Evaluation of multidisciplinary simulation training on clinical performance and team behavior during tracheal intubation procedures in a pediatric intensive care unit

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Objective: Tracheal intubation in the pediatric intensive care unit is often performed in emergency situations with high risks. Simulation has been recognized as an effective methodology to train both technical and teamwork skills. Our objectives were to develop a feasible tool to evaluate team performance during tracheal intubation in the pediatric intensive care unit and to apply the tool in the clinical setting to determine whether multidisciplinary teams with a higher number of simulation-trained providers exhibit more proficient performance.

Design: Prospective, observational pilot study.

Setting: Single tertiary children’s hospital pediatric intensive care unit.

Subjects: Pediatric and emergency medicine residents, pediatric intensive care unit nurses, and respiratory therapists from October 2007 to June 2008.

Interventions: A pediatric intensive care unit on-call resident, a pediatric intensive care unit nurse, and a respiratory therapist received simulation-based multidisciplinary airway management training every morning. An assessment tool for team technical and behavioral skills was developed. Independent trained observers rated actual intubations in the pediatric intensive care unit by using this tool.

Measurements and Main Results: For observer training, two independent raters (research assistants 1 and 2) evaluated a total of 53 training sessions (research assistant 1, 16; research assistant 2, 37). The correlation coefficient with the facilitator expert (surrogate standard) was .73 for research assistant 1 and .88 for research assistant 2 (p < .001 for both) in the total score, .84 for research assistant 1 and .77 for research assistant 2 (p < .001 for both) in the technical domain, and .63 for research assistant 1 (p = .009) and .84 for research assistant 2 (p < .001) in the behavioral domain. The correlation coefficient was lower in video-based observation (.62 vs. .88, on-site). For clinical observation, 15 intubations were observed in real time by raters. The performance by a team with two or more simulation-trained members was rated higher compared with the team with fewer than two trained members (total score: 127 ± 6 vs. 116 ± 9, p = .012, mean ± SD).

Conclusions: It is feasible to rate the technical and behavioral performance of multidisciplinary airway management teams during real intensive care unit intubation events by using our assessment tool. The presence of two or more multidisciplinary simulation-trained providers is associated with improved performance during real events. (Pediatr Crit Care Med 2011; 12:000–000)

KEY WORDS: intubation; infant; simulation; airway; teamwork

Tracheal intubation in the pediatric intensive care unit (PICU) is often performed on critically ill children in emergency situations. It is an essential part of stabilization and resuscitation in cases of acute respiratory failure, shock, or acute neurologic failure. The risks of tracheal intubation, however, are well described in adults and children with unstable conditions (1–8). Some of the specific tracheal intubation-associated complications that can occur are esophageal intubation, mainstem bronchial intubation, hypotension, or cardiac arrest in the worst scenario. Although many of those complications are clearly associated with patient-specific anatomical and physiologic conditions, complications are potentially preventable or at least modifiable when the individual airway provider skills and the bedside airway team skills are excellent.

Airway management skill training is critically important for PICU staff, including the rotating residents (9, 10). This critical skill includes several key components: recognition of impending respiratory failure, provision of effective bag-valve-mask ventilation with oxygen, preparation for tracheal intubation, anticipation of and preparation for potential

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complications, effective placement of the tracheal tube, confirmation of correct placement with primary and secondary techniques, and securing the tracheal tube. Acquisition and retention of this important skill are a challenge for trainees and practitioners in all disciplines (physicians, nurses, and respiratory therapists) because of limited training opportunities, highly variable educational methods, and a lack of standardized training goals and objectives (11). A recent report showed tracheal intubation occurs only once in 2–3 days in a busy tertiary PICU, and pediatric residents were the primary operators in only 28% of initial orotracheal intubations (12). Emergency advanced airway management in PICU is typically performed by an ad hoc airway team (team members are not fixed) comprised of physicians, nurses, and respiratory therapists. This makes team training more challenging. Furthermore, the psychomotor skills are known to decay over time and require refresher training to retain provider competence (13–16).

Simulation-based medical education has been used to improve technical skill and behavioral (teamwork) skill performance in clinical settings (17–19). Simulation offers trainees the opportunity to have repeated practice and experimentation in a controlled and safe learning environment. The use of a realistic, computerized manikin simulator has allowed trainees to practice basic and advanced airway skills. Several studies confirmed that simulation-based airway management training is realistic and effective to improve provider technical skills (20–22). Overly et al (20) showed that the success rate for pediatric resident intubation attempts on manikins was 56%, and the success rate for these residents on children in the emergency department was 50%. Hall et al (21) demonstrated that the intense manikin intubation training was as effective as training on actual patients to achieve technical skill competence.

Based on that knowledge, we previously designed and implemented a just-in-time (JIT) multidisciplinary advanced pediatric airway management training simulation program. This program uses pediatric patient simulators and facilitators to train a portion of the PICU airway management team members (an on-call PICU physician resident, a PICU nurse, and a respiratory therapist) to a standardized methodology for airway management. The objective of this training is to better prepare the team members for airway management situations that may arise in the PICU during the subsequent resident on-call duty or during the next nurse or respiratory therapist shift. Both technical and behavioral skills are systematically addressed, scored, and videotaped during the brief simulation scenario and debriefing.

Our primary aim in this pilot study was to evaluate the feasibility of implementing our newly developed simulation task-based scoring tool to evaluate the team performance during real tracheal intubations in the PICU. Our secondary aim was to evaluate the effectiveness of our simulation program team training on actual performance in real clinical settings by using trained observers. We hypothesized that the bedside team performance evaluation by using our task-based scoring system would be feasible and that teams with more simulation-trained providers would exhibit more proficient technical and behavioral skill performance.

MATERIALS AND METHODS

Subjects and Study Design

This pilot prospective, observational study was conducted in the PICU at The Children’s Hospital of Philadelphia. This PICU is a 45-bed tertiary PICU staffed with 20 faculty, 15 pediatric critical care medicine fellows, and approximately 150 nurses. At least four respiratory therapist staffs are always on duty in the unit. The institutional review board approved the study, and it was conducted in compliance with the Health Insurance Portability and Accountability Act.

During the study period (June 2007 to August 2008), a PICU on-call resident (postgraduate year: PGY1-3 pediatric residents and PGY3-4 emergency medicine residents), a PICU nurse, and a respiratory therapist received a brief simulation-based multidisciplinary JIT airway management training session every morning from 6:30 AM to 7:00 AM. The details of the training are described in the simulation section below. On-call residents who participated in the training stayed on service for the next 30 hrs. Many PICU nurses and respiratory therapists participated in the training at the end of their shift, but many of them returned in 12 hrs for the next shift. During the 14 months, a total of 202 JIT training sessions were conducted for 54 pediatric and 24 emergency medicine residents (each provider’s median number of JIT sessions was 3, with a range from 1 to 6), 122 PICU nurses (each provider’s median number of JIT sessions was 1, with a range from 1 to 6), and 65 respiratory therapists (each provider’s median number of JIT sessions was 2, with a range from 1 to 10). The study design is presented in Figure 1.

Development of Assessment Tool and Rater Training

Our task-based team evaluation scale for pediatric intubation outside the operation room was developed by using the healthcare failure

![Image](https://example.com/image.png)
mode and effect analysis approach (23, 24). Using the healthcare failure mode and effect analysis, we identified important processes and subprocesses necessary for safe advanced airway management in the PICU and developed an evaluation tool. Based on the risk priority score assigned by the healthcare failure mode and effect analysis, the team assigned an item-specific weight to each item and named the tool as the JIT pediatric airway provider performance scale (JIT-PAPPS). After piloting, evaluating, and adjusting this prototype JIT-PAPPS tool with trained raters by using both videotaped and live simulation training events, the scale was refined, and JIT-PAPPS version 3 was finally developed (Appendix 1).

The JIT-PAPPS version 3 consists of two domains: a technical domain consisting of 14 items and a behavioral domain consisting of 20 items. This categorization was accomplished by expert group consensus based on the teamwork conceptual model by Flin and Maran (25) and Fletcher et al (26). Scores were calculated by a weighted sum of the technical and behavioral domains, and the total score represents the composite sum of weighted scores of both domains. The maximum possible technical domain score is 62: the behavioral domain maximum is 80, and the total score maximum is 142. In this study we assessed inter-rater reliability between an expert facilitator and two trained raters (research assistants [RAs]). The expert facilitators were healthcare providers with extensive pediatric advanced airway management experience who were involved in the development and refinement of this JIT-PAPPS and operational definitions, and also functioned as facilitators of the training. They consisted of three pediatric critical care attending physicians, one neonatology fellow, and one PICU respiratory therapist educator. The experts rated the team performance immediately after each training session on site, while RAs rated approximately 20% of the performance via video review. Once inter-rater reliability statistics were established, actual PICU intubations were observed by one of the two trained raters (RAs) with JIT-PAPPS version 3.

### Multidisciplinary Simulation-Based Airway Management Team Training

The JIT pediatric advanced airway management training occurred in the morning from 6:30 AM to 7:00 AM on weekdays except Thursday, in a videotaped simulation training room within our PICU. The training room was configured to be identical to the patient rooms. JIT 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 by using a pediatric (5-yr-old) manikin (MegaCode Kid, Laerdal, Wappingers Falls, NY), and 2) brief, standardized scenario-based team training with a high-fidelity human infant (6–8 months) simulation manikin (SimBaby, Laerdal, Stavanger, Norway) in respiratory failure, which requires bag and mask ventilation and orotracheal intubation, followed by a scripted short debrief using JIT-PAPPS as a checklist. For this second part, the team received simulation-based airway management training using a whole-body simulator (Appendix 2). The team performance during JIT training sessions was rated by two trained independent reviewers with specific rating criteria and operational definitions blinded to the participant’s background.

### Clinical Observations of PICU Intubation Events

A convenience sample of actual intubations that occurred in the PICU in human patients during the workday (from 8 AM to 5 PM) was observed by one of the two RAs (RA1 or RA2) to evaluate the team performance by using JIT-PAPPS version 3. The RA was alerted on an airway pager for a potential intubation by unit staff. In this study, we defined an actively participating physician(s), nurse(s), and respiratory therapist(s) in advanced airway management as airway team members. The trained observer was not considered an airway team member. The training status of each member of the emergency airway team was confirmed by the JIT training database. We hypothesized a priori that the team performance with more than one JIT-trained member present would be better than when only one or no JIT-trained member was present. This was based on the assumption that two trained providers are necessary to improve communication that is critical for better team performance and task completion.

We excluded the data from the existing change-of-tube (oral to nasal) intubations because the procedure and sense of urgency were perceived differently from primary orotracheal intubation, and the JIT training focused on primary orotracheal intubation procedures. We also evaluated the clinical outcome of the airway management. Here, overall intubation success was defined by the criteria of having two or fewer attempts at an orotracheal intubation because more than two intubation attempts are associated with worse outcomes for in-hospital settings (5, 6). The incidence of adverse tracheal intubation-associated events (Table 1) during airway management was also used as the clinical outcome (2, 11, 12).

The actual intubation process and outcome data were collected by the National Emergency Airway Registry for Kids adapted from the National Emergency Airway Registry format, an established multicentered adult and pediatric emergency department intubation registry (3, 27, 28). The data include patient and practitioner information, indication, difficult airway evaluation, intubation events (including complications), and tracheal intubation success. The data collection form was filled out by one of the airway team members during and immediately after the intubation and was cross-checked by a designated respiratory quality improvement officer within 24 hrs of the event. The use of the quality improvement data for this study was also approved by the institutional review board.

### Statistical Analyses

Inter-rater reliability was calculated from the scores by two independent RAs and by the expert facilitator from the JIT training sessions. The actual PICU intubation airway team performance score was compared between teams with two or more JIT-trained members vs. zero or one JIT-trained member(s). Linear regression was also applied to evaluate the effect size of the number of JIT simulation-trained providers on the measured team performance score. After the normality of the training score was confirmed from all JIT training sessions, the descriptive statistics with mean ± SD were calculated. Categorical variables were analyzed with a contingency table method by using Fisher’s exact test. The
unpaired t test was used to compare two parametric variables. Pearson's correlation coefficient was used for inter-rater reliability statistics. A two-tailed test with $p < 0.05$ was used as the statistically significant cutoff. STATA 10.0 (Stata SE, College Station, TX) was used for analysis.

RESULTS

Inter-Rater Reliability for Independent Raters of Simulated Events

A total of 53 JIT training team performances were evaluated by two RAs (RA1, 16 training sessions; RA2, 37 training sessions) with JIT-PAPPS version 3.

There were ten JIT training sessions (RA1, eight sessions; RA2, two sessions) that were scored by video analysis and 43 sessions (RA1, eight sessions; RA2, 35 sessions) scored by direct observation. The correlation coefficients with the expert were RA1, .73 ($p = .001$) and RA2, .88 ($p < .001$) in total score; RA1, .84 ($p < .001$) and RA2, .77 ($p < .001$) in the technical domain; and RA1, .63 ($p = .009$) and RA2, .84 ($p < .001$) in the behavioral domain. Comparing the video-based evaluation to the direct observation, the correlation coefficient of total scores was lower in video-based observation (.62 vs. .88). This difference came from the poor correlation coefficient in the behavioral domain (technical domain: .73 vs. behavioral domain: .34).

Evaluation of Real Intubations in the PICU

A total of 15 primary orotracheal pediatric intubations were observed by independent raters (RA1, 4; RA2, 11) in the PICU. The characteristics and outcomes of each actual intubation observed in the PICU are illustrated in Table 2. Data from 12 of 15 patients were available. The median (interquartile range) age of the patients intubated in this study was 26 months (interquartile range: 17.3–75 months), and the most common indication was respiratory failure (n = 6), followed by an elective procedure (n = 5) (Table 3). Three patients had anticipated difficult airway components (one had a history of difficult airway with limited neck motion, one had limited mouth opening, and the other had a history of surgically repaired trachea). Six residents (four PGY2, two PGY3), and ten fellows

### Table 2. Airway team performance outcome

<table>
<thead>
<tr>
<th>Airway Team</th>
<th>Just-in-Time–Trained Team Members, n</th>
<th>Resident</th>
<th>Registered Nurse</th>
<th>Respiratory Therapist</th>
<th>First Attempt Success</th>
<th>Overall Success</th>
<th>Tracheal Intubation-Associated Events, n</th>
<th>Intubator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>0</td>
<td>NP/registered nurse tried twice then Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow then Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow then Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>0</td>
<td>Anesthesia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Resident</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Resident</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Attending</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>3</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>0</td>
<td>Fellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>0</td>
<td>Resident</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each number indicates one clinical provider’s experience. For example, in team 12, there were two respiratory therapists; overall success is defined as intubation success within two attempts; see Table 1; *mainstem intubation with delayed recognition. Note: This table is sorted by number of just-in-time–trained team members.

### Table 3. Patient characteristics

<table>
<thead>
<tr>
<th>Team Number</th>
<th>Age</th>
<th>Weight (kg)</th>
<th>Indication</th>
<th>History of Difficult Airway</th>
<th>Feature of Difficult Airway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 yr 4 mos</td>
<td>11</td>
<td>Hypoxia, hypercarbia</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>11 mos</td>
<td>10.5</td>
<td>Hypercarbia</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>1 yr 10 mos</td>
<td>13</td>
<td>Procedure</td>
<td>No</td>
<td>Limited mouth opening</td>
</tr>
<tr>
<td>4</td>
<td>1 yr</td>
<td>11</td>
<td>Procedure</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>Procedure</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>6</td>
<td>3 mos</td>
<td>4.3</td>
<td>Procedure</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>2 yrs</td>
<td>8</td>
<td>Unplanned extubation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>18 yrs</td>
<td>78</td>
<td>Hypercarbia</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>16 yrs</td>
<td>65</td>
<td>Hypercarbia, unstable</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>1 yr 7 mos</td>
<td>8.3</td>
<td>Unstable hemodynamics</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>n/a</td>
<td>n/a</td>
<td>Procedure</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>5 yrs</td>
<td>14</td>
<td>Hypoxia, Hypercarbia</td>
<td>Yes</td>
<td>Limited neck mobility, small jaw, large tongue</td>
</tr>
<tr>
<td>13</td>
<td>7 yrs</td>
<td>19</td>
<td>Upper airway obstruction</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>14</td>
<td>6 yrs</td>
<td>23</td>
<td>Hypoxia</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>15</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

n/a, Data not available.
Airway team performance during real trauma-based multidisciplinary team training on pediatric intensive care unit intubation

This is the first study to systematically evaluate the effect of brief, simulation-based multidisciplinary team training on airway team performance during real tracheal intubations on patients in a tertiary PICU. The feasibility of using evaluation tools (JIT-PAPPS) and real-time direct observers trained during realistic in situ manikin simulations of the critical event was pioneered. The consistency of the inter-rater reliability and transference between simulated and real critical events supports the feasibility of this innovative approach.

Airway teams with two or more JIT simulation-trained team members performed significantly better compared with the teams with fewer than two JIT simulation-trained team members. There was also a statistically significant association between the number of simulation-trained team members and clinical performance. This finding suggests that brief, JIT simulation-based multidisciplinary training can improve team process of care and operational performance outcomes during tracheal intubation events in the PICU. The proportion of intubations with tracheal intubation-associated events, however, did not show a statistically significant difference among those performed by the airway teams with two or more JIT simulation-trained members and those by the teams with fewer than two JIT-trained members. This study was conducted as a pilot observational study and was not designed to power for clinical outcomes. These findings are based on a small number of events and warrant confirmation in a larger, prospective study.

Simulation-based education has its innate strength in multidisciplinary team training in the acute care setting, such as resuscitation, trauma, or sepsis (29–34). Although many studies have shown the effectiveness of multidisciplinary simulation-based education to improve crisis resource management, communication, and cognitive and psychomotor skill competence in simulation settings, this study is one of the few to demonstrate the transference of improved operational performance during simulation-based team training to improved operational performance during real clinical interventions with patients (17–19, 35). This is a critical step toward improving patient outcomes with simulation-based intervention.

Designing and conducting a prospective clinical trial that seeks to determine the impact of simulation-based multidisciplinary team training on safety outcomes during low-frequency clinical events is challenging because 1) the number of possible multidisciplinary simulation-training exposures is limited by logistic difficulties of setting up, gathering the multidisciplinary team members, and running the courses; 2) the low frequency of certain events of interest (intubation, cardiac arrest, etc.) renders them difficult to study well, and 3) owing to the ad hoc nature of team assembly in the healthcare setting, clinicians may reassemble in such a way as to exclude simulation-trained providers, and include nontrained providers, thus diluting the impact of prior simulation training. We will discuss these three challenges further.

The sample size calculation for simulation-based multidisciplinary educational intervention was potentially problematic in our study for two reasons. First, the number of interventions might have been limited. The simulation-based multidisciplinary training can be labor and time intensive to gather facilitators and trainees and to conduct a reasonable simulation scenario followed by effective debriefing. The logistics to provide the team training in a consistent manner is challenged when the multidisciplinary team members are the medical providers in acute patient care areas such as emergency departments or intensive care units, even though these are the provid-

Table 4.

<table>
<thead>
<tr>
<th>Just-in-Time Members in Team, n</th>
<th>Intubations, n</th>
<th>Total Scores</th>
<th>Technical</th>
<th>Behavioral</th>
<th>Overall Success (%)</th>
<th>First Attempt Success (%)</th>
<th>Tracheal Intubation-Associated Events*, n</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>123</td>
<td>52.5</td>
<td>70.5</td>
<td>50 (1/2)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>112.75</td>
<td>52.25</td>
<td>60.5</td>
<td>75 (3/4)</td>
<td>50 (2/4)</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>125</td>
<td>53.25</td>
<td>71.75</td>
<td>100 (4/4)</td>
<td>75 (3/4)</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>127</td>
<td>58</td>
<td>69</td>
<td>75 (3/4)</td>
<td>75 (3/4)</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>125</td>
<td>58</td>
<td>73</td>
<td>100 (1/1)</td>
<td>100 (1/1)</td>
<td>0</td>
</tr>
<tr>
<td>&lt;2 Trained members</td>
<td>6</td>
<td>116 ± 9</td>
<td>52 ± 5</td>
<td>64 ± 7</td>
<td>67 (4/6)</td>
<td>33 (2/6)</td>
<td>1</td>
</tr>
<tr>
<td>2 Trained members</td>
<td>9</td>
<td>127 ± 6</td>
<td>56 ± 4</td>
<td>71 ± 5</td>
<td>89 (8/9)</td>
<td>78 (7/9)</td>
<td>0f</td>
</tr>
</tbody>
</table>

Mean ± SD; p is based on comparison between a team with fewer than two trained members vs. more than two trained members; *p = .012, t test; **p = .13, t test; ***p = .057, t test; *p = 1.0, Fisher’s exact test; **p = .14, Fisher’s exact test; ***p = . A, Fisher’s exact test; *see Table 1.
ers who would get most benefit from multidisciplinary team training. In our study, multidisciplinary simulation training was held in the morning from 6:30 AM to 7:00 AM on weekdays, since this is the only time that participants from all three disciplines (residents, nurses, and respiratory therapists) could reliably attend. Our simulation training needed to finish on time, because the nursing sign-out was expected to start at 7:00 AM.

Secondly, actual clinical emergency events such as resuscitation or tracheal intubation do not occur as a daily basis. Even in our busy PICU, one of the largest tertiary care centers in the United States, primary tracheal intubation occurs only once in 2–3 days (12). While this justified a JIT simulation-based team training approach to prepare for uncom, unexpected emergencies, it made the actual clinical evaluation more difficult due to a limited sample size. One potential approach for this challenge is to develop and use a reliable and valid process measurement tool to evaluate these clinical events. In our study we developed and piloted JIT-PAPPS to evaluate the multidisciplinary team’s clinical performance. Our data suggest that using direct observation by trained RAs and JIT-PAPPS to evaluate the actual pediatric airway management is feasible to evaluate the simulation-based team training effect in both simulated and real clinical settings. One caveat for this approach is that it is necessary to develop a clinically meaningful difference on the scale using a reference standard. Our future studies should address this issue by using JIT-PAPPS. Once this is established, a hypothesis-testing prospective study can be designed with a sufficient power to detect this minimally clinically meaningful difference. Another potential approach is to develop a multi-centered collaborative to increase the sample size.

The dilution of training effect is another potential challenge for multidisciplinary team training approaches in the acute care setting. During a medical emergency, the bedside clinical teams typically consist of mixtures of trained and untrained practitioners (ad hoc team). This means that trained team members who rehearse together during simulated procedures do not necessarily participate together with the same team during real procedures. Furthermore, while PICU residents underwent JIT simulation training for the laryngoscopist role, only 35% of all PICU intubations during the study period were actually performed by residents as laryngoscopists because of the attending physician and PICU fellow’s assessment of the patient’s anatomical and physiologic appropriateness for trainee intubation attempts. One potential approach would be to minimize the discrepancy between the trained vs. actual airway team members (e.g., mitigate the ad hoc team effect). Another potential approach would be to train all of the potential team leaders and laryngoscopists, not just the resident trainees as laryngoscopists. These logistic approaches have been piloted in trauma team resuscitation and in an in-hospital adult cardiopulmonary resuscitation (13, 36).

There are very few studies that have attempted to show the clinical impact of simulation-based training in real acute care settings. Knudson et al (36) reported that simulation-based trauma resuscitation education for surgical residents improved the crisis management skills during real trauma resuscitation. Eighteen midlevel surgical residents were randomized to receive five training sessions (a total of 10 hrs) of either lectures or simulation-based training. Cognitive skills were evaluated by written post-test, and both groups performed equally well (lecture group: 65 ± 14% vs. simulation group: 68 ± 14%). However, during actual trauma resuscitation, the resuscitation team led by a simulation-trained resident performed significantly better in its crisis management skills (all crisis management skills—lecture group, 74 ± 22 vs. simulation group, 83 ± 17, p = .14; teamwork skills—lecture group, 72 ± 24 vs. simulation group, 87 ± 19, p = .04), whereas initial treatment skills (technical skills) did not differ between those two groups (p = .48).

Wayne et al (35) reported the effectiveness of simulation-based adult cardiac life support refresher training. In their study, second-year medicine residents received 10 hrs of simulation-based education and 4 hrs of adult cardiac life support refresher training by using a whole-body simulator. They compared 48 adult cardiac life support events (20 led by a simulator-trained resident and 28 led by a traditionally trained resident) and demonstrated that the events led by a simulation-trained resident had better adherence to adult cardiac life support guidelines (68% vs. 44%, p ≤ .001). The study by Knudson et al (36) used a video-based assessment by experts, and the study by Wayne et al (35) used a retrospective resuscitation record review. They both trained the potential team leaders in their intervention.

Our study was distinctly different from those studies in at least three aspects: 1) the use of the direct observation method by using trained evaluators (RAs), 2) the attempt to educate multidisciplinary team members (residents, nurses, and therapists) instead of the potential team leaders (attending physicians and ICU fellows), and 3) the deliberate systematic development of an evaluation tool by using the prospective healthcare failure mode and an effect analysis approach to attain high content validity.

In our study, although each technical and behavioral (crisis management) skill did not independently reach statistical significance, the behavioral skill ratings were higher in teams with two or more simulation-trained members present compared with teams with fewer than two simulation-trained members. This finding was similar to that in the study by Knudson et al (36). Our study provides further validation of the effectiveness of simulation-based airway management training to improve team skills in pediatric acute care. This study also demonstrates the benefit of simulation-based education: deliberate, repetitive practice without risking patients for training, especially when learners have steep learning curves.

Our study results need to be interpreted in light of several important limitations. Because this was a pilot study, we were limited to a small sample size and the nature of convenience (nonsystematic) sampling. We did include all available data into the analysis. The risk for sampling bias thus cannot be excluded. A formal hypothesis-testing study with a sufficient power to detect a minimally clinically significant with systematic sampling (or complete follow-up) to eliminate ascertainment bias will be the next step.

Second, although our JIT training was targeted to the resident physician as laryngoscopist and leader of the airway team during simulations, a critical care medicine attending and/or fellow was always in attendance at each real intubation. The presence of a higher-level provider is likely to have influenced the team behavior and the success and outcome of each intubation. Despite this nonclassifi-
education bias (an attending physician was present at all intubations), our total score for actual intubation was significantly higher in the airway teams with two or more team members trained by JIT simulation. The result might have been more dramatically different without this potential systematic bias. Thus, the demonstration of differences associated with JIT training status was remarkable and important. Due to our limited sample size, we were not able to further quantify the impact of the training stratified by discipline. Due to the ad hoc nature of bedside airway team composition in our PICU, the duration between JIT simulation training and the real clinical intubation was variable. Our clinical observation data were insufficient to quantify the effect of decay after the training.

Another limitation of our study was the independent rater’s training status. The overall inter-rater reliability was good. There was a rapid learning curve of their training, which was included in our analysis. In addition, the inter-rater reliability of the nontechnical domain in JIT-PAPPS was suboptimal when it was applied in video-based analysis, especially given the technical noise, sound capture, and video capture challenges. Importantly, this limitation does not affect our evaluations of real intubation events, since all real intubations were observed directly (not by video). We acknowledge that we did not document the achievement of a certain level of competence during simulation-based training.

Although this was a pilot study, there are several implications for further research on this topic. We have demonstrated that this brief JIT multidisciplinary airway team training may substantially improve the airway management process of care. Furthermore, this format of multidisciplinary team training on time-sensitive, high-risk procedures can be applied to many clinical areas.

In conclusion, our study demonstrated that the technical and behavioral team performance rating is feasible during real advanced airway management events in the PICU using trained observers. The presence of two or more providers who have participated in recent multidisciplinary simulation training is associated with improved operational performance in real advanced airway management.

Further research is required to vigorously evaluate the impact of JIT and just-in-place simulation education training on provider confidence, competence, operational performance, and patient outcomes.

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APPENDIX 1

The second column (T/NT) denotes the categories of action (technical task vs. behavioral [nontechnical] tasks). The third column (NT, cat) denotes the categories of action in behavioral tasks. SA, situation awareness; DM, decision making; TM, task management; TW, teamwork.

Scoring Instruction

A score of 2 is given if the task is done correctly, timely. A score of 1 is given if the task is done incorrectly or the task is done but not in a timely fashion. A score of 0 is given if the task is not performed.

Calculation of a Domain-Specific Score and a Total Score

Each domain score (for a technical and a behavioral domain) is calculated as a weighted sum of the scores. The score for each task is multiplied by point (weight), which was generated from healthcare failure mode and effect analysis. Then, those are aggregated by domain. The total score was a sum of a technical and a behavioral domain score.

Global Rating (Items 36 and 37).

Not used in this presented study.

APPENDIX 2

Part 2. Just-in-Time Scenario

An 8-month-old infant with acute respiratory distress due to suspected viral infection was admitted to the pediatric intensive care unit 2 hrs ago. Now the respiratory rate has increased from 50 to 80 with decreased saturation on pulse oximetry from 95% to 85% with 3 L of oxygen via nasal cannula. One hundred percent oxygen with tight sealed mask increased saturation up to 89%. Severe suprasternal and subcostal retraction are noted on your exam. Chest radiograph on admission showed hyperinflated lungs without cardiomegaly. Nebulizer treatment with albuterol or racemic epinephrine was not helpful. She has not taken any food or fluid by mouth for the last 6 hrs and is receiving intravenous fluid.

A. 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 oxygen source is turned on;
○ Apply mask correctly (cover nose and mouth, avoid to cover eyes);
○ Provide bag and mask ventilation to have good chest rise, and
○ Prepare for intubation (call for suction, oral airway, tracheal tube, check laryngoscope, medication: sedatives and paralytics).

Simulator: After medication (sedatives and paralytics) are given, the patient will become apneic.

B. Advanced Airway Management

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

Expected Intervention

○ Apply laryngoscope with left hand;
○ Achieve appropriate direct laryngeal visualization without rocking;
○ Tracheal tube placement in 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 tracheal tube when stylet is removed;
○ Primary confirmation, and
○ Secondary confirmation with a colorimetric end-tidal CO2 detector (this information will be given to a team by a facilitator if tracheal intubation is confirmed by a simulator).