Motion of a Cadaver Model of Cervical Injury During Endotracheal Intubation With a Bullard Laryngoscope or a Macintosh Blade With and Without In-line Stabilization

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Background: Endotracheal intubation in patients with potential cervical injury is a common dilemma in trauma. Although direct laryngoscopy (DL) with manual in-line stabilization (MILS) is a standard technique there is little data on the effect of MILS on cervical motion. Likewise there is little data available regarding alternative airway techniques in this setting. This study compared intubations with and without MILS in a cadaver model of cervical instability. We also used this model to compare intubations using DL with a Macintosh blade versus a Bullard laryngoscope (BL).

Methods: Complete C4–C5 disarticulations were surgically created in 10 fresh human cadavers. The cadavers were then intubated in a random order with either BL or DL with and without MILS. The motion at the unstable interspace was measured for subluxation, angulation, and distraction.

Results: MILS did not significantly affect maximal motion of this model in any of the three measures using either DL or BL. There were no clinically significant differences in maximal median motion in any of the three measures when comparing the two blades. However, there was significantly more variance in the subluxation caused by DL than by BL.

Conclusions: We were unable to demonstrate any significant effect of MILS on the motion of an unstable cervical spine in this cadaver model. The BL appears to be a viable alternative to DL in the setting of an unstable lower cervical spine.

Key Words: Endotracheal intubation, Cervical spine injury, Cervical spine instability, Endotracheal intubation techniques, Airway equipment.

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The need for endotracheal intubation of patients with known or potential cervical spine instability is a common dilemma in trauma. Direct laryngoscopy (DL) is known to cause considerable motion of the cervical spine in normal patients, primarily at the occipital-C2 segments and less so at C3 to C5.[1] Movement of the cervical spine at a site of spinal column instability might create or worsen a potentially catastrophic spinal cord injury, although the few case reports postulating this do not establish a clear link between intubation and the postoperative neurologic deficit.[2–4] Despite its clinical importance, the best approach to intubating a patient with an unstable cervical spine has not been established. A significant percentage of trauma airways are difficult.[5] A well-performed awake fiberoptic intubation may be the preferred technique when possible,[6] because awake intubation maintains spontaneous ventilation, allows a postintubation neurologic examination, and may be safer if patients are able to protect themselves from cervical injury because they are awake. However, awake intubation is often not feasible in the trauma patient because of time constraints, provider expertise, or lack of patient cooperation.

Attempts to assess the motion of cervical spines during laryngoscopy in trauma have used normal patients, a mixed population of patients with cervical injuries, or cadaver models with reproducible surgically created injuries (reviewed in Ref. 7). DL with manual in-line stabilization (MILS) is a very common technique.[8] Despite the fact that intubation with MILS is the recommendation of the American College of Surgeons Committee on Trauma,[9] it has not been established that MILS reduces overall motion of an unstable cervical segment during intubation. The use of MILS is supported by several moderate-sized clinical series[8,10,11] but is physically awkward to perform, can result in a poorer view of the tracheal opening during intubation,[12] and increases the time required for intubation.[13] The use of the gum elastic bougie in conjunction with MILS has been postulated to decrease cervical motion during intubation with MILS,[14] but this has not been tested by direct assessment of cervical motion in either normal or unstable spines.

Although alternative techniques such as rigid oral fiberoptic or lightwand intubation seem appealing because they cause less overt motion of the neck than does DL, few studies describe the motion of normal cervical spines during intubation with alternative methods and none have examined the effect of any alternative intubation technique on the motion of an unstable cervical spine. The Bullard laryngoscope (BL, Gyrus ACMI, Maple Grove, MN) is a rigid fiberoptic intubating device, which allows intubation in a neutral position with little overt cervical motion. We have found the BL clinically useful in the setting of cervical trauma, and there is a support for this practice from studies of patients with cervical immobilization.[13,15,16]

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However, like other alternative intubation techniques, there has been no direct examination of the effect of intubation with the BL on the motion of an unstable cervical spine.

For this study, we used a cadaver model of an unstable cervical spine to compare the motion of these spines during intubations using DL with a Macintosh blade and BL. Intact cervical spines in cadavers such as these have been demonstrated to mimic the motion seen in intact, anesthetized patients during DL and intubation.[17] The model of the injured cervical spine consists of a complete ligamentous disruption between the fourth and fifth cervical vertebrae, thus creating anterior and posterior instability. The purposes of this study were twofold: (1) to assess the effect of MILS on the motion of the unstable cervical segment during intubation with DL or BL, and (2) to compare the motion of the unstable cervical segment during intubation with the same two techniques.

MATERIALS AND METHODS

Ten fresh frozen cadavers, free of head or neck abnormality, were studied after thawing at room temperature. Six of the cadavers were men and four women; mean age at death was 75 (±15), mean BMI was 25.7 (±7.2), and mean time between death and data collection was 10 days (±5). Complete anterior and posterior C4-C5 disarticulations were surgically performed according to the method of Lennarson et al.[17,18] Anterior releases were performed sharply through an anterior cervical approach with complete disruption of the anterior longitudinal ligament, disc and annulus, and posterior longitudinal ligament. Posterior disarticulations were performed through a posterior approach with complete disruption of the C4–5 facet joints sharply and with curettes as needed. All incisions were closed at the fascia and skin with sutures. The independent motion of C4 and C5 during flexion and extension with the application of traction was confirmed manually after the disarticulation and again using fluoroscopy for each cadaver. Although formal measurements were not made, in every case the motion seen in all three variables was severalfold greater than that seen during any of the intubations. The cadavers were intubated using a 7.0-mm wire reinforced endotracheal tube in a random order with and without MILS using either DL with a No. 3 Macintosh blade or the BL. All of the intubations were performed by the same experienced laryngoscopist. The same senior neurosurgical resident performed MILS for all intubations by placing his index fingers in the external auditory canals, palms on the parietal bones, thumbs on the forehead, and remaining fingers under the mastoid processes without applying axial traction. Cadavers were manually returned to baseline using the fluoroscope after each intubation. MILS was applied before data collection began, and if MILS inadvertently caused distraction of the unstable segment this was relieved before data collection began. In each intubation, the minimal glottic visualization necessary to successfully intubate the cadaver was used. For Mac intubations, this involved visualizing the arytenoid cartilages and passing the endotracheal tube over them; for Bullard intubations, this involved visualizing the lower portions of the true vocal cords. Movement of the cervical spine during each intubation was recorded using video fluoroscopy. Images were continuously captured for all intubation sequences. After data collection were completed, digital stills from the fluoroscopy recordings were captured at five points during each intubation sequence: before laryngoscopy began (T1), when the laryngoscope blade entered the posterior pharynx (T2), when the laryngoscope blade was positioned for intubation (T3), when the endotracheal tube just reached the vocal cords (T4), and with the tube in place at the completion of the intubation (T5). Representative radiographs from each of these time points during a cadaver intubation with BL are shown in Figure 1. These time points correspond to baseline, L1, L2, tube, and post, respectively from the work of Lennarson et al. The fluoroscopic still images were then analyzed using the UTHSCSA ImageTool program V3.00 (University of Texas Health Science Center at San Antonio, TX; available from the Internet by anonymous FTP from http://ddsdx.uthscsa.edu/dig/itdesc.html) to measure changes in angulation and subluxation at the disarticulated interspace using consistent and reproducible boney landmarks on the vertebral bodies. In keeping with the method of Lennarson et al., subluxation was measured as the change in the relative anterior or posterior position of the C4 and C5 vertebral bodies to one another from a fixed horizontal line, angulation was measured as the change from baseline in the angles between C4 and C5 vertebral bodies, and distraction was

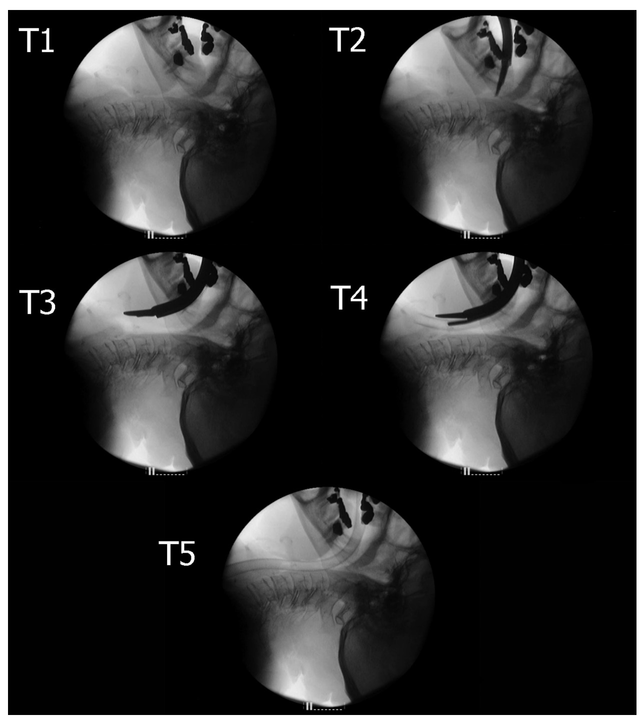

Figure 1. Representative still radiographs from the video fluoroscopic recording of a cadaver intubated using a Bullard laryngoscope. *T1* represents baseline, *T2* is when the tip of the blade is in the posterior pharynx, *T3* is when the blade is positioned for intubation, *T4* is when the endotracheal tube is in the glottic opening, and *T5* is at the conclusion of the intubation.

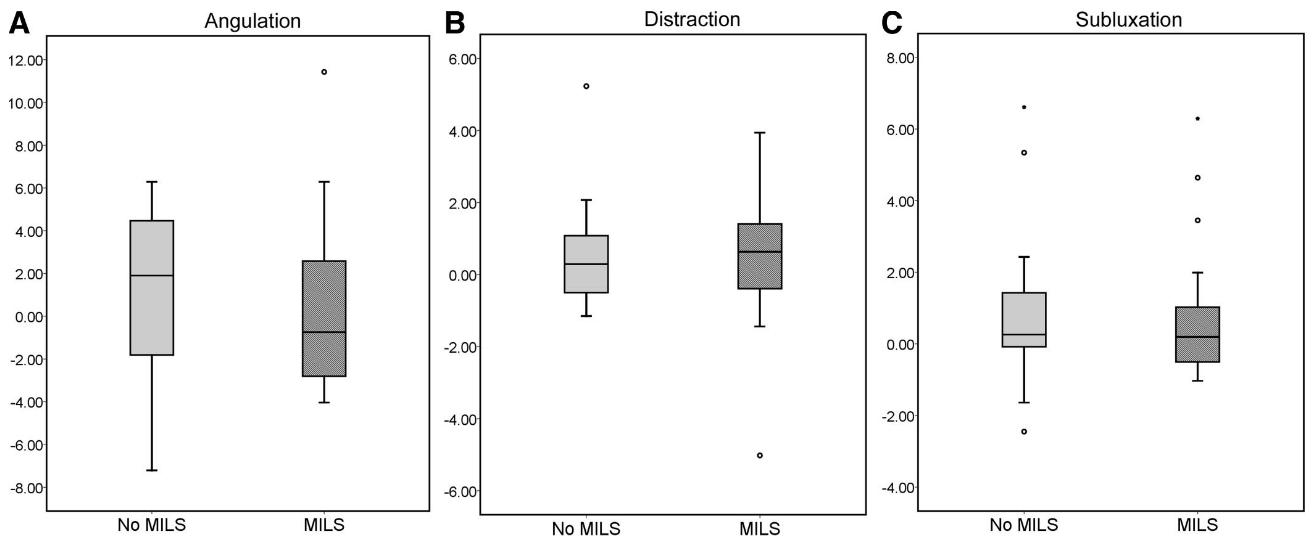

Figure 2. The maximal movement of the unstable cervical segment during intubation without and with MILS. Graph A displays angulation, Graph B displays distraction, and Graph C displays subluxation for intubations without and with MILS. Data from both Mac and Bullard intubations is pooled. Changes from baseline in angulation between C4 and C5 are expressed in degrees, whereas changes in distraction or subluxation at C4 to C5 are shown in millimeter. The box plots show group median (line), the middle two quartiles (within the boxes), the least and greatest data points within the 10th-90th percentiles (within the lines), and any outliers in the group (as solitary data points). There were no significant differences in either medians or variances between the two groups.

measured as the distance between the inferior posterior border of C4 and the superior posterior border of C5 along the axis of the spinal canal. For the purposes of this study, the maximum movement of the cadaver in these three dimensions at either T3 or T4 during each intubation was used in the statistical analysis.

STATISTICAL ANALYSIS

The distribution of measurements from the cadavers were assessed using the Kolmogorov-Smirnov test for normality. Because the data distributions were often not normal, median movements were compared using the Wilcoxon's signed-rank test. Levene's test for homogeneity of variance was used to compare variance, because this test is robust to non-normality of the data. All statistical analysis was performed using SPSS for Windows 15.0 and $p < 0.05$ was considered to be significant. SPSS was also used to create the graphs in the article.

RESULTS

Figures 2 and 3 show the maximal movement of the unstable cadavers at the C4–C5 interspace relative to baseline. Changes in subluxation or distraction at C4–C5 are shown in mm, whereas changes in angulation between C4 and C5 are expressed in degrees.

The maximum movements of the C4–C5 segments during intubation with and without MILS for both blades are shown in Figure 2. Maximal angulation during intubation is shown in Figure 2, A, distraction is shown in Figure 2, B, and subluxation in Figure 2, C. Application of MILS did not significantly change the median motion seen during intubation in any of the three measures. Median motions without and with MILS were angulation (1.9 vs. −0.74 degree), distraction (0.29 vs. 0.64 mm), and subluxation (0.26 vs. 0.20 mm). When the results were subdivided according to the blade used, no significant difference was seen for any of the three variables with either of the blades with or without MILS (data not shown).

The foregoing data showing that the application of MILS did not affect the motion of the unstable segment justified pooling these measures to compare cervical motion as a function of the blade used for intubation. Median maximal angulation during intubation is shown in Figure 3, A, distraction is shown in Figure 3, B, and subluxation in Figure 3, C. The maximal angulation at the unstable interspace caused by BL was significantly different from that caused by DL (−1.58 vs. 2.48 degree, $p < 0.05$, Fig. 3, A), although neither exceeded 2.5 degree absolute difference from baseline. BL caused statistically less maximal distraction at the unstable interface (−0.03 vs. 0.93 mm, $p < 0.05$, Fig. 3, B). Maximal median subluxation during laryngoscopy and intubation was not significantly different between the two blades (0.00 vs. 0.43 mm, Fig. 3, C). There were no significant differences in the variances between the two blades for angulation or distraction. However, there was significantly less variance in the maximal subluxation caused by BL than by DL (variance = 0.86 vs. 6.68 mm, $p < 0.05$, Fig. 3, C).

DISCUSSION

The motion of normal cervical spines during intubation using a variety of techniques has been well described (see Ref. 7). However, what is much less well understood is how that motion is affected by the presence of cervical instability.

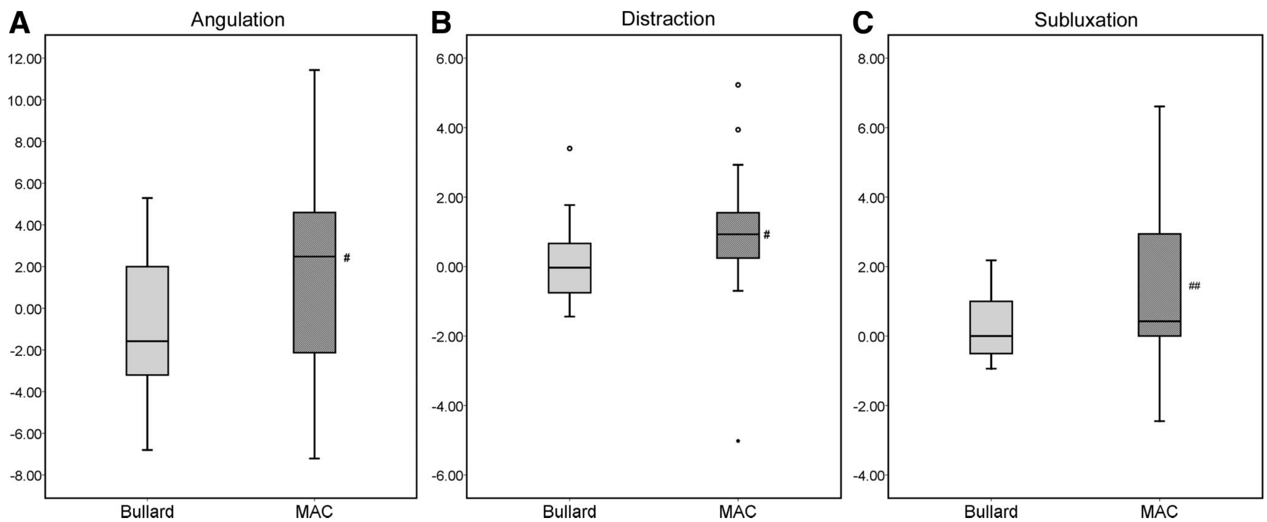

Figure 3. The maximal movement of the unstable cervical segment during intubation with the two laryngoscopes at each time point relative to baseline (*T1*). Graph A displays angulation, Graph B displays distraction, and Graph C displays subluxation for intubations using the Bullard laryngoscope or a Macintosh blade. Data with and without MILS is pooled. Changes from baseline in angulation between C4 and C5 are expressed in degrees, whereas changes in distraction or subluxation at C4–C5 are shown in mm. Box plots are defined as for Figure 1. Statistically different ($p < 0.05$) medians (#) and variances (##) are marked on the figures.

This problem is made more difficult by the variety of cervical injuries seen in clinical practice and the difficulties of performing cadaver studies on populations with representative classes of injury with the variety of airway tools that may be used.

The interpretation of the results of cervical spine studies depends in part on what constitutes normal physiologic motion of the cervical column. Under most circumstances, motion during intubation that is less than normal should be neurologically nonthreatening. Panjabi et al.[19,20] postulates that subluxation of less than 20% of vertebral body size (or 3 mm in adults), distraction less than 1.4 mm, and angulation of less than 11 degree constitute normal motions after correction for radiographic magnification.[17] It seems likely that the presence of preexisting cervical abnormality such as stenosis affects the neurologic consequences of these "normal" motions, but this is unknown.

There is no clearly preferred technique for endotracheal intubation in an unconscious or anesthetized patient in the presence of potential cervical instability. Indeed, it has been postulated that minimizing the risk of cervical cord injury during intubation depends more on the practitioner's awareness of the potential for cervical instability than on the particular technique chosen.[7] DL with MILS is a recommended approach with a long clinical history for airway management in patients with potentially unstable cervical spines to minimize the motion of the unstable cervical segment. It is an inconvenient technique that often results in poorer visualization of the laryngeal opening and longer duration of laryngoscopy than oral intubation without stabilization. Our results revealed no significant differences in maximal cervical motion at an unstable C4C5 interspace during intubation as a function of MILS.

In a study of 16 patients, Majernick et al.[21] demonstrated reductions in external measures of cervical motion during DL when MILS was compared with standard DL or DL with a Philadelphia collar. However, all of their patients had normal cervical spines and there was no direct assessment of the cervical spinal column. Hastings and Wood[12] showed that "best view" of the glottic opening could be achieved with less head extension in the presence of MILS, but this study also used patients with normal cervical spines and external measures of extension without direct assessment of cervical spinal column motion. Watts et al.[13] demonstrated radiographically that overall cervical extension (occiput-C5) was reduced to roughly half by the use of MILS for both Macintosh blades and the BL, but this study was performed in 29 patients with normal cervical spines and did not assess the effect of MILS on an unstable cervical segment.

Gerling et al.[22] studied the motion of an unstable C5–C6 segment in 14 cadavers using intubation by DL with three different blades. MILS reduced angulation, distraction, and subluxation, but the control intubations were performed with a cervical collar and no measurements were taken during standard laryngoscopy without MILS. It may be that a Philadelphia collar, by restricting motion at stable segments of the cervical column, accentuates the movement of the unstable segment. In addition, their results were published using measurements relative to vertebral body size as opposed to measurement of actual distances, thus making comparison difficult. Panjabi et al had reported in his study that 3 mm subluxation (20% of the adult vertebral body size) is the limit of physiologic motion, thus the motion seen in the study by Gerling et al. with or without MILS appears to be within physiologic limits.

For the purposes of assessing the effect of MILS on cervical motion, the study most directly comparable to ours is the one from which we took our model, that of Lennarson et al.[18] They were able to demonstrate eliminated distraction and decreased angulation at the cost of increased subluxation at the unstable C4–C5 segment when MILS was used. As with the present data, the differences were small and not clinically significant. The difference between the results of Lennarson et al. and ours is not clear but may have to do with differing cadaver populations. The median maximal motion of all three variables displayed by our cadavers was less and the variance appears to be greater than they reported. In any case, neither the study by Lennarson et al. nor our study provides support for the use of MILS in an effort to decrease overall motion at an unstable lower cervical segment.

Our results along with those of Lennarson et al. suggest that MILS does not clinically decrease total motion of an unstable interspace in the lower cervical spine. Furthermore, hypoxia is common and poorly tolerated in neurotrauma[23,24]; thus, since MILS increases the time required for and difficulty of intubation it may be decreasing rather than increasing patient safety. Although MILS is at present considered a standard of care, our results support releasing MILS if it interferes with intubation to minimize the extent and duration of potential hypoxia. Important caveats, however, are that the intubator (as in this study) must be aware of the potential for cervical instability and attempt to intubate with the minimum force and movement possible. In addition, it remains to be seen how well the data from studies of lower cervical injuries applies to injuries at the upper end of the cervical column.

Because of the inconvenience and difficulty of DL with MILS, alternative methods of airway management that cause less overt cervical motion are often advocated. The BL has been advocated on the basis of clinical experience.[25] Our results when comparing DL with the BL showed no difference in median angulation or distraction between the two techniques. Median angulation was significantly different between BL and DL (-1.58 vs. 2.48 degree) but in neither case was movement outside of physiologic norms. Median distraction, although statistically greater for DL, was not clinically greater (0.1 vs. 0.9 mm). Conversely, there was significantly more variance in the subluxation (but not angulation or distraction) caused by DL than BL, and three cadavers exceeded 3 mm subluxation during DL but none did during BL. Thus, in this model, the BL appears to have an advantage, at least in some of the cadavers.

Hastings et al.[15] performed a study on normal patients who underwent sequential laryngoscopy with Macintosh, Miller, and BLs using serial radiographs. They demonstrated in normal spines that the BL caused significantly less extension throughout the cervical column than did either of the direct blades. Overall cervical extension was 11 degree with the Mac blade as opposed to 2 degree with the Bullard, whereas occiput-C1 extension was 12 degree and 6 degree, respectively. Watts et al.,[13] in a similar study, demonstrated that cervical extension was reduced from 25.9 degree using a Macintosh blade without MILS to 5.6 degree using the BL with MILS, at the cost of prolonging the time to intubation by approximately 20 seconds. Cohn and Zornow[16] in a study of 17 adult patients with varying cervical abnormality were able to establish that Bullard visualization and intubation could be performed more quickly than fiberoptic bronchoscopy, but they did not assess cervical motion.

Our study focused on the motion of the unstable C4–C5 segment. Any motion at uninjured segments is overwhelmingly likely to be within physiologic limits, and therefore, of no clinical significance. There were no clinically significant differences in the maximal median motions of the unstable segment during intubation with a Mac blade or the BL for any of the three motions analyzed. Our data suggest that the Bullard is a viable alternative to DL in this setting and may indeed be a preferable to DL in patients with some kinds of cervical instability.

LIMITATIONS AND CONCLUSIONS

This model was developed to provide a reproducible cervical injury, which is so unstable that it is likely to show differences in motion between intubation techniques if any exist. Although cadavers have been shown to mirror the motion of intact cervical spines during intubation, it is conceivable that with the introduction of this injury that cadavers no longer model well the situation in a live patient. The soft tissue dissection performed to create the instability (which would likely not be seen to this extent in a traumatized neck) may further contribute to the ability of the unstable segment to move. However, the injury is so catastrophic that in patients it is not likely to be survivable. Although it is likely that data from cadavers with this severe injury is relevant to the care of patients with less unstable injuries that hypothesis remains to be tested. In addition, our focus on an unstable lower cervical interspace leaves open the question of what occurs with a higher injury. Because the majority of motion during a normal DL occurs from the occiput through C2, MILS or the choice of laryngoscopic technique may have effects with upper cervical fractures that we did not see at C4C5.

Cadaveric models have another major limitation in that they do not apply to the spectrum of cervical instabilities seen clinically. Cadaveric models have been chosen to provide a (small) population of cervical spines with reproducible injuries. Nevertheless, we saw substantial differences in the motion caused by laryngoscopy among the cadavers. Some cadavers, despite being demonstrably completely unstable, nevertheless displayed practically no motion at the unstable segment during any intubation, whereas others displayed dramatic motion. Subjectively, this appeared somewhat related to the difficulty of the laryngoscopy, although most of our cadavers were elderly and had cervical osteophytes that could also limit motion. Our study supports the conclusion that the cadavers, like patients, are not as reproducible as might be hoped.

In conclusion, this study of an unstable lower cervical spine revealed no clinically significant differences in the median motions of the unstable segment during intubation with or without MILS using either a Macintosh blade or a BL. These results suggest that the Bullard may be a useful alternative to DL with a Mac blade in the setting of lower cervical injury.

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