Effect of Cervical Spine Immobilization Technique on Pediatric Advanced Airway Management

A High-Fidelity Infant Simulation Model

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Objective: Current guidelines recommend cervical spine immobilization during orotracheal intubation when traumatic injury is suspected in infants. We evaluated the effect of cervical spine immobilization techniques on orotracheal intubation performance with a high-fidelity infant simulator.

Methods: A randomized control study with repeated measurement. Nonanesthesia pediatric practitioners certified for intubation performed 6 intubations with 3 different cervical spine immobilization techniques (no physical protection, manual in-line immobilization, and cervical collar: C-collar). Time to accomplish key actions, cervical extension angle, and observed intubation associated events such as mainstem intubation, esophageal intubation with or without immediate recognition were recorded.

Results: Twenty-six practitioners performed 156 successful orotracheal intubation. Time to intubation from end of mask assist ventilation was 29.0 ± 12.2 seconds in no physical protection, 33.0 ± 17.4 seconds in C-collar, and 33.0 ± 17.1 seconds in manual in-line immobilization ($P = 0.39$). Maximal cervical extension angle in no physical protection (2.39 ± 2.56°) and C-collar (2.65 ± 1.79°) were significantly greater compared with 0.85 ± 1.05° in manual in-line immobilization ($P < 0.0001$). The number of intubation attempts and intubation associated events were not different among 3 techniques. Laryngeal visualization measured by Cormack-Lehane Scale was more difficult in C-collar compared with other 2 techniques ($P < 0.001$).

Conclusions: In this high-fidelity infant simulator model, cervical spine immobilization technique affected cervical extension angle and laryngeal visualization. Tracheal intubation associated events occurred in 33% of intubation attempts but were not different by technique. Time to achieve tracheal intubation, number of intubation attempts needed to succeed, and intubation-associated events were not affected by immobilization techniques. These results support Advanced Trauma Life Support recommendations to perform manual in-line immobilization in infants.

Key Words: airway management, cervical spine, trauma, simulation, manual in-line immobilization

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Cervical spine injury is seen in 1% to 4% of all trauma victims,[1,2] and more common in patients with severe injuries or depressed mental status.[3]

Pediatric cervical spine injury is rare, but it can be devastating.[4] Traumatic spine injury is seen in 4%[5] and cervical spine injury in 1 % to 2%[6,7] of all pediatric trauma victims in level 1 trauma center. Younger children tend to have higher cervical injury, whereas older children have lower cervical injury more often. This is due to anatomic and biomechanical difference. A greater mobility of the spine because of ligamentous laxity, shallow angulations of facet joints, immature development of neck musculature, incomplete ossification, and a larger head to torso ratio contribute to those differences between pediatric and adult cervical spines.[6–8] Despite the appropriate management in the level 1 trauma center, the mortality of the pediatric patients with cervical spine injury is 18% to 28%.[6,7]

Establishment of a stable airway is a critical component in pediatric trauma resuscitation and stabilization. Protected unobstructed airway and adequate ventilation takes high priority.[8] Definitive airway is required when there is a need for airway protection such as unconsciousness or risk of aspiration, or need for ventilation because of inadequate respiratory efforts. Orotracheal intubation is the most commonly used method to establish a definitive airway.

Failure to immobilize the neck during tracheal intubation in patients with cervical spine injuries can potentially result in devastating neurologic outcome,[3,8–10] although rare.[11,12]

Current guidelines from Advanced Trauma Life Support recommend manual 2-person in-line cervical spine immobilization technique in both pediatric and adult patients.[8]

Several studies have reported the effect of orotracheal intubation in normal and injured cervical spine with various cervical spine protection techniques. Most studies used adult cadaveric models with artificially created lower cervical spine injury with a measurement of cervical spine movement by cinefluoroscopy.

However, no pediatric study to date has evaluated cervical spine movement during orotracheal intubation with various cervical spine immobilization techniques.

This type of study would be very hard to accomplish clinically in real pediatric patients because of the potential harm to subjects such as potential airway complication and irradiation for measurement.

The current study was designed to evaluate the effect of 3 cervical spine immobilization techniques on pediatric orotracheal intubation by experienced pediatric practitioners using realistic high-fidelity infant simulators. We hypothesized that cervical spine immobilization by rigid cervical collar would make orotracheal intubation more difficult with longer intubation time and more intubation associated events such as mainstem intubation or esophageal intubation despite its cervical spine immobilization effect. The significance of this study would be to critically examine the current recommendation of advanced airway management in pediatric trauma victims.

METHODS

Study Design

This study was approved by the Institutional Review Board of the Children's Hospital of Philadelphia.

The study was conducted in a simulation room located adjacent to the Pediatric Intensive Care Unit. Nonanesthesiology pediatric practitioners who are credentialed in orotracheal intubation in our institution performed orotracheal intubation in 6 preprogramed scenarios requiring 1 orotracheal intubation each. Each participant was required to perform 6 scenarios under 3 conditions (3 different cervical spine protection techniques: no physical protection, C-collar, in-line immobilization). Each technique was repeated once. Each scenario lasted approximately 5 minutes, and the entire simulation evaluation lasted approximately 1 hour.

This study is conducted with using a realistic high-fidelity infant simulator (SimBaby, Laerdal Medical Corp, Norway). The simulator was programed to demonstrate and quantify the following functions for this study: capability for practitioners to perform bag valve mask ventilation and tracheal intubation with a reasonable level skill requirement,[13] capability to demonstrate chest rise with spontaneous ventilation or positive pressure ventilation, breath sounds, palpable pulses in left brachial, radial, and bilateral femoral artery locations, exhaled CO_2 function with CO_2 tank. A monitor displayed pulse oximetry saturation waveform, electrocardiography waveform, and respiratory rate. End-tidal CO_2 was measured by a portable end-tidal detector (Handheld Capnograph/Oximeter Model 715; Respironics Novametrix, Inc, Wallingford, CT). Each subject performed the role of a primary airway person in the simulated trauma scenarios (Appendix 1). The study subject assigned an assistant who facilitated the intubation process as directed by the study subject (eg, to hold the in-line cervical immobilization, to hand off the tracheal tube).

Briefly, the case was a 6-month-old infant involved in motor vehicle crash. This case was repeated identically 6 times. She arrives in the emergency department in a car seat and C-collar (Stifneck; Laerdal Medical Corp, Wappingers Falls, NY). She appears obtunded, with oxygen saturation of 93% despite 100% oxygen via a properly fitted face mask. She has been moved to a stretcher for primary evaluation and advanced airway management.

The simulator was preprogramed to demonstrate saturation and heart rate changes during advanced airway management (Appendix 2).

Each subject was requested by the trauma team leader to perform orotracheal intubation with 1 of 3 cervical spine protection techniques: no physical protection, C-collar protection, or in-line manual immobilization.

No physical protection was defined as no particular cervical spine immobilization technique is applied to manikin during the scenario. Each subject was reminded to "pay attention to" the potential cervical spine injury, but a person was not assigned to immobilize the neck.

C-collar protection was defined as a rigid cervical collar in place during the orotracheal intubation. Proper C-collar placement was confirmed before each scenario by a single investigator.

In-line manual immobilization was defined as a second person holding both hands on the manikin's head with index or the middle finger held approximately at the opening of auditory canal to maintain cervical spine in a neutral position without movement, as taught in the American College of Surgeons Advanced Trauma Life Support course. The person performing in-line immobilization crouched next to the directed side of the intubator.[3,14]

Each subject was asked to perform a total of 6 orotracheal intubations with 3 different cervical protection techniques during the session (one orotracheal intubation for each scenario). Miller 1 blade and 3.5 uncuffed endotracheal tube with a stylet were used in all intubation.

The order of the cervical spine immobilization technique was randomized. Each subject repeated intubation once with each cervical spine immobilization technique. For example, 1 subject performed orotracheal intubation with cervical protection in an order of N, N, C, C, M, M, where N, nonprotection; C, C-collar; M, manual in-line immobilization (Appendix 3). Each participant was instructed that they should intubate as if there was a third person applying appropriate cricoid pressure. Cricoid pressure was not actually applied because of the difficulty to control constant cricoid pressure on the study manikin.

Participants

Experienced nonanesthesia pediatric practitioners who are credentialed to perform orotracheal intubation in this pediatric tertiary institution were asked to participate voluntarily in this study. Total of 26 subjects (16 pediatric transport team nurses, 6 pediatric critical care fellows, and 4 pediatric emergency medicine fellows) participated in the study between October 2006 and February 2007. Pediatric transport team nurses are primary airway providers during interhospital pediatric transport for critically ill children in our hospital.

Pediatric residents were excluded from the study enrollment because their intubation rate and intubation success rate have been low in the local airway registry data. No subjects dropped out during the study sessions. A written consent was obtained from each subject.

Each subject indicated their years of clinical pediatric tracheal intubation experience (Table 1).

Data Collection and Processing

The key actions were prospectively identified and defined as follows: initiation of advanced airway management as cessation of bag valve mask ventilation for intubation, initiation of direct laryngoscopy as the laryngoscope inserted into oral cavity of the simulator, initiation of tracheal tube insertion as tracheal tube inserted into oral cavity. As used in the procedural definitions for the National Emergency Airway Registry (NEAR),[15] duration of an intubation attempt is defined by the process starting at insertion of the laryngoscope to time of removal of the laryngoscope. Successful orotracheal intubation event is defined as tracheal intubation with confirmed endotracheal tube position with primary (chest rise and auscultation) and secondary confirmation (positive end-tidal CO_2).[16]

Outcome Measures

The time to key action, such as initiation of direct laryngoscopy, attempt of intubation, and rescue breath, was recorded by an investigator at the scene onto a simulation event log along with the automatic programed response from the simulator (vital signs, pulse oximeter, and physical examination change). This event log was later reviewed to document the lowest saturation during each scenario and any tracheal intubation-associated event during the scenario. The simulator demonstrates lung expansion on an investigator laptop computer, and the investigator is able to document the intubation-associated events based on this, with the subject blinded to this information. One investigator attended all study sessions to ensure consistency. Tracheal intubation associated events were defined as SpO_2 lesser than 60%, bradycardia, hypotension, intubation failure: no intubation success within 15 minutes, esophageal intubation with immediate recognition (before the removal of laryngoscope), esophageal intubation with delayed recognition (after the removal of laryngoscope, but recognized by a subject), missed esophageal intubation (never recognized by a subject), mainstem intubation with immediate recognition (before the removal of laryngoscope, mainstem intubation with delayed recognition (after the removal of laryngoscope, but recognized by a subject), and missed mainstem intubation (never recognized by a subject).[15]

TABLE 2. Time to Successful Intubation and Maximal Cervical Extension Angle Between Three Cervical Spine Protection Techniques

	Time to Intubation Seconds (mean ± SD) Maximal A	P Cervical Angle Movement (mean ± SD)
Nonrestriction	29.0 ± 12.2* (27.2 ± 7.0)‡	2.239 ± 2.56†
C-collar protection	33.0 ± 17.4* (29.6 ± 7.7)‡	2.65 ± 1.79†
Manual in-line immobilization	33.0 ± 17.1* (29.9 ± 7.1)‡	0.85 ± 1.05†

*Analysis with all intubation event. $P = 0.39$, RM ANOVA.
†$P < 0.001$, RM ANOVA.
‡Analysis with single successful intubation attempt. $P = 0.18$, RM ANOVA.

Each subject was asked to fill out an intubation worksheet at the end of each scenario containing the checklist for completion of tracheal intubation (positive assessment of bilateral chest rise, positive assessment of exhaled CO_2 check, SpO_2 been at or above 90% for at least 15 seconds), and self-reported Cormack-Lehane score (grade 1, no difficulty; grade 2, only posterior extremity of glottis visible; grade 3, only epiglottis seen; grade 4, no recognizable structures[17] as an evaluation of laryngeal exposure during laryngoscopy.

Cervical spine extension angle was measured by a tilt sensor (EZ-TILT-2000 rev-2; Advanced Orientation Systems, Inc, 2000, Linden, NJ) as a positive angle change from baseline (the angle when advanced airway management was started) on a sagittal plane. This digital output tilt module uses DX type dual axis sensors to measure the tilt angle. Those sensors are commonly used in biomechanical engineering and are reported to have good reliability.[18] The sensor was rigidly implanted into the occiput of the SimBaby.

TABLE 1. Demographics of Study Participants

Discipline	Subjects (n)	Age (Median, IQR)	Sex (Male vs Female)	Experience in Pediatric Intubation (Year: Median, IQR)*	Duration From Last Intubation Training†(Month: Median, IQR)‡
Transport	16	40 (37–47)	4 vs 12	3 (2–5.250)	2.5 (0–9)
PEM Fellow	4	31 (30–38)	1 vs 3	3.5 (1.75–5.75)	5 (2–9)
PCCM Fellow	6	31 (30–32)	3 vs 3	4 (3–5)	3 (0–4)

*$P = 0.80$, Kruskal-Wallis.
†Last intubation training includes manikin-based training.
‡$P = 0.82$, Kruskal-Wallis.
Transport indicates Pediatric Transport Nurse; PCCM Fellow, Pediatric Critical Care Medicine Fellow; PEM Fellow, Pediatric Emergency Medicine Fellow.

TABLE 3. Intubation-Associated Events by Different Cervical Spine Protection Technique

Method	Intubation Attempt > 1 time*	Any Intubation Associated Events†	Mainstem Intubation With Delayed Recognition‡
No-restriction	2	16	12
C-collar	3	15	13
Manual in-line	2	20	17

Total number of intubation = 52 for each cervical spine protection technique.
*$P = 1.00$.
†$P = 0.63$.
‡$P = 0.60$, Fisher exact test.

The output signal was recorded once per second by a second laptop computer which was connected to this system. The measurement was started simultaneously when advanced airway management was initiated. Once-per-second measurement rate was sufficient to record a smooth trend of the cervical extension angle during intubation.

Primary Data Analysis

Data accuracy and time intervals were confirmed by reviewing the simulation log and then analyzed by using STATA 9.0 (Stata Corp, College Station, Tex).

Descriptive statistics was expressed as mean ± SD, median (interquartile range, IQR), when appropriate. A repeated-measures analysis of variance (RM ANOVA) was used to test for significant differences in time to successful intubation as a function of techniques and attempt.[19] The dependent variable was cervical spine protection technique, which had a repeated measure.

The cervical extension angle was analyzed by RM ANOVA with a cervical immobilization technique as a variable. Post-analysis follow-up comparison was performed with Tukey honestly significant difference method. Categorical binomial variables are analyzed by Fisher exact test. Categorical ordinal variables and nonparametric variables were analyzed by Wilcoxon rank sum test or Kruskal-Wallis test, when appropriate. All statistical tests were performed with 2 tails, $\alpha = 0.05$ as significant.

RESULTS

Twenty-six subjects (16 pediatric transport team nurses, 6 pediatric critical care fellows, and 4 pediatric emergency medicine fellows, Table 1) participated between October 2006 and February 2007. Each performed 6 orotracheal intubations during 1 session. No subjects dropped out during the study sessions.

Previous experience in pediatric intubation was 3.8 ± 2.0 years. Duration from last intubation training was median 3.5 months (IQR 0–8.5). Both were not significantly different by discipline. The time to successful orotracheal intubation also did not differ by discipline (transport nurses 31.7 ± 19.3 seconds, pediatric emergency fellows 31.7 ± 6.3 seconds, pediatric critical care fellows 31.7 ± 7.7 seconds, $P = 1.00$, ANOVA). The large SD in transport nurse group was because of the intubation which required second attempts with rescue bag and mask ventilation.

Time to successful orotracheal intubation was 29.0 ± 12.2 seconds in no protection, 33.0 ± 17.4 seconds in C-collar protection, and 33.0 ± 17.1 seconds in manual in-line immobilization (Table 2). The RM ANOVA resulted in a nonsignificant technique by order interaction ($F_{2,\ 26} = 0.09$, $P = 0.91$), a nonsignificant effect due to technique ($F_{2,\ 52} = 0.97$, $P = 0.39$), and a significant effect due to order ($F_{1,\ 78} = 4.25$, $P < 0.05$). The nonsignificant technique by order interaction indicates that changes in average time to successful intubation, from first to second attempt, did not vary as a function of technique. The nonsignificant effect attributable to technique reveals that, averaging over 2 attempts, time to successful intubation did not vary significantly between the different cervical spine protection techniques. The result regarding the effect of cervical spine protection techniques was similar when we restricted the analysis to the first successful intubation attempt (Table 2).

Maximal cervical extension angle was 2.39 ± 2.56° in no protection, 2.65 ± 1.79° in C-collar protection, and 0.85 ± 1.05° in manual in-line immobilization. Repeated-measures analysis of variance analysis revealed cervical spine protection technique as a significant variable (F2, 52 = 25.98, $P < 0.0001$). The maximal cervical extension angle was significantly less in manual in-line immobilization compared with no protection ($P < 0.001$, Tukey honestly significant difference test), or to C-collar protection as the cervical spine protection technique ($P < 0.001$).

TABLE 4. Timing of Maximal Cervical Extension Angle by Different Cervical Spine Protection Technique

Method	Mask Off-Laryngoscopy	Laryngoscopy-Tube Insertion	Tube Insertion-Intubation	Rescue Breath	Total
Norestriction	13	21	17	1	52
C-collar	0	33	17	1	51*
Manual in-line	20	12	19	1	52

Mask off: cessation of bag-valve-mask ventilation.
Laryngoscopy: insertion of laryngoscope.
Tube insertion: insertion of endotracheal tube into oral cavity.
Intubation: Completion of tracheal intubation with positive exhaled CO_2.
$P \leq 0.001$, Fisher exact test.
*Data were not able to be obtained in 1 session because of the mechanical condition.

TABLE 5. Glottic Exposure Level by Different Cervical Spine Protection Techniques

Cormack scale	Grade 4 	Grade 3 	Grade 2 	Grade1 	
No restriction	0	0	12	40	
					p < 0.001*
C-collar	0	0	32	20	
					p < 0.001*
Manual in-line	0	0	14	38	

*Wilcoxon rank sum test

All participants achieved successful tracheal intubation within 2 attempts. Two intubations required a second attempt in the no protection technique, 3 required a second attempt in C-collar protection, and 2 required a second attempt in manual in-line stabilization, not significantly different. The prospectively defined intubation-associated events were seen commonly in 51 out of 156 total intubations (Table 3). However, there was no significant difference among different cervical spine protection techniques ($P = 0.63$, Fisher exact test). The most common intubated associated event was mainstem intubation with delayed recognition, seen in 42 (27%) of 156 intubations. No intubation success took more than fifteen minutes. This was not significantly different among the 3 different cervical spine protection techniques ($P = 0.60$, Fisher exact test). The timing of maximal cervical spine extension during the advanced airway management differed significantly among the 3 cervical spine protection techniques ($P < 0.001$, Fisher exact test, Table 4). Advanced airway management caused maximal cervical spine extension angle during direct laryngoscopy before tracheal tube insertion to oral cavity in no protection and C-collar protection. However, with in-line manual immobilization, the maximal cervical extension angle occurred between removing the mask and inserting laryngoscope into mouth.

The Cormack-Lehane Scale reported by subjects as a level of laryngeal exposure is shown in Table 5. Although no subject reported grade 3 and grade 4 in this study, the cervical spine protection with C-collar is associated with poorer laryngeal exposure compared with no protection, and compared with in-line manual protection ($P < 0.001$ for both, Wilcoxon rank sum test), whereas there was no significant difference between no-protection and in-line manual immobilization ($P = 0.65$).

The significant order effect revealed that, averaged over technique, time to successful intubation decreased on the second scenario (first 34.4 ± 20.3 vs second 28.9 ± 8.5, $P < 0.05$).

DISCUSSION

In this realistic high-fidelity infant simulator model, cervical spine immobilization technique affected cervical extension angle and laryngeal visualization during orotracheal intubation, but not time to achieve tracheal intubation, number of intubation attempts needed to achieve tracheal intubation success, or numbers of intubation associated events. Important tracheal intubation associated events occurred in approximately 33% of intubation attempts, but frequency did not differ by technique.

This study is the first to use simulation to examine the effect of the cervical spine protection technique on advanced airway management outcomes in children.

Despite consensus recommendations by the American College of Surgeons Advanced Trauma Life Support program in the United States,[8] a recently published systematic review of manual in-line immobilization for suspected cervical spine injury revealed that there is limited evidence to support the effectiveness of this practice based on 5 case series which included 120 patients with unstable cervical spine.[12] None of these patients clinically deteriorated as a result of airway management, supporting the clinical effectiveness. However, an adult cadaveric model with created cervical spine injury had mixed results for immobilization of unstable cervical spine segments. Authors concluded that direct laryngoscopy and intubation are unlikely to cause clinically significant movement and that manual in-line immobilization may not immobilize injured segments.

Furthermore, there was no specific pediatric evidence to support the recommendation of in-line immobilization in pediatric trauma victims. This kind of study could not be practically conducted on actual pediatric trauma victims with cervical spine injury. Cadaveric study is not feasible for children, and studying healthy subjects with cinefluoroscopy would cause significant radiation to pediatric patients and intubators. Thus far, there is only 1 pediatric case report with limited information regarding cervical spine mobility during intubation.[20] Therefore, this study with a high-fidelity infant simulator was proposed as innovative and appropriate in this condition.

Medical simulation has innate strength to test or train a high-risk, low-incidence situation repeatedly.[21,22] High-fidelity simulation function with realistic anatomy and simulated physiology made many clinical education and training more effective.[23] This has been used in critical care and trauma education.[24,25]

This study utilized this benefit of medical high-fidelity simulation: realistic airway, no patient variance in airway anatomy and physiological vital sign changes, safety of the patients and study subjects. The level of realism of airway management in this simulator model (SimBaby; Laerdal Medical Corp) is validated by Overly et al.[13] They identified the pediatric resident intubation attempt success rate was 56%, which correlated well with pediatric residents' performance in the emergency department (first intubation attempt success rate of 50%).[15] The high fidelity of this study condition is further validated by the similar clinical results such as the rate of intubation associated events (mainstem bronchial intubation, esophageal intubation) in addition to its well-accepted content validity. The incidence of mainstem intubation with delayed recognition in our study was comparable (2%) to Sagarin's report (7%) from NEAR.[15] The incidence of esophageal intubation was also similar (our study: 1.3% vs NEAR: 3.2%).[15] The overall rate of tracheal intubation associated events (33%) was comparable to the non-OR, non-ICU intubation:16% to 25%, NEAR,[15] and 54%, Easley et al.[26]

Our analysis revealed that there was a significant order effect on time to successful intubation. This means, regardless of technique, participants, on average, were able to intubate the simulator with significantly less time on the second scenario with the same technique. This suggests that simulator training experience is valuable for advanced airway management training for practitioners.

Time to successful intubation was not significantly different among the cervical spine protection techniques, or subjects. Despite that Cormack-Lehane score reported by participants showed that C-collar made laryngeal visualization more difficult, the effect was not strong enough to affect the time to successful intubation on standard pediatric airway. It is prudent to speculate that this result might change if the pediatric airway becomes more difficult. A recent systematic review of manual in-line immobilization for airway management reports that manual in-line immobilization degrades laryngoscopic view,[12] which was not found in our study. This may be due to a different level of airway difficulty in our study model compared with other studies which used adult cadavers.

There are several reasons that C-collar can make laryngeal visualization difficult. First, the mouth opening will be significantly restricted during direct laryngoscopy.[27,28] This was vocalized by a few participants during this study. The second reason is the restriction of cervical motion due to the C-collar. Despite this common misunderstanding that C-collar restricts large cervical spinal mobility, the cervical extension angle during advanced airway management was significantly larger in C-collar technique compared with inline manual immobilization in our study. This finding was consistent with the report by Huerta et al.[29] They demonstrated that a rigid cervical collar allows the cervical spine extension to up to 15 degrees with patient's spontaneous movement when used without other fixation technique such as taping to the spine board. No previous pediatric study evaluated the effect of cervical spine protection method during advanced airway management.

The effect of in-line manual immobilization on the cervical movement has been examined in adult cadaveric models.

Gerling et al[1] studied this effect on fresh-frozen cadavers with a complete C5-C6 transection. The axial distraction, anterior-posterior displacement, and angular rotation of C5-C6 spine were measured with cinefluoloscopy. Significantly less anterior-posterior displacement was seen in manual in-line immobilization group compared with the C-collar group. The difference in axial distraction and angular rotation was not significant.[1]

Lennarson et al[30] used adult cadavers with combined anterior and posterior injuries at C4-C5 level. Manual in-line immobilization eliminated distraction and decreased angulation, however, subluxation was increased. Brimacombe et al[31] used adult cadavers with C3 posterior destabilization. Orotracheal intubation with direct laryngoscopy with manual in-line immobilization did not prevent posterior displacement.

Those models may not be applicable in young pediatric patients with cervical spine injury because the younger patients have higher cervical injury,[5,6] and the maximal cervical motion occurs at a higher level (Occiput-C1, C1-C2) even in adults during orotracheal intubation.[32,33]

In our study, the maximal cervical spine motion was observed between the insertion of laryngoscopy to oral cavity and the tracheal tube insertion into oral cavity. Because our study does not have a method to detect the location of laryngoscope blade instantaneously, this seemed to occur during an attempt of visualization of larynx with direct laryngoscopy. This result was consistent with previous studies with healthy patients[32] and cadaveric models.[30,33]

In this study, modified rapid sequence intubation technique was used. Standard rapid sequence induction without positive pressure ventilation after administration of sedative and paralytic agents is recommended for intubation in trauma patients.[15] However, because of relatively small functional residual capacity, pediatric patients with hypoxia will not tolerate the apneic period during the rapid sequence induction. Therefore, modified rapid sequence induction with simultaneous administration of sedative and paralytic agents, with application of cricoid pressure and continuous bag valve mask ventilation before intubation attempt, and continuous cricoid pressure during direct laryngoscopy, was adopted in our study. This is consistent with our current practice.[34]

Our study results need to be interpreted in light of several limitations.

First, despite its face validity,[13,23] the infant high-fidelity simulator used in this study may have different biomechanical and anatomical airway characteristics compared with live infants.

The incidence of mainstem bronchial intubation and esophageal intubation in our study was close to the data from actual clinical registry, which supports the validation of our model to some degree.

Second, the fidelity of the simulation was limited in our study because the investigator provided a history and the investigator was visibly present in the room. Oral trauma or bleeding was not simulated in this scenario because of the technical difficulty and reproducibility of the condition. Furthermore, several other potential tracheal intubation-associated events such as vomiting with or without aspiration, dental or lip trauma were not replicated.

Third, we did not measure the cervical spine angle changes during the bag valve mask procedure. We chose to use the head flexion angle at the beginning of advanced airway management; cessation of bag, valve mask ventilation, and a removal of a mask from a simulator. This might affect the measurement of head tilt angle during the advanced airway management. One study showed chin lift/jaw thrust procedure causes the maximal cervical spine movement.[35] However, there was no difference in the baseline cervical extension angle among 3 cervical spine protection technique (ANOVA, P = 0.23, data not shown) when bag valve mask ventilation was held for intubation. It should be noted that our result was analyzed as a change from baseline because there is no dangerous "threshold" known for cervical extension angle in infants with potential cervical spinal trauma. This simulator model reflects the proportion of a 6- to 8-month infant with relative kyphosis. This study was conducted on a stretcher without a backboard. Because the simulator head weight is limited, the effect to cervical angle due to the mattress softness is considered minimal.

Fourth, we instructed study subjects that they were to intubate the patient as if they were receiving cricoid pressure during the laryngoscopy, although we did not have another person to actually perform this procedure. We chose not to actually provide cricoid pressure/laryngeal manipulation during laryngoscopy because the degree of cricoid pressure may vary from session to session, and it may affect the measured head tilt angle. This might have slightly decreased the degree of fidelity in this study. Of note, 1 adult cadaveric study reported that application of cricoid pressure did not result in movement in an injured upper cervical spine.[35]

Fifth, despite our best effort to recruit participants with advanced airway skills, there may be a significant variance in participants' skills. We excluded anesthesiologists as study participants because of the following: (1) they are not primary airway providers in trauma and emergency settings in our hospital; (2) our purpose of study is to examine the effect of C-spine protection in our usual clinical settings including inter-hospital transport. A learning effect during the study was observed, despite the lack of individual feedback provided to participants.

CONCLUSIONS

Orotracheal intubation with a standard laryngoscope using manual in-line immobilization technique was associated with similar intubation time and significantly less cervical extension angle compared with C-collar protection or no cervical protection in a normal pediatric airway model. C-collar protection made laryngeal visualization significantly more difficult compared with manual in-line immobilization and to non-protection.

This result supports the current Advanced Trauma Life Support Program recommendation for advanced airway management in pediatric trauma victims.

Important tracheal intubation associated event occurred in approximately 33% of intubation attempts, but frequency did not differ by technique. The maximal cervical extension occurred during direct visualization of the larynx in C-collar protection and in nonprotection.

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APPENDIX 1
A SIMULATED PEDIATRIC TRAUMA SCENARIO

Scenario

A 6-month-old infant was involved in a motor vehicle crash and was restrained in an infant safety seat without obvious signs of traumatic injury. The infant is unconscious with labored breathing. Coarse, equal breath sounds are noted on auscultation. There is no evidence of hemothorax or pneumothorax. The infant has no evidence of increased intracranial pressure at this moment. The attending physician requests that you prepare to perform tracheal intubation before CT scan evaluation of the brain.

The infant is given appropriate rapid sequence intubation medications including appropriate paralytics and sedatives and is currently unconscious and paralyzed. With pre-oxygenation and good bag-valve mask ventilation technique, the SpO_2 has risen to 92%, but you are unable to achieve higher oxygen saturation.

You are instructed by the attending physician to intubate the infant's trachea using an appropriate laryngoscope and endotracheal tube (eg, Miller 1 laryngoscope blade and 3.5 mm uncuffed tracheal tube). Please pay particular attention to cervical spine immobilization, confirm correct tracheal position (using clinical and Exhaled CO_2 capnography) and oxygenate and ventilate the infant.

Given this scenario, participants will then perform tracheal intubation on the infant simulator with 1 of the 3 C-spine protection methods:

1. Non-restricted neck mobility
2. Immobilization using a rigid cervical collar
3. Immobilization using manual in-line stabilization by a second "rescuer"

APPENDIX 2
A VITAL SIGN CHANGE DURING ADVANCED AIRWAY MANAGEMENT IN HIGH-FIDELITY SIMULATION

This table demonstrates approximate relationships between time since last oxygenation, SpO_2, possible hypoxia precipitated events and the time necessary to reach an adequate SpO_2 once oxygenation has resumed.

Time Since Last Oxygenation (Seconds)	Oxygen Saturation (%)	Event (Precipitated by SpO_2)	Time to Reach an SpO_2 of 90% Once Reoxygenation Reached (Seconds)
10	99		–
30	98		–
60	90		–
90	80		10
120	70	Bradycardia	30
180	60	Hypotension	80
240	50		240

Columns 1 and 2 (time since oxygenation and SpO_2) will be collinear. Hypoxia induced events (column 3) will be entered into the simulation at pre-determined SpO_2 levels as indicated in the table. The time to reach an SpO_2 of 90% after reoxygenation is reestablished will initially be roughly collinear with SpO_2 and will become greater than collinear as SpO_2 drops below a pre-determined level.

APPENDIX 3
ORDER OF TRACHEAL INTUBATION

Each participant will intubate the SimBaby in the order designated by her/his group designation. Each set consists of a pair of 2 same scenarios which requires orotracheal intubation.

Order of Tracheal Intubation

Group	First Set	Second Set	Third Set
1	Nonrestricted	Cervical collar	Manual
2	Nonrestricted	Manual	Cervical collar
3	Manual	Nonrestricted	Cervical collar
4	Manual	Cervical collar	Nonrestricted
5	Cervical collar	Nonrestricted	Manual
6	Cervical collar	Manual	Nonrestricted

Table Key: nonrestricted indicates nonrestricted neck mobility; manual, using manual in-line immobilization; cervical collar, immobilization using a rigid cervical collar.