injury, which could be more susceptible to forces in the AP direction based on the morphological shape of the spinal canal. However, other injuries due to congenital instability such as extension and lateral stretch injuries are known to occur and may be sensitive to lateral forces (Funk & Wells, 1975). Therefore, based on the above results, caregivers may choose to avoid certain techniques with particular injuries or be wary of the aspects of a method that may produce unwanted forces. Hopefully, increased awareness of these shortcomings may spur development of improved techniques and enable caregivers to further minimize the risk of iatrogenic neurologic injury when using these methods.

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