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Comparison of Four Airway Devices on Cervical Spine Alignment in Cadaver Models of Global Ligamentous Instability at C1-2

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Abstract

Background—The effects of advanced airway management on cervical spine alignment in patients with upper cervical spine instability are uncertain.

Methods—To examine the potential for mechanical disruption during endotracheal intubation in cadavers with unstable cervical spines, we performed a prospective observational cohort study with three cadaver subjects. We created an unstable, type II odontoid fracture with global ligamentous instability at C1-2 in lightly embalmed cadavers, followed by repetitive intubations with four different airway devices (Airtraq laryngoscope, Lightwand, intubating LMA, and Macintosh laryngoscope) while manual in-line stabilization was applied. Motion analysis data were collected using an electromagnetic device to assess the degree of angular movement in three axes (flexion-extension, axial rotation and lateral bending) during the intubation trials with each device. Intubation was performed by either an emergency medical technician or attending anesthesiologist.

Results—Overall, 153 intubations were recorded with the four devices. The Lightwand technique resulted in significantly less flexion extension and axial rotation at C1-2 than with the intubating LMA (mean difference in flexion-extension 3.2 degrees [95% CI 0.9 to 5.5], $p=0.003$; mean difference in axial rotation 1.6 degrees [95% CI 0.3 to 2.8], $p=0.01$ and Macintosh laryngoscope (mean difference in flexion extension 3.1 degrees [95% CI 0.8 to 5.4], $p=0.005$; mean difference in axial rotation 1.4 degrees [95% CI 0.1 to 2.6], $p=0.03$).

Conclusions—In cadavers with instability at C1-2, the Lightwand technique produced less motion than the Macintosh and intubating LMA.

INTRODUCTION

Frequently, patients presenting with known or suspected cervical spine disease have other conditions that necessitate rapid advanced airway management to prevent further harm. Neurologic injury may occur in these patients as a consequence of mechanical disruption at the level of instability. However, neurologic injury may also result from a systemic decrease in oxygen delivery as a result of hypoventilation and hypoxemia from a prolonged or failed intubation technique. In patients with upper cervical spine instability requiring intubation, the best technique should be rapid, efficacious, and be associated with as little mechanical disruption and cardiopulmonary compromise as possible.¹⁻⁶

The technique most appropriate for achieving successful endotracheal intubation in the patient with upper cervical spine instability is unknown. Techniques that minimize cervical movement, theoretically, offer an advantage.

Previous work on this topic evaluated different techniques of airway management on cervical alignment with a variety of subjects,⁶ including anesthetized adult patients without cervical spine disease undergoing elective intubation, adult patients presenting for elective

surgical management of cervical spine disease, retrospective studies of trauma victims who required intubation, and cadavers with unstable cervical spines.

Our primary hypothesis was that the magnitude of flexion-extension movement during endotracheal intubation in cadavers with a simulated type II odontoid fracture would differ among the airway devices. Cadavers were used similar to others.⁷⁻²¹ We created global ligamentous instability at the C1-2 segment (simulated type II odontoid fracture) in fresh cadavers, followed by intubation with four airway devices [Airtraq Optical Laryngoscope (AT), King Medical Systems, Newark, DE; Fastrach LMA (ILMA), LMA North America, San Diego, CA; Lightwand (LW), Bovie Aaron Medical, St. Petersburg, FL; and Macintosh laryngoscope (MAC), SunMed, Largo, FL] while recording displacement in three dimensions with electromagnetic motion analysis. No previous work has evaluated the AT against these other devices with global instability at the C1-2 segment.

MATERIALS AND METHODS

In this IRB-exempt, observational cohort trial, we measured the angular movement of four different airway devices in cadavers with created global ligamentous instability at the C1-2 segment. Secondary outcomes examined the correlation of movement across all axes, as well as the correlation between the time required for intubation and movement in each separate axis.

Three lightly embalmed cadavers were used. The cadaver subjects underwent the embalming process within 24 hours of death as per institutional requirements for whole body anatomical gifts. This embalming process preserves the tissues without adversely affecting the soft tissue mechanical properties. The stiffness of the joints and tissues of these cadavers was grossly similar to that of fresh cadavers. The light embalming process allowed a longer period of cadaver use before significant tissue degradation occurred, and enabled completion of the experimental protocol. The light embalming formula is a mixture of formalin and glycerin, with less formalin than is used in traditional embalming. The cadavers were stored in a cooler to preserve tissue, but testing was done at room temperature. The three cadavers were a mean age and weight of 83.3 years (range 79 - 85) and 61.2 kg (range 58.3 – 63.5 kg), respectively. The range of motion prior to the creation of spinal instability was similar to that reported in normal geriatric adults²²⁻²⁴ (Table 1). An unstable spine was simulated by the surgical creation of a complete segmental injury in the cadavers, resulting in global instability. To standardize the injury, all of the lesions were created at the C1-2 spinal segments by the same surgeon. The lesion involved the creation of a posterior ligamentous resection between C1-2 and a transverse odontoid osteotomy, simulating an unstable type II odontoid fracture. These cadaver subjects were part of a series of investigations of medical interventions on the alignment of the unstable cervical spine.^{13,14,21}

Two attending anesthesiologists and three emergency medical technician paramedics were involved in the investigation. Emergency medical technician paramedics are allowed, under New York state law, to provide advanced airway management, including rapid sequence intubation and cricothyrotomy. The providers were instructed by one of the attending

anesthesiologists in the technique to be used during this investigation. The providers were then allowed time to practice with each device until they were comfortable with the technique. Prior experience with each device was not recorded. After this training period, each provider intubated each cadaver three times with each intubation device, in random order, following the same technique. All intubations were performed from the head of the supine cadavers with a 7-mm internal diameter endotracheal tube (ETT). All three cadavers were not able to be intubated by all five practitioners due to unavailability. An electromagnetic motion analysis device (Liberty device; Polhemus Inc., Colchester, VT) was used to assess the amount of angular and linear motion during each maneuver as in previous studies.^{7-19, 21} In short, the Liberty device uses electromagnetic fields to establish the three-dimensional position and orientation of its sensors. It can detect angular motions with a precision of 0.3°. For our current study, sensors were affixed to C1 and C2 posteriorly with custom-made fiberglass mounting brackets, and positioning data were recorded at a sampling rate of 240 Hz. The relative motion produced between C1-2 was measured as each intubation technique was applied to the cadavers.

All data were recorded directly from the Liberty device to a laptop computer. The method of calculating angular motion in each axis is described in our previous publications.^{7-19,21} Angles were calculated using the Tilt-Twist method described by Crawford.²⁵

The cadavers were placed in the supine position. Manual in-line immobilization (MILI) was maintained for all test trials. The procedure for applying MILI was done by a single physician with over 20 years of experience in caring for spine-injured patients. The cadaver's head was held at the temples in a neutral position throughout the intubation attempt. Neither cricoid nor thyroid pressure was used in this study. A flexible fiberoptic bronchoscope was used to confirm intubation.

With regard to the AT, the technique used for intubating the cadavers was based on instructions provided by the Airtraq Optical Laryngoscope website.[Footnote A] An AT Regular (Size 3) device was used.

The ILMA used for all intubations was a Fastrack LMA, Size 4 (LMA North America, San Diego, CA), and the technique used was blind intubation, as delineated in the manufacturer's instruction manual.[Footnote B] Once the ETT was deemed to be in the trachea, the ETT connector was removed, the ILMA cuff was deflated, and the ILMA was withdrawn over the ETT.

For all intubations, the LW used was the Surch-Lite 15" (Aaron Medical), and the technique employed with this device was as described by Liem et al.[Footnote C]

Footnote A: Airtraq® Guided Video Intubation. Available at: <http://www.airtraq.com/airtraq/portal.portal.action>. Accessed September 15, 2011.

Footnote B: Instruction Manual, LMA Fastrack Reusable & LMA Fastrack Single Use, revised 2006. San Diego, CA: LMA North America; Revised 2006. Available at: http://www.lmana.com/docs/LMA_Fastrack_manual.pdf. Accessed September 15, 2011.

Footnote C: Liem EB. Lighted Stylet Intubation. The Virtual Airway Device. Intubation Techniques and Tutorials. The University of Florida Center for Simulation, Advanced Learning and Technology, Gainesville, FL. Available at: <http://vam.anest.ufl.edu/airwaydevice/lightedstylet/index.html>. Accessed September 15, 2011.

A standard Macintosh size 3 blade was utilized for all MAC intubations. For all intubations with this device, the blade was held in the operator's left hand, and was placed in the right corner of the cadaver's mouth while the tongue was swept to the left. The blade was advanced along the floor of the mouth, and was lifted in an anterior-caudad direction to expose the glottis to direct vision. Once the glottis was visualized, the ETT was advanced with the right hand into the glottis under direct visualization. If the glottis was not visualized, the blade was slowly withdrawn. If the glottis was still not visualized, the blade was removed and reintroduced, repeating the technique until the glottis was visualized and the trachea was intubated. A malleable stylet was placed in the lumen of the ETT to assist with all MAC intubations. The technique was concluded when the stylet was removed from the ETT after intubation.

Each technique was attempted up to three times per trial, and each trial was repeated for a total of three trials per airway device with each practitioner and cadaver. If the above maneuvers still failed, the overall attempt was considered a failure.

A linear mixed model was first applied to compare movement in each axis during intubation. A review of the residual plots of random effects did not demonstrate gross departures from normality. In this model, the axes of flexion-extension, lateral bending, and axial rotation were compared as direct effects on the dependent variable of movement. The cadaver and airway device were considered random effects, and the identity of the person performing the intubation as the subject random effect. The identity of the intubating individual was entered as the subject random effect in order to test the general random effects according to the intubating individual. The Kenward-Roger method was used to calculate the denominator degrees of freedom due to the unbalanced study design.²⁶ Comparisons of movement in each axis were conducted by the differences between least squares means. Correlations among axes of movement were then examined using a simple Pearson correlation, with normality assumed by the central limit theorem. To examine the association between time required for intubation and movement at C1-2, a Spearman rank correlation was performed between time required and each axis separately and plotted using a locally-weighted regression plot.

The primary outcome, the effect of the airway device on movement at the C1-2 level, was then examined using a mixed models approach. Each axis was treated as a separate outcome. The airway device was entered into the model as a fixed effect, and the person intubating as the subject random effect. The cadaver and the interaction between airway device and cadaver were entered as general random effects. Denominator degrees of freedom were calculated using the Kenward-Roger method due to the unbalanced study design. Summary statistics of movement along each axis were reported for each airway device, as was the statistical significance of the airway device's contribution to movement along each axis. Results were reported as means with 95% confidence intervals for all continuous data, along with mean differences with adjusted 95% confidence intervals, using least square means methods for comparisons where appropriate. The Tukey-Kramer method was used to adjust for multiple comparisons, and adjusted p-values were reported. For all analyses, alpha was designated as 0.05. Data were analyzed using SAS 9.2 (SAS, Cary, NC).

RESULTS

Overall, 153 intubation trials were conducted for each of the three axes of movement. Our providers failed to intubate with the ILMA on 3 of 39 attempts. All other intubations were successful. Motion data was analyzed only with successful intubation. Table 2 details the number of intubations performed by each provider.

First, we assessed the overall impact of intubation on movement. Overall, the most significant movement was noted in the flexion-extension axis. Movement in the flexion-extension axis was greater than both lateral bending (mean difference 3 [95% CI 2.4 to 3.5], $p<0.0001$) and axial rotation (mean difference 3.1 [95% CI 2.5 to 3.6], $p<0.0001$), with no evidence of a significant difference between lateral bending and axial rotation (mean difference 0.1 [95% CI -0.4 to 0.7], ($p=0.86$) (Figure 1). Movements during intubation significantly correlated with all measured directions of movement (FE by LB Spearman $r=0.5$ [95% CI 0.4 to 0.6], $p<0.0001$; FE by AR Spearman $r=0.7$ [95% CI 0.6 to 0.8], $p<0.0001$; AR by LB Spearman $r=0.5$ [95% CI 0.4 to 0.6], $p<0.0001$). The time required for intubation is significantly correlated with movement for all axes ($r=0.6$, $p<0.0001$) (Figure 2).

Summary statistics are listed in Table 3 that describe the movement along each axis by the airway device. Overall, the airway device had a statistically significant effect on motion in flexion-extension ($p=0.002$) and axial rotation ($p=0.007$), but not on lateral bending ($p=0.10$) axes of movement. For flexion-extension and axial rotation, the LW technique resulted in significantly less movement than with the ILMA (mean difference in flexion-extension: 3.2° [95% confidence interval 0.9 to 5.5°], $p=0.003$; mean difference in axial rotation 1.6° [95% confidence interval 0.3 to 2.8°], $p=0.01$) and MAC (mean difference in flexion-extension 3.1° [95% confidence interval 0.8 to 5.4°], $p=0.005$; mean difference in axial rotation 1.4° [95% confidence interval 0.1 to 2.6°], $p=0.03$). Tables 4-6 depict the statistical comparisons between each device in the three degrees of motion evaluated.

DISCUSSION

Management of the airway during elective intubation in the patient with upper cervical spine disease affords the practitioner several options, including awake flexible fiberoptic intubation with awake positioning and serial neurologic assessments. However, fiberoptic intubation is impractical due to the longer time required for intubation in emergency situations.²⁷ In addition, patient cooperation is usually required for awake fiberoptic intubation, and, as such, patients requiring emergency intubation may offer far fewer alternatives for the safe management of the airway.

Occasionally, rapid and effective advanced airway management must be completed in the patient with known or suspected upper cervical spine instability in the prehospital setting. Neurologic injury may occur due to mechanical disruption at the unstable segments, but care must also be taken to not compromise global perfusion and oxygen delivery with multiple prolonged intubation attempts or failed intubation, which could also exacerbate neurologic injuries. Therefore, consideration for speed and success of intubation must be weighed

heavily due to the likely harm from failed intubation, with resultant hypoxia, hypercarbia, risk of aspiration, and unrecognized esophageal intubation.¹⁻⁶

We have shown that the LW technique created the least flexion-extension and rotational motion at C1-2 during advanced airway management with in-line stabilization while the ILMA and MAC produced the most movement. Progression of neurologic injury in patients with upper cervical spine disease is common, but the exact cause of the deterioration remains unclear. Expert opinion, in general, recommends minimizing cervical spine movement. Previous investigations considered a 10 to 30% reduction in motion to be a clinically significant result.^{28,29} In cadavers with a simulated type II odontoid fracture, the LW technique resulted in more than three degrees less extension than with the ILMA and MAC, which represents more than a 40% reduction in extension over the ILMA and MAC techniques. Whether just over one degree less rotation is clinically relevant between the LW and the ILMA and MAC is less certain. The correlations between the time required and magnitude of movement were low and of questionable clinical relevance.

Direct visualization from the oropharynx to the glottis with techniques such as the MAC typically requires the patient to assume the “sniffing position,” with extension of the upper cervical spine and flexion of the lower cervical spine.³⁰ Therefore, there are theoretical benefits to devices that facilitate intubation without direct visualization, such as the LW, AT, and ILMA. A number of studies have evaluated cervical spine motion utilizing various techniques. The reported extent to which each cervical segment is displaced is variable, depending on which segment is measured, how the displacement is measured, and which population is studied. In the published literature, the range of reported cervical spine extension created by direct visualization with techniques such as the MAC at the C1-2 segment is as low as 4° and as high as 13.5°.^{20,31-38} Techniques such as the LW have been reported to produce approximately 2° of extension at the C1-2 segment.³⁶ With indirect visualization techniques, such as the AT, Bullard, and Glidescope, the range of reported cervical spine extension at C1-2 is 3 to 10.4° with the AT, 2.6 to 4.5° with the Bullard, and 4 to 7° with the Glidescope.³⁴⁻³⁹ The impact of the ILMA technique on cervical spine extension at C1-2 has also been reported from less than 1° to 5°.⁴⁰⁻⁴²

Our results lie within these ranges for all techniques, except for the ILMA, with which we found a mean degree of extension of 7.43°. This difference highlights the strengths and weaknesses of our study methods. We used electromagnetic motion analysis to assess motion at the unstable segment, and were able to directly and simultaneously track displacement in three dimensions. The previously cited studies only used lateral fluoroscopic images to measure motion in two dimensions. Fluoroscopy has a number of significant limitations, most notably the interobserver variation in measurements. In addition, the Polhemus device is extremely accurate and able to detect differences in angular motion to 0.3°. We used cadavers with a created global instability at C1-2 while most other investigations used normal adult patients undergoing elective surgical procedures. The use of cadavers allowed us to repeatedly study the worst possible instability under the same patient conditions, thus limiting the variability in motion due to the variable airway anatomy between patients. While the use of cadavers may be considered a weakness due to tissue degradation and rigor, we used only lightly embalmed cadavers to attempt to make the

situation as close to *in vivo* as possible. The range of motion prior to the creation of instability was similar to that reported in normal geriatric adults. Another limitation of our study is the variability introduced by the heterogeneity in the experience and background of our practitioners. We included five providers, two attending anesthesiologists, and three emergency medical technician paramedics who utilized the same techniques to intubate. These groups have significant differences in levels of academic accomplishment, training, and experience; however, these practitioners may be representative of those called upon to provide advanced airway support to the patient with a known or suspected unstable cervical spine. Practitioners will have broad differences in experience with different techniques. Further, the prehospital use of these and other similar airway devices, such as the AT, GlideScope, C-MAC, LW, and supraglottic airways like the ILMA, used by emergency medical technicians and other types of providers has been documented.⁴³⁻⁵² Therefore, we believe the results recorded in our study may reflect the care provided to a patient with a known or suspected unstable spine. The variance imparted by the practitioners' differing backgrounds in airway management and cadavers in an unbalanced, repeated-measures design was managed through the use of mixed models. Unfortunately, we discarded the data of three unsuccessful intubations with the ILMA prior to analysis. The data analyzed in this study was only from successful intubations.

This is the first study to evaluate the AT in subjects with C1-2 instability and compare the use of the AT to other devices in a controlled, reproducible manner. These four devices were selected for study because they are amenable for use in a wide array of settings, including the prehospital setting, since they are simple, inexpensive, and portable. Each technique was shown to have some advantages over the others in terms of speed, success rate, and cervical spine motion. It must be recognized that while the ILMA required the most time to complete by our practitioners, intermittent ventilation could continue during the procedure, and, although it had a lower success rate for our providers when using the blind technique, an improved success rate would be expected if a flexible fiberoptic scope was used to facilitate ILMA intubation, although that was not tested.

In conclusion, during intubation of the cadavers with created global instability at C1-2 (simulated type II odontoid fracture), the LW technique resulted in significantly less extension and axial rotation at C1-2 than with the ILMA and MAC techniques.

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Figure 1.

Overall distribution of movement of all devices. Motion in flexion-extension was significantly greater than axial rotation or lateral bending. No difference was found between axial rotation and lateral bending.

Figure 2.

Locally weighted regression plots demonstrating the correlation between time to intubate and increased motion in each axis.⁵³ The solid line is obtained by first degree LOESS (local regression) using smoothing parameters 0.67 for FE, 0.62 for LB, and 0.76 for AR; these were automatically determined minimizing the corrected Akaike information criterion (AICC). Shaded region represents a 95% confidence interval based upon the mean predicted value for each observation. Spearman rank correlation coefficients are also reported to demonstrate a correlation between time to intubate and increased motion in each axis.

Table 1

Mean and Range of Motion of Cadaver Cervical Spine Prior to Type II Odontoid Fracture

Cadaver	Flexion-Extension (°)	Lateral Bending (°)	Axial Rotation (°)
1	29.3 (27.4 to 31.23)	20 (17.8 to 22.3)	54.3 (46.5to 62.1)
2	8 (6.4 to 9.6)	7.2 (6.7 to 7.8)	43.3 (38.6 to 48.1)
3	25.8 (22.3 to 31.3)	12.4 (11.4 to 13.5)	45.7 (44.2 to47.3)

Table 2

Number of Intubations by Each Practitioner

Practitioner	Airtraq	ILMA	Lightwand	Macintosh
MD 1	9	8 (1 failure)	9	9
MD 2	6	6	6	6
EMT 1	9	8 (1 failure)	9	9
EMT 2	9	8 (1 failure)	9	9
EMT 3	6	6	6	6
Total Successful Intubations	39	36	39	39

MD, attending anesthesiologist; EMT, emergency medical technician paramedic; ILMA, intubating laryngeal mask airway

Table 3Summary Statistics for Movement at the C1-2 Level^{*}

Airway Device	Movement	Mean Degrees (95% Confidence Interval)
Airtraq	Flexion-extension	5.8 (4.9 to 6.8)
	Lateral bending	2.9 (2.4 to 3.5)
	Axial rotation	2.9 (2.2 to 3.5)
ILMA	Flexion-extension	7.4 (6.3 to 8.5)
	Lateral bending	3.9 (3.2 to 4.5)
	Axial rotation	3.8 (3.2 to 4.3)
Lightwand	Flexion-extension	4.2 (3.3 to 5.2)
	Lateral bending	2.7 (2 to 3.4)
	Axial rotation	2.2 (1.8 to 2.7)
Macintosh	Flexion-extension	7.3 (6.3 to 8.4)
	Lateral bending	3.5 (2.7 to 4.3)
	Axial rotation	3.6 (3 to 4.2)

^{*} Mean and 95% confidence interval for each device and axis of movement in degrees. ILMA, intubating laryngeal mask airway.

Table 4

Differences between Airway Devices in Flexion-Extension at C1-2

Airway Device 1	Airway Device 2	Mean Difference (95% CI)	P-value
Airtraq	ILMA	-1.7 (-4 to 0.7)	0.24
Airtraq	Lightwand	1.6 (-0.7 to 3.9)	0.27
Airtraq	Macintosh	-1.5 (-3.8 to 0.8)	0.29
ILMA	Lightwand	3.2 (0.9 to 5.5)	0.003
ILMA	Macintosh	0.1 (-2.2 to 2.4)	1
Macintosh	Lightwand	3.1 (0.8 to 5.4)	0.005

ILMA, intubating laryngeal mask airway

* Confidence intervals and P-value adjusted using Tukey-Kramer method.

Table 5

Differences between Airway Devices in Lateral Bending at C1-2

Airway Device 1	Airway Device 2	Mean Difference (95% CI)	P-value
Airtraq	ILMA	-1.1 (-2.6 to 0.4)	0.23
Airtraq	Lightwand	0.2 (-1.3 to 1.7)	0.98
Airtraq	Macintosh	-0.6 (-2.1 to 0.9)	0.69
ILMA	Lightwand	1.3 (-0.2 to 2.8)	0.11
ILMA	Macintosh	0.5 (-1 to 2)	0.84
Macintosh	Lightwand	0.8 (-0.7 to 2.3)	0.46

ILMA, intubating laryngeal mask airway

*Confidence intervals and P-value adjusted using Tukey-Kramer method.

Table 6

Differences between Airway Devices in Axial Rotation at C1-2

Airway Device 1	Airway Device 2	Mean Difference (95% CI)	P-value
Airtraq	ILMA	-0.9 (-2.2 to 0.3)	0.22
Airtraq	Lightwand	0.7 (-0.6 to 1.9)	0.50
Airtraq	Macintosh	-0.7 (-2 to 0.5)	0.42
ILMA	Lightwand	1.6 (0.3 to 2.8)	0.01
ILMA	Macintosh	0.2 (-1.1 to 1.5)	0.97
Macintosh	Lightwand	1.4 (0.1 to 2.6)	0.03

ILMA, intubating laryngeal mask airway

*Confidence intervals and P-value adjusted using Tukey-Kramer method.