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Effect of Just-in-time Simulation Training on Tracheal Intubation Procedure Safety in the Pediatric Intensive Care Unit

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ABSTRACT

Background: Tracheal intubation-associated events (TIAEs) are common (20%) and life threatening (4%) in pediatric intensive care units. Physician trainees are required to learn tracheal intubation during intensive care unit rotations. The authors hypothesized that "just-in-time" simulation-based intubation refresher training would improve resident participation, success, and decrease TIAEs.

Methods: For 14 months, one of two on-call residents, nurses, and respiratory therapists received 20-min multidisciplinary simulation-based tracheal intubation training and 10-min resident skill refresher training at the beginning of their on-call period in addition to routine residency education. The rate of first attempt and overall success between refresher-trained and concurrent non–refresher-trained residents (controls) during the intervention phase was compared. The incidence of TIAEs between preintervention and intervention phase was also compared.

Results: Four hundred one consecutive primary orotracheal intubations were evaluated: 220 preintervention and 181 intervention. During intervention phase, neither first-attempt success nor overall success rate differed between refresher-trained residents *versus* concurrent non–refresher-trained residents: 20 of 40 (50%) *versus* 15 of 24 (62.5%), $P = 0.44$ and 23 of 40 (57.5%) *versus* 18 of 24 (75.0%), $P = 0.19$, respectively. The resident's first attempt and overall success rate did not differ between preintervention and intervention phases. The incidence of TIAE during preintervention and intervention phases was similar: 22.0% preintervention *versus* 19.9% intervention, $P = 0.62$, whereas resident participation increased from 20.9% preintervention to 35.4% intervention, $P = 0.002$. Resident participation continued to be associated with TIAE even after adjusting for the phase and difficult airway condition: odds ratio 2.22 (95% CI 1.28–3.87, $P = 0.005$).

Conclusions: Brief just-in-time multidisciplinary simulation-based intubation refresher training did not improve the resident's first attempt or overall tracheal intubation success.

What We Already Know about This Topic

- ❖ Tracheal intubation-associated adverse events in pediatric critical care units might be reduced if simulation education were provided just before resident rotation on this service

What This Article Tells Us That Is New

- ❖ In 401 consecutive orotracheal intubations in a pediatric critical care unit, simulation-based resident education just before the on-call period increased resident participation, but not success rate or incidence of intubation-associated adverse events

TRACHEAL intubation in the pediatric intensive care unit (PICU) is often a life-saving procedure for critically ill children. It is an integral part of stabilization and resusci-

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tation. The risks of tracheal intubation are well described in adults and children.[1–8] Skilled laryngoscopists and multidisciplinary bedside teams are essential for safe pediatric airway management to avoid unwanted tracheal intubation-associated events (TIAEs) such as esophageal intubation, aspiration, or cardiac arrest.

Although pediatric intubation outside the operating room setting is uncommon, and tracheal intubation, therefore, is infrequently accessible to resident trainees, the Accreditation Committee for Graduate Medical Education in the United States mandates that pediatric residents receive sufficient experience in this procedure during clinical rotations in the delivery room, neonatal intensive care unit (ICU), emergency department, and PICU.‡‡ This poses substantial challenges for academic PICUs to achieve the balance between resident procedural education during actual intubations and the potential increased risk of exposing critically ill patients to a less-experienced intubator.[9] As a result, residents had limited opportunities to participate in PICU airway management as laryngoscopists in our PICU.

Recently, a greater emphasis is being placed on measuring and improving clinical care through enhanced physician performance. A "just-in-time" practice-learning approach meeting learner's demand during or just before when it is needed is useful to maximize an educational outcome for introducing new therapies or implementing practice guidelines.[10] On the basis of this theory, we developed a prospective interventional study to evaluate whether providing brief refresher simulation training (*e.g.*, guided practice, as an addition to their standard residency education) to nonanesthesiology residents would improve procedural participation, success, and patient safety outcomes of PICU intubations. Our intervention provided 20-min multidisciplinary simulation-based training and 10-min airway management skill refresher training for one of two incoming on-call residents, in addition to their standard pediatric and emergency residency curriculum. This just-in-time method was chosen to reinforce essential teamwork and technical skills very near to the time in which they might be required, thus attempting to overcome routine decay in airway management skills[10] and to enhance learner's motivation because the learning objectives are temporally close to the clinical use. Preselected key learning points based on failure mode and effect analysis (systematic approach to identify steps proactively in a process that could help reduce or eliminate a failure from occurring by multidisciplinary team) and identification of processes and subprocesses in PICU tracheal intubations were emphasized during the standardized debriefing process,[11] to help the residents to recognize, relearn, and practice the points for safe tracheal intubation at a the beginning of their on-call shift, close to the time that they would really be performing the procedure in the PICU. The multidisciplinary method was chosen to provide just-in-time refresher technical and behavioral skill training to novice residents and other airway team members (PICU nurses and respiratory therapists) in a realistic setting with high conceptual and emotional realism.[12,13] In our PICU, we consider one resident, two PICU nurses, one respiratory therapist, and a supervising experienced fellow and/or attending physician as an essential bedside airway team. Intubations were expected to occur within 24 h of the refresher training.

We hypothesized that the just-in-time multidisciplinary simulation-based tracheal intubation refresher training for ICU residents would improve resident skills, as determined by first-attempt success rate and overall success rate, without increasing TIAEs during real ICU intubations.

Materials and Methods

This prospective interventional study was conducted in the PICU at the Children's Hospital of Philadelphia (Philadelphia, Pennsylvania) from June 12, 2007 to August 31, 2008 for 14 months. The PICU is a 45-bed, tertiary PICU staffed with 20 faculty, 15 pediatric Critical Care Medicine fellows, and approximately 150 nurses. Eight to 10 pediatric or emergency medicine (nonanesthesiology) residents rotate in PICU every month. At least four respiratory therapists are always on duty in the unit. The PICU consists of two adjoining (connected with a short, $<$ 25-m length of corridor) but physically separate units on the same floor (seven east and seven south) of identical size, with identical capabilities, patient mix, and staffing; each has a 24-h physician coverage team comprising an attending pediatric intensivist, fellows, and residents. Each ICU intubation is supervised by a Pediatric Critical Care Medicine Board Certified or Eligible ICU attending and a PICU fellow. Other members of the bedside airway team include a resident, two ICU nurses, and at least one ICU respiratory therapist. The decision of "who performs laryngoscopy" is made by the bedside airway team, with the discussion of the fellow and in-house attending physician who are present for every intubation in our PICU. The Institutional Review Board at the Children's Hospital of Philadelphia approved this study, which was conducted in compliance with the Health Insurance Portability and Accountability Act. A written informed consent was obtained from all subjects. Patient consent was waived because the intervention was limited to simulation-based education.

Subjects

Subjects of this study were postgraduate year 1–3 pediatric residents and postgraduate year 3–4 Emergency Medicine residents who were assigned to 4-week rotations in the PICU during the study period. One of two residents who were on call each day and night in one side of PICU (seven south) received the simulation-based training. Because each resident was scheduled to be on call every 4–5 days, they were trained

‡‡ Accreditation Committee for Graduate Medical Education Program Requirements for Graduate Medical Education in Pediatrics. 2007. Available at: http://www.acgme.org/acWebsite/downloads/RRC_progReq/320pediatrics07012007.pdf. Accessed March 21, 2010.

one to four times during their 4-week PICU rotation. In addition, one of the on-duty PICU nurses and respiratory therapists joined the multidisciplinary simulation training. PICU nurses and respiratory therapists joined from both sides of the PICU, unlike PICU residents who were always from one side (seven south). Many of them joined at the end of their clinical shift work, and some of them returned to work in one of those two sides of the PICU in next 12 h.

Interventions

The training intervention occurred at the beginning of the 24-h on-duty period for the resident on call before bedside rounds, on weekdays except Thursday, in a videotaped simulation training room within our PICU. The training room is configured to be identical to the patient rooms. The simulation-based training consisted of two parts: (1) hands-on training for the incoming on-call resident with bag and mask ventilation skills and orotracheal intubation skills using a pediatric (5 years old) manikin (MegaCode Kid; Laerdal Medical Corporation, Wappinger Falls, NY) and (2) brief, standardized multidisciplinary team training with a high-fidelity infant (6–8 months) simulation manikin (SimBaby; Laerdal Medical Corporation, Stavanger, Norway) emulating acute respiratory failure. The hands-on resident skill training was conducted for only 10 min (approximately four practice bag mask transitions to tracheal intubation) with coaching and followed by multidisciplinary team training lasting approximately 20 min including a scripted debriefing (appendix). The airway team consisted of one on-call resident, one PICU nurse, and one respiratory therapist as trainees. One confederate was present to act a role for the second PICU nurse, who prepared the medication and served as a documenter as requested by a team. Each simulation-based training episode was videotaped and reviewed after training for consistency and effectiveness.

Data Collection

The PICU intubation process and outcome data were collected in a secure relational database (Access; Microsoft Corporation, Redmond, WA) within the National Emergency Airway Registry for Kids adapted from National Emergency Airway Registry, an established, multicenter adult and pediatric emergency department intubation registry.[3,14–17] In our PICU, all intubations were captured in this database since December 2004 with institutional review board approval. The data include patient and practitioner demographics, indication, difficult airway evaluation, intubation events (including complications), and tracheal intubation outcomes. The unwanted TIAEs are described in table 1. The videotaped team training session was reviewed by investigators for quality control of the training session and scripted debriefing session and for verification of successful resident acquisition of tracheal intubation skill.

Table 1. Tracheal Intubation-associated Events

Severe TIAE	Minor TIAE
Hypotension requiring treatment	Esophageal intubation with immediate recognition
Vomit with aspiration	Mainstem bronchial intubation with delayed recognition
Cardiac arrest (patient survived)	Dental/lip trauma
Cardiac arrest (patient died)	Vomit without aspiration
Esophageal intubation without immediate recognition	Hypertension requiring treatment
Laryngospasm	Epistaxis
Malignant hyperthermia	Medication error
Pneumothorax pneumomediastinum	Dysrhythmia
Direct airway injury	Pain/agitation requiring additional medication and delaying intubation

TIAE = tracheal intubation-associated event.

Data Analysis

Our primary outcome was the first-attempt success of orotracheal intubation performed by residents as laryngoscopists. The performance of just-in-time simulation refresher-trained residents was concurrently compared with residents who did not receive simulation refresher training during the intervention period.

Our *a priori* selected secondary outcomes included resident overall success (including several attempts) and incidence of unwanted TIAEs. All primary and secondary outcomes were also compared with historical controls from all PICU intubations performed during December 2004 to June 2007 (*e.g.*, "before" *vs.* "after"). This entire cohort was chosen because just-in-time refresher training participating team members (nurses and respiratory therapists) are from both sides of PICUs, whereas residents were only from one side of PICUs.

The incidence of TIAEs during the intervention period was compared with the historical controls: PICU intubations performed during December 2004 to June 2007. This was chosen because, if the team training was effective and participating nurses and respiratory therapists improved performance, the incidence of TIAEs would decrease regardless of the resident participation during actual intubation. Also, there was a concern that incidence of TIAEs might increase because of an increase in number of resident participating as laryngoscopists. For this reason, intubations in both sides of PICU are analyzed for resident participation and incidence of TIAEs, instead of one side of PICU (seven south) where residents were receiving just-in-time training.

In this study, a difficult airway was defined as intubation requiring three or more laryngoscopists or as intubation requiring three or more laryngoscopy attempts by an experienced nonresident provider(s) to achieve successful intubation. This is based on an association between a higher number of fellows and attending laryngoscopists and airway difficulty in our preliminary data, and there is no single validated definition of a difficult airway condition in the PICU. Because the simulation training was based on primary oral intubation, we excluded primary nasal intubations and endotracheal tube change procedures.

Sample Size Consideration

Based on the available preliminary data, with a two-sided α of 0.05 and 80% power, 50 resident intubations after simulation-based training would be required to demonstrate absolute improvement by 30% with intervention. Based on the frequency of our PICU tracheal intubation, the planned study duration was 70 weeks (approximately 18 months).

Statistics

Descriptive statistics with median and interquartile range were reported for nonparametric variables. Fisher exact and chi-square tests were used for univariate analysis with a dichotomous outcome. Wilcoxon rank sum test was used for nonparametric dependent variables. Multivariate logistic regression analysis was performed to evaluate the overall effect of the multidisciplinary simulation-based training on primary and secondary outcomes, adjusting for patient age category and difficult airway status. All analyses were two-tailed, and $\alpha = 0.05$ was used as threshold for statistical significance. Stata version 11 (STATA Corporation, College Station, TX) was used as statistical software.

Results

One hundred percent of consecutive tracheal intubations were captured through a redundant process of notification and quality improvement review. Two hundred two simulation-based training events were conducted from June 2007 to August 2008. Seventy-eight residents, 122 PICU nurses, and 65 respiratory therapists received the training. Fifty-four (69%) were pediatric residents, and 24 (31%) were emergency medicine residents. The majority of residents were postgraduate year 2 (62%) or postgraduate year 3 (26%; table 2). The median number of attendance for each practitioner was resident: 3 times (range: 1–6), nurse: 1 time (range: 1–6), and respiratory therapist: 2 times (range 1–10). Forty (51%) residents had previous intubation experience less than or equal to five times.

Performance on Actual PICU Intubations

There were 220 primary orotracheal intubations in the preintervention phase and 181 during the intervention phase. The patient demographics between preintervention and intervention phases did not differ (table 3). Indications were not different between those two phases, except for elective intubation: more elective procedures (such as anesthesia for emergent or urgent invasive and noninvasive procedures) were reported during the intervention phase ($P = 0.004$).

Table 2. Just-in-time Simulation: Resident Demographics

Age, yr	29.8 ± 3.8
Sex	
Male	26 (33)
Female	52 (67)
Discipline	
Pediatrics	54 (69)
Emergency medicine	24 (31)
Training level	
PGY 1	4 (5)
PGY 2	48 (62)
PGY 3	20 (26)
PGY 4 and 5	6 (8)
Previous intubation (n)	
None	4 (5)
1–5	36 (46)
6–10	7 (9)
11–20	7 (9)
>20	24 (31)

Data are presented as mean ± SD or n (%).
PGY = postgraduate year.

Difficult airway cases were reported in 12 (5.5%) during the preintervention phase and in 11 (6.1%) during the intervention phase, which was not statistically different ($P = 0.83$).

Resident First Attempt Success and Overall Success Rate

Just-in-time Refreshed *versus* Concurrent Nonrefreshed Resident Laryngoscopists. The first-attempt success rates and overall success rates were similar between the two groups (20 of 40: 50% in refresher-trained *vs.* 15 of 24: 62.5% in nonrefreshed, $P = 0.44$ and 23 of 40: 57.5% in refresher-trained *vs.* 18 of 24:75.0% in nonrefreshed, $P = 0.19$, respectively; fig. 1). There was no difference among the simulation refresher-trained *versus* non–refresher-trained residents in their training level ($P = 0.22$, Wilcoxon rank sum test) or their discipline ($P = 0.77$, Fisher exact test). A subgroup analysis was performed based on the resident previous intubation experience (categorized into four groups as previous intubation experience ≤5 times, 6–10 times, 11–20 times, or more than 20 times before the just-in-time refresher training). The actual intubation first-attempt success rate was 9 of 22: 41% for less than or equal to 5 times of previous experience, 2 of 2: 100% for 6–10 times of previous experience, 2 of 4 (50%) for 11–20 times, and 7 of 12 (58%) for more than 20 times. The difference did not reach statistical significance ($P = 0.36$, chi-square test for trend).

Resident First Attempt Success and Overall Success Rate

Preintervention *Versus* Intervention Phase Resident Intubations. First attempt success rate and overall success rate did not differ between those two phases (35 of 64: 54.7% in intervention phase *vs.* 21 of 46: 45.7% in preintervention phase, $P = 0.44$, and 41 of 64: 64.1% in

Table 3. Patient Demographics (401 Oral Intubations)

Phase	Preintervention (December 23, 2004 to June 11, 2007)	Intervention (June 12, 2007 to August 31, 2008)	*P* Value
Intubation, n	220	181	
Age			
< 12 mo	49 (22.2)	46 (25.4)	1.00
1–7 yr	82 (37.3)	75 (41.4)	
≥ 8 yr	62 (28.2)	57 (31.5)	
Unknown	27 (12.3)	3 (1.7)	
Weight, kg*	14.5 (3.7–70)	15 (4–76)	0.30
Indication of primary intubation			
Oxygen failure	111 (50.5)	74 (40.9)	0.057
Ventilation failure	80 (36.4)	52 (28.7)	0.11
Elective procedure	33 (15.0)	49 (27.1)	0.004†
Upper-airway obstruction	22 (10.0)	17 (9.4)	0.87
Shock/CPR	20 (9.1)	9 (5.0)	0.13
Weakness, decreased protective reflex	12 (5.5)	6 (3.3)	0.34
Pulmonary toilet	7 (3.2)	8 (4.4)	0.60
Therapeutic hyperventilation	5 (2.3)	4 (2.2)	1.00
Emergency drug administration	1 (0.5)	1 (0.6)	1.00
History of DA	18 (8.2)	20 (11.5)	0.019†
Sign of potential DA by examination			
Limited mouth opening	44 (20.0)	45 (24.9)	0.04†
Small thyromental space	19 (8.6)	21 (11.6)	0.089
Upper airway obstruction	25 (11.4)	21 (11.6)	0.95
Limited neck extension	17 (7.7)	20 (11.1)	0.30
Any sign of potential DA by examination	102 (46.4)	78 (43.1)	0.55
Difficult airway (defined by ≥ 3 providers, or ≥ 3 attempts by nonresident provider)	12 (5.5)	11 (6.1)	0.83

Data are presented as n (%) or median (interquartile range).
* Wilcoxon rank-sum test. † $P < 0.05$, Fisher exact test.
CPR = cardiopulmonary resuscitation; DA = difficult airway.

intervention phase *vs.* 28 of 46: 60.9% in preintervention phase, $P = 0.84$, respectively; fig. 2). After adjusting for patient age and difficult-airway status, resident participation as a laryngoscopist, but not resident first-attempt success or overall success by resident provider, was associated with intervention phase (odds ratio 2.02, 95% CI 1.27–3.22).

Tracheal Intubation-associated Events: Preintervention *Versus* Intervention Phase. Resident participation as a laryngoscopist significantly increased during the intervention phase: 64 of 181 (35.4%) I *versus* 46 of 220 (20.9%) in preintervention phase ($P = 0.002$, Fisher exact test; fig. 2).

Despite an increased resident participation as a laryngoscopist during the intervention phase, the overall occurrence of TIAEs did not increase (22.0% during the preintervention phase and 19.9% during the intervention phase, $P = 0.62$, fig. 2). All TIAEs observed in intubations performed by residents during the intervention phase were classified as minor TIAEs (esophageal intubation with immediate recognition: n = 13, mainstem bronchial intubation with delayed recognition: n = 6, dental/lip trauma: n = 2).

Multivariate regression analysis revealed that resident participation as a laryngoscopist remained to be significantly associated with the occurrence of TIAEs even after adjusting for patient age, intervention phase, and difficult airway status (odds ratio 2.22, 95% CI 1.28–3.87, $P = 0.005$; table 4).

Discussion

In this study, we sought to determine the number of successful intubations by residents who underwent just-in-time simulation refresher training compared with residents who did not receive refresher training during the intervention period. We found that the percentage of successful intubations by residents with simulation refresher training did not differ from the success of concurrent residents who did not receive refresher training during this intervention period. Of our secondary hypothesis, the percentage of successful intubations and intubations with unwanted TIAEs were compared with historical controls. We found that both the first attempt and overall success and the intubations with unwanted TIAEs did not differ compared with the historical control.

This study attempted to find a solution for a fundamental dilemma: providing safe and high-quality practice while providing necessary education for trainees in clinical settings. Although pediatric airway management was built into the residency curriculum, the individual trainee's competence level was not optimal. Therefore, as additional training practice for these novice laryngoscopists, this just-in-time simulation-based airway man-

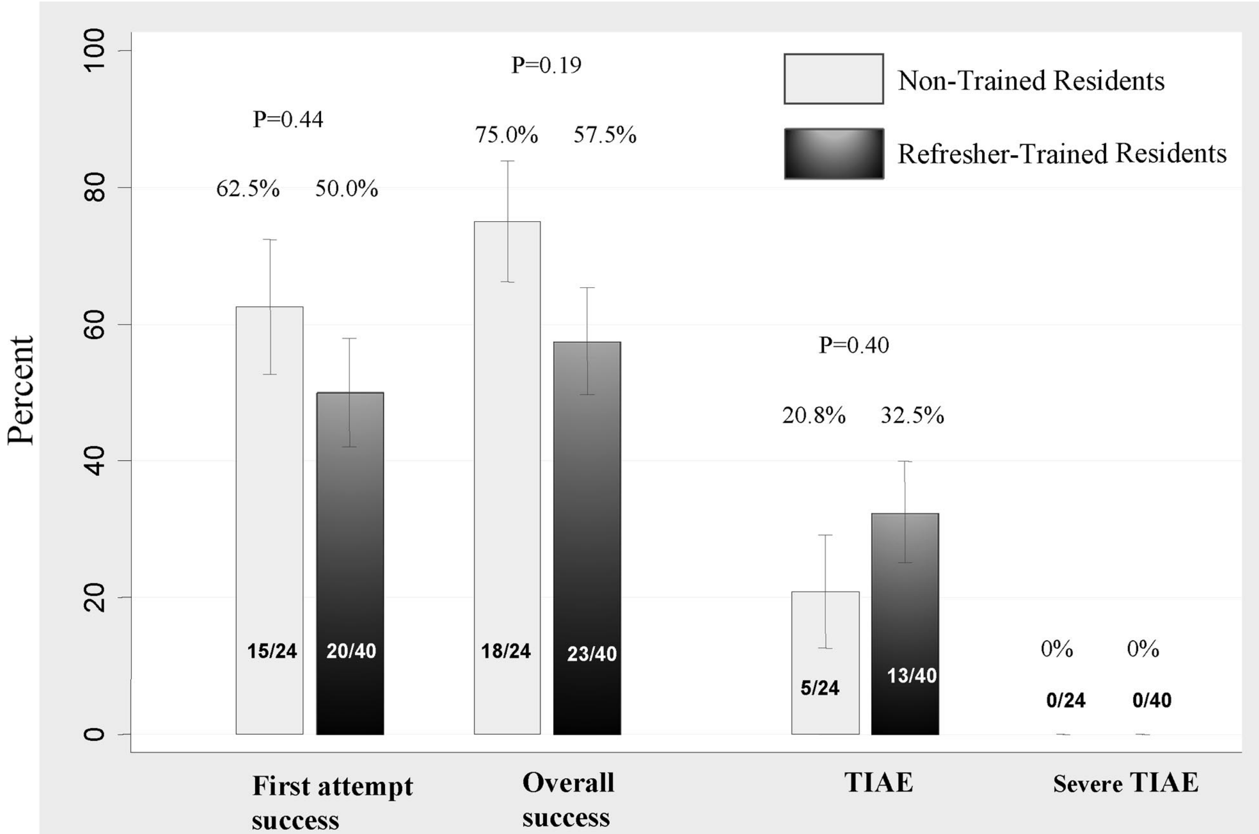

Fig. 1. Performance of non–refresher-trained *versus* refresher-trained resident on actual intubation during intervention phase. TIAE = tracheal intubation-associated events (table 1).

agement refresher training was introduced as a study intervention. Two distinct methodologies to maximize the educational effect of simulation were used: multidisciplinary simulation and a just-in-time refresher training method.

The multidisciplinary simulation training method was designed to enhance the conceptual and emotional fidelity of simulation.[12,13] In previous studies, multidisciplinary simulation training has been shown to be highly effective to improve team performance in simulated emergency settings for critical care,[18] obstetrics,[19] trauma,[20,21] anesthesia, and surgical teams.[22,23]

The just-in-time concept was used based on knowledge that both technical and teamwork skills decay over time,[24–26] and the effectiveness of refresher training is also associated with the duration from the last training.[27]§§ Because the evidence regarding the interval between airway management training to maintain competence is lacking,[9] the just-in-time strategy was used to attempt to prevent the rapid decay of the refreshed psychomotor or teamwork skills for pediatric tracheal intubation.

There was no statistical difference in primary and secondary endpoints between the refresher and nonrefresher groups during the intervention phase; however, there was a trend toward worse metrics in the refresher group. This suggests that the technical skills of participating residents were never acquired fully. Alternatively, the simulation may not have prepared the subjects for airway difficulty encountered in real patients. Finally, more competent non–refresher-trained residents may have been selected at the bedside to perform intubation, which made the performance seem better in our concurrent control (non–refresher-trained) group during the intervention period. It is less likely that the simulation-based education made the resident overconfident or that the team "overtrusted" the resident skill competence because those rates by refresher-trained residents were quite comparable with the resident-participated intubations in the preintervention phase.

In comparison with preintervention phase, there was no effect on incidence of TIAEs during the intervention phase, which could have increased with our increased resident participation as a laryngoscopist. We speculate that this may be attributable to an effect of multidisciplinary training because many TIAEs can be prevented by having competent nonlaryngoscopist team member(s).

§§ Nishisaki A, Scrattish L, Boulet J, Kalsi M, Maltese M, Castner T, Donoghue A, Hales R, Tyler L, Brust P, Helfaer M, Nadkarni V: Effect of recent refresher training on *in situ* simulated pediatric tracheal intubation psychomotor skill performance. Advance in patient safety: New directions and alternative approaches. Performance and Tools. Rockville, MD, AHRQ Publication No. 08-0034-3. Available at: http://www.ahrq.gov/downloads/pub/advances2/vol3/Advances-Nishisaki_44.pdf. Accessed March 21, 2010.

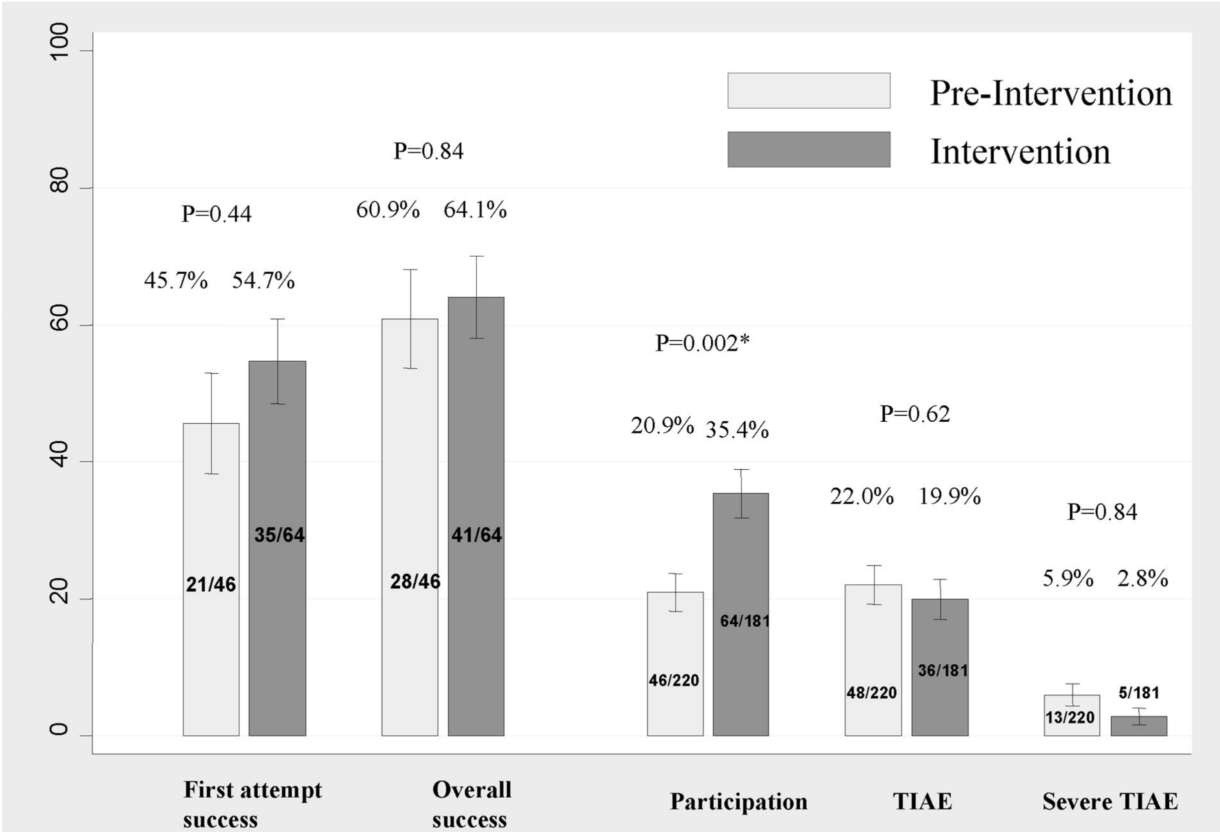

Fig. 2. Resident first-attempt success, overall success, intubation participation, TIAE, and severe TIAE in preintervention *versus* intervention phase. TIAE = tracheal intubation-associated events (table 1).

Our study results need to be interpreted in the light of several limitations. First, participation of just-in-time simulation refresher-trained residents as laryngoscopists in actual tracheal intubations was lower than we estimated, although it was significantly increased during the intervention phase. This may reflect the high-illness severity of the PICU patients and the attending physicians' reluctance for residents to make first attempts at tracheal intubation on those critically ill children. This led to an underpowered study result to compare the performance of simulation refresher-trained residents with concurrent non–refresher-trained residents.

Table 4. Explanatory Factors for Tracheal Intubation-associated Events (Multivariate Analysis)

	Odds Ratio (95% CI)	*P* Value
Resident participation	2.22 (1.28–3.87)	0.005*
Simulation intervention period	0.68 (0.40–1.15)	0.15
Difficult airway (defined by ≥ 3 providers, or ≥ 3 attempts by nonresident provider)	9.37 (3.39–25.93)	< 0.0001*
Patient age		
Infant (< 12 mo)	Reference	
Child (1–7 yr)	1.55 (0.80–3.03)	0.20
Older child (≥ 8 yr)	1.12 (0.54–2.31)	0.76

Number of observations = 369; likelihood ratio (chi-square test, *df* = 5) = 27.26; *P* = 0.0001; Pseudo-R^2 = 0.07.
* $P < 0.05$.
CI = confidence interval.

In this study, we did not implement any specific intervention to increase resident participation as a laryngoscopist; rather, we intended to provide an educational intervention to resident trainees with simulation. Although our educational intervention increased resident participation as laryngoscopists, we are uncertain whether this is due to: (1) team leader's acceptance of resident as trained laryngoscopists as they became aware of the just-in-time training intervention, (2) resident's increased self-confidence to speak out to take an opportunity to be a laryngoscopist, (3) team members' acceptance and willingness to assist residents as laryngoscopists, as they might have trained together during multidisciplinary simulation. The decision as to who is to be a laryngoscopist is typically made by a team leader (fellow or attending physician) in our PICU throughout the study period during the preintervention and intervention phases.

Second, our study result is subject to potential biases inherent to the study design, specifically from: (1) nonrandomized selection of residents during the intervention period and (2) uncontrolled practice change over the time as a confounder. The increase in elective procedures (table 3) might have facilitated resident participation during intervention period, for example.

In addition, our sample size calculation might have been too ambitious, although it was based on available preliminary data. The effect size of our brief simulation refresher training might have been overestimated.

Third, we did not confirm the resident and team skill acquisition to *a priori* determined competence level at the end of the each simulation training. Future study intervention should strongly consider adopting "train to excellence" or a "simulation-based mastery learning" concept using preset passing criteria at the completion of training to ensure acquisition of the skill.[28,29]

Fourth, the team of PICU nurses and respiratory therapists and residents who trained together did not remain as a team due to shift changes. This highlights the practical challenge of multidisciplinary simulation-based training in clinical settings. The training effect dilutes when team members are trained together. Strong buy-in and leadership are necessary to implement and sustain just-in-time multidisciplinary simulation-based refresher training.

Fifth, our definition of the difficult airway status is arbitrary and subject to provider's assessment skills. The clinical features of difficult airway reported in table 3 are also subjective and are not validated in a critically ill pediatric population.

Sixth, we were not able to measure and assess the residents' airway assessment and bag-valve-mask ventilation skill competencies: critical skill competencies for nonanesthesiology residents. This could be done with a direct clinical observation of actual PICU intubation processes to evaluate the effectiveness of the refresher training by trained raters. We also did not have accurate time to action such as duration of apneic time for tracheal intubation.

Our study was primarily focused on the clinical patient outcomes. This is different from other many simulation-based intervention studies that measure the effectiveness of training using simulated patients and surrogate outcomes. A recent review highlighted the relative paucity of data regarding the transportability of clinical skills learned through simulation into clinical settings.[30] This study was designed to address this challenge in a simulation-based education. This study showed that the residents were able to participate as laryngoscopists in more intubations without increasing unwanted TIAE rates, with additional effective multidisciplinary simulation-based refresher training. This highlights a potential role for simulation-based education in postgraduate training: demonstration of skills and experience in refresher training in simulation facilitated further hands-on training in clinical settings on actual patients.

Contrary to our primary hypothesis, however, the simulation-based intervention was not effective in significantly improving procedural success by residents, although it did not increase unwanted TIAEs.

There are several reasons that could explain this gap: improved performance in a simulation setting does not necessarily transfer into improved performance in a clinical setting.

First, the training effect was diluted because of the ad hoc nature of the healthcare emergency. By practical necessity, our 6:30–7:00 AM multidisciplinary simulation training team members consisted of the incoming on-call resident and the on-duty registered nurse and a respiratory therapist who were going to leave at the morning shift change. Further, the critical care fellow and ICU attending on clinical service were not present during the training, but they were always present during the real intubations. Thus, the clinical bedside airway team rarely if ever consisted of the full team that trained together. This large variation might have served to minimize the effect of resident training to improve patient outcome. A recent meta-analysis conducted by Salas *et al.*[31] also pointed out the negative impact of ad hoc teams on the effectiveness of team training.

Second, the baseline technical and teamwork skills of resident participants were low, and the procedure was difficult; therefore, they were difficult to boost up to a consistent competence level with only a brief psychomotor skill refresher and multidisciplinary simulation training. The majority of resident participants had less than six previous intubations experience. The first-attempt success rate even for experienced residents (more than 20 previous intubations, primarily adult patients) was only 58%. More initial intensive skill development training with emphasis on the difference between adult and pediatric airway management may be necessary before short refresher training would become successful. This can be achieved by a structured airway management training integrating four steps: (1) technical skill (psychomotor) training with intubation training manikins, (2) technical skill training in the operation room under a control setting, (3) multidisciplinary simulation training with a focus on teamwork training in addition to technical skills, (4) actual intubation in PICU, using a stepwise approach with a requirement of competence demonstration by trainee at each step (*i.e.*, mastery learning concept).

By using various standards, previous anesthesia studies suggest that acquisition of intubation technical skill competence occurs after 40 intubations.[32] Comparing this previous study that measured adult intubation skill learning curve in a operation room suites, our first-attempt success rate for relatively experienced resident laryngoscopists (previous intubation > 20 times) was quite low (58% for experience median 50 times in our study *vs.* 80% at 50 times of intubation in the previously published study). This suggests the technical and teamwork complexity of pediatric intubations in PICU.

In summary, multidisciplinary pediatric tracheal intubation simulation refresher training was not associated with an improvement in resident proficiency, first or overall success, or decrease in unwanted TIAEs. It is unclear whether this negative result is from a small sample size or from suboptimal competence even after the completion of training. Simulation-based training should be calibrated to the desired provider and team competence targets. The concept of maintenance of skills by just-in-time refresher training should be used when baseline competence level of a trainee is adequate. Future studies with simulation-based educational intervention should vigorously evaluate the effect on operational performance and outcomes in clinical patient settings.

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Appendix: Multidisciplinary Training Scenario

An eight-month-old infant with acute respiratory distress because of suspected viral infection was admitted to PICU 2 h ago. Respiratory rate increased from 50 to 80 with decreased saturation on pulse oximetry from 95 to 85% with 3 l oxygen *via* nasal cannula. One hundred percent oxygen with tight-sealed mask increased the saturation up to 89%. Severe suprasternal and subcostal retraction were noted on examination. Chest x-ray on admission showed hyperinflated lungs without cardiomegaly. Nebulizer treatment with albuterol or racemic epinephrine was not helpful. She had not taken any food or fluid by mouth for the last 6 h and received intravenous fluid.

Basic Airway Management

Simulator: saturation on pulse oximetry will improve to 97% with 100% oxygen with effective bag-valve-mask ventilation (with visible bilateral chest rise). Saturation will remain low if the team does not provide effective bag-valve-mask ventilation with 100% oxygen.

Expected intervention:

- Open airway with head tilt-chin lift or jaw thrust maneuver
- Choose right size mask
- Check whether oxygen source is turned on
- Apply mask correctly (cover nose and mouth and avoid covering eyes)
- Provide bag and mask ventilation to have good chest rise
- Prepare for intubation (call for suction, oral airway, end-endotracheal tube, check laryngoscope, and medication: sedatives and paralytics)
- Simulator: after medication (sedatives and paralytics) is given, the patient will become apneic.

Advanced Airway Management

Simulator: after the mask is removed from the simulator or manikin's face, in 30 s, the saturation will start to decrease from 98 to 85 over next 30 s. It will improve after five rescue breaths up to 98%. This will stay for the next 30 s if the mask is removed from the face and will start to decrease from 98 to 85% over 30 s. This will be repeated until successful intubation and primary and secondary confirmation are performed.

- Apply laryngoscope with left hand
- Achieve appropriate direct laryngeal visualization without rocking
- End-endotracheal tube placement in the trachea (this will be detected with chest rise by a simulator, visible to a facilitator on the computer monitor screen)
- Avoid mainstem intubation (this will be detected with unilateral chest rise by a simulator, visible to a facilitator on the computer monitor screen)
- Hold end-endotracheal tube when a stylet comes out
- Primary confirmation
- Secondary confirmation with a colorimetric end-tidal carbon dioxide detector (this information will be given to a team by a facilitator if tracheal intubation is confirmed by a simulator).