An Innovative Nonanimal Simulation Trainer for Chest Tube Insertion in Neonates

WHAT’S KNOWN ON THIS SUBJECT: Practitioners caring for critically ill infants need to acquire competence in insertion of chest tubes for pneumothorax. Ethical and logistic concerns inhibit the use of animals, and there are no realistic simulation models available for neonatal chest tube insertion training.

WHAT THIS STUDY ADDS: An inexpensive, nonanimal chest tube insertion model can be easily constructed and used effectively to train interns and residents to improve their knowledge, clinical skills, and comfort levels to perform the chest tube insertion procedure in infants.

abstract

BACKGROUND AND OBJECTIVE: Competence in the chest tube insertion procedure is vital for practitioners who take care of critically ill infants. The use of animals for training is discouraged, and there are no realistic simulation models available for the neonatal chest tube insertion procedure. The objective of this study was to assess the effectiveness of teaching the chest tube insertion procedure by using an easily constructed, nonanimal simulation model.

METHODS: An inexpensive infant chest tube insertion model was developed by using simple hardware. A prospective cohort study with pre-posttest intervention design was conducted with pediatric and combined internal medicine–pediatrics residents. Residents completed a questionnaire about their previous experience of chest tube insertion, knowledge, self-evaluation of knowledge, comfort, and skills; pre, post, and a month after an individualized education session and demonstration of the procedure on the model. Clinical skills were assessed by using a 32-point scoring system when residents performed the procedure on the model immediately after training and a month later.

RESULTS: All residents had significant improvement in knowledge and self-evaluation of knowledge, comfort, and skills scores after the education session and training on the model and this improvement was retained after 1 month ($P < .001$). Clinical skills scores decreased slightly 1 month after training ($P = .08$). Scores were not significantly different between the levels of trainees.

CONCLUSIONS: An educational intervention using an easily constructed and inexpensive chest tube insertion model is effective in improving knowledge, comfort, and skills in trainees. The model can be used repeatedly to maintain proficiency. Pediatrics 2014;134:e798–e805

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KEY WORDS pneumothorax, chest tube insertion, simulation, nonanimal model

ABBREVIATIONS CS—clinical skills
K—knowledge
SEG—self-evaluation of comfort
SEK—self-evaluation of knowledge
SES—self-evaluation of skills

Dr Gupta conceptualized and designed the model and study, collected data, carried out the analyses, and drafted the manuscript; Dr Ramasethu assisted in designing the model, designed the data collection instruments, coordinated and supervised data collection and analysis, and revised and reviewed the manuscript; and both authors approved the final manuscript as submitted.

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Pneumothorax is a serious and potentially life-threatening complication in neonates, occurring primarily in sick preterm neonates on assisted mechanical ventilation and in term neonates with meconium aspiration syndrome. Although advances in mechanical ventilation have reduced the incidence of pneumothorax in infants, it still remains a significant problem.1,2 Management of pneumothorax is an emergency and often necessitates needle thoracocentesis and insertion of a chest tube drain.

Competence in inserting chest tubes is vital for all practitioners who take care of critically ill infants in ICUs and in emergency rooms. If performed incorrectly, there is a potential risk of complications, such as laceration or perforation of the lungs, liver, spleen, major vessels, diaphragm, stomach, or the heart, with catastrophic consequences.3–5 Correct technique of chest tube insertion is crucial to avoid these complications and to ensure the effectiveness of the chest tube in draining the pneumothorax.

Many physicians lack the basic knowledge and skills required to insert chest tubes because of lack of experience and exposure.6 Animal models have been used in the past to teach the procedure to residents and junior doctors by using anesthetized cats,7 rabbits,8,9 and chicken models.10 The use of animal models has come under increased scrutiny and is not feasible in every academic setting. According to a new federal regulation (HR4310, 112th: National Defense Authorization Act of Fiscal Year 2013),11 using live animals for teaching medical procedures is discouraged in the military, and simulation-based training methods are recommended.

There are limited simulation models available for neonatal chest tube placement. There are a few infant resuscitation models available, which are purportedly useful for learning chest tube insertion, but they do not provide a realistic experience, as they have a permanent hole in the chest to simply insert a chest tube; in addition, they are quite expensive.12,13 There is a definitive need for an inexpensive nonanimal simulation model for effective training of chest tube insertion technique in infants.

Our objective was to construct an inexpensive, nonanimal simulation training model for chest tube insertion in infants, and to evaluate the effectiveness of an educational intervention by using this model to improve the knowledge, comfort, and skills of pediatric residents by increasing their familiarity with the equipment and sequential steps of the procedure in a safe environment.

**METHOD/DESIGN**

We developed a chest tube insertion model by using simple hardware material (Fig 1). The clavicles and rib cage were constructed by using 14-gauge electrical cable wires. The “simulated chest” had 2 “pleural” cavities, created by using a Styrofoam block in the middle of the rib cage, so that the procedure could be performed on either side. Inflated plastic sandwich bags placed within the cavity simulated the pneumothorax. The chest model with inflated sandwich bags was wrapped with thick shelf liner (Nonadhesive Grip Premium Liner; Con-Tact brand, Kittrich Corporation, La Mirada, CA) to simulate the muscle layer and placed in a hollow polyurethane infant doll with the anterior chest and abdominal wall cut away. Thin shelf liner (Lite adhesive Lite Tack shelf liner; Con-Tact brand; Kittrich Corporation) was wrapped around the chest and abdomen of the infant model to simulate the skin layer; and nipples were marked with a permanent marker at the fourth intercostal space. We ensured that the ribs could be counted, and the intercostal spaces could be palpated. Three neonatologists, 2 senior fellows, and 2 experienced nurse practitioners performed the procedure on a prototype of the model during the process of development, and provided valuable feedback, which was used to change materials and modify the model so that it provided a more realistic experience.

Eight neonatologists and 3 nurse practitioners then performed the procedure on the final model and validated it by using a Likert scale, scoring it for realism and utility for teaching. The cost of the materials for the model was <$50.00.

We conducted a prospective cohort study at MedStar Georgetown University Hospital with pediatric and combined internal medicine–pediatrics residents, and first-year neonatology fellows as subjects, by using a pre-posttest intervention design. There were 3 groups of residents: interns (acting interns and first-year residents), junior residents (second-year residents), and senior residents (third- and fourth-year residents and first-year neonatology fellows). Residents completed a questionnaire about any previous experience of chest tube insertion, and also self-evaluated their knowledge (SEK), comfort (SEC), and skills (SES) about the chest tube insertion procedure on a 10-point Likert scale. A resident’s actual theoretical knowledge (K) of chest tube insertion was assessed by a test with a maximum score of 10, consisting of questions about the appropriate site for incision, sequential steps of the procedure, and direction of chest tube insertion.

After pretesting assessment, we conducted individual teaching sessions with each resident by using a PowerPoint and video presentation that included the indications and contraindications of chest tube insertion, sequential steps of the procedure, possible complications, troubleshooting, and knowledge of radiographs. A preceptor (A.O.G.) performed a step-by-step demonstration of the correct technique of the procedure on our model by using standard equipment.
After the teaching session and demonstration of the procedure by the preceptor on the model, residents performed the procedure on the model, and as they performed the procedure, the preceptor scored them on a clinical skills (CS) checklist (Table 1). The CS checklist has a maximum score of 32 points and includes 16 sequential steps, starting from “time out,” in accordance with the Joint Commission guidelines, to securing the chest tube, representing key components of safe and effective chest tube insertion procedure. CSs were not evaluated before teaching because most residents had no experience with placement of chest tubes. Postteaching, residents answered another questionnaire evaluating their SEK, SEC, SES, and K.

Residents performed the procedure again after 1 month (this time without additional teaching or demonstration). Although residents were aware that they would be retested after 1 month, they were not prescheduled for the test and did not have the opportunity to revise anatomy or practice doing the procedure again before being asked to repeat the task. Clinical skills were again assessed using the CS checklist and assessments of SEK, SEC, SES, and K were repeated to evaluate retention of learning.

Statistical analysis was carried out by using SAS 9.3 (SAS Institute, Inc, Cary, NC) for comparison of preteaching assessments to immediate postteaching and a month later and to compare the assessments of different training levels. Analysis of variance for repeated measures and Wilcoxon signed rank test were used for statistical analysis of nonparametric variables.

The study qualified for “exemption from review” by the Institutional Review Board of Georgetown University.

RESULTS

Sixty residents participated in the study. There were almost equal numbers of interns (21), junior residents (20), and senior residents (19). Fifty-eight residents completed all the assessments (preteaching, postteaching, and retention/1 month); 2 residents (an intern and a junior resident) could not complete the 1 month assessment. Fifty-two (87%) of 60 residents had no previous experience of chest tube insertion.
TABLE 1 Clinical Skills Checklist

<table>
<thead>
<tr>
<th>Steps of Procedure</th>
<th>Performed Well (2)</th>
<th>Partially Performed (1)</th>
<th>Not Performed (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Time out</td>
<td></td>
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</tr>
<tr>
<td>2. Identify and mark the site</td>
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<td></td>
<td></td>
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<tr>
<td>3. Checked equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Positioning of infant</td>
<td></td>
<td></td>
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<tr>
<td>5. Skin preparation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6. Drape surgical area</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7. Locate landmarks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Removed trocar from the tube</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Estimate length of insertion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Use of lidocaine</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>11. Incision</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Spread hemostat during blunt dissection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Correct plane of dissection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Correct angle of insertion of chest tube</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Positioning of chest tube angle toward midclavicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Securing the chest tube</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Among the 8 residents (13%) who had some experience, 4 (7%) reported being unsuccessful, 3 (5%) had experience of successful placement of chest tubes in adults and older children, and only 1 of the 60 residents had the experience of successfully inserting a chest tube in an infant.

Figure 2 A, B, C, and D demonstrates comparison of training levels (interns, junior residents, and senior residents) in SEK, SEC, SES, or K, preteaching, immediate postteaching, and after 1 month. SEK scores were significantly higher in senior residents as compared with the interns (mean 2.4 ± 0.4 vs 1.2 ± 0.4, P < .001) in the preteaching assessment (Fig 2A). However, there was no significant difference in the K scores among the 3 groups (Fig 2D). SEC and SES scores were also significantly higher in senior and junior residents as compared with interns (P < .001) in preteaching assessment (Fig 2B and C). All 3 levels of residents showed significant improvement in SEC, K, SES, and K scores from preteaching to postteaching with no significant decline in scores after 1 month (Fig 2 A, B, C, and D). CS scores were not significantly different among the different levels of trainees (Fig 3).

DISCUSSION

Surfactant therapy and volume-targeted ventilation modes have reduced the incidence of pneumothorax in preterm newborns,1,14,15 but it continues to remain a significant problem in NICUs. Pneumothorax is a well-recognized complication in preterm infants on mechanical ventilation or on continuous positive airway pressure,16 in late-preterm and early-term infants born by elective Cesarean delivery,17,18 and in infants with meconium aspiration syndrome.2 Pneumothorax may be a life-threatening complication in neonates, with hypoxemia, hypercarbia, and impaired venous return contributing to mortality and impaired neurodevelopmental outcomes.17,19,20 Although some infants may be managed expectantly, many have acute decompensation requiring immediate intervention with chest tube placement.17,20–22 Incorrect placement of chest tubes may be associated with serious complications, including perforation of the lung;23 misplacements into the liver, peritoneal space, heart, spleen, subclavian vessels, colon, esophagus, and inferior vena cava;24 and phrenic nerve paralysis.25 All practitioners who take care of critically ill infants should learn to insert chest tubes properly. The Accreditation Council for Graduate Medical Education Program Requirements for Graduate Medical Education in Pediatrics does not require pediatric residents to be competent in chest tube placement by

TABLE 2 Comparison of SEK, SEC, SES, K, and CS scores: Pre, Post, and 1 Month After Teaching

<table>
<thead>
<tr>
<th>Maximum Score</th>
<th>Preteaching, n = 60, Mean ± SD</th>
<th>Postteaching, n = 60, Mean ± SD</th>
<th>After 1 mo, n = 58, Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEK</td>
<td>6</td>
<td>1.9 ± 1</td>
<td>4.1 ± 0.8*</td>
</tr>
<tr>
<td>K</td>
<td>10</td>
<td>4.8 ± 1.4</td>
<td>8.8 ± 1*</td>
</tr>
<tr>
<td>SEC</td>
<td>8</td>
<td>1.0 ± 1.1</td>
<td>3.8 ± 1*</td>
</tr>
<tr>
<td>SES</td>
<td>8</td>
<td>0.5 ± 0.9</td>
<td>3 ± 1*</td>
</tr>
<tr>
<td>CS</td>
<td>32</td>
<td>NA</td>
<td>28.5 ± 1.6</td>
</tr>
</tbody>
</table>

NA, not assessed.

*P < .001 as compared with preteaching assessment.
the end of the training period. However, the Accreditation Council for Graduate Medical Education stipulates that pediatric residents must be competent in the understanding of the indications, contraindications, and complications of chest tube placement and thoracentesis; furthermore, residents should receive real and/or simulated training when these procedures are important for their postresidency position.26 Pediatric residents and fellows have limited opportunities to learn chest tube placement in patients during the training period. In a retrospective review of 261 critical procedures over a 12-month period in a tertiary-level pediatric emergency department in the United States, 18 tube thoracostomies were noted, but only 3 were performed by pediatric emergency medicine fellows and 1 by a pediatric resident; 9 were performed by surgery.27 A review of the critical events and procedures in the first 24 hours in 304 pediatric patients who were admitted to the PICU from a tertiary-level Canadian emergency department over 2 years found that 3 patients required intercostal chest drainage.28 A survey of 117 physicians who treated pediatric patients in 23 general community emergency departments found that more than 25% expressed significant discomfort (“uncomfortable and would

FIGURE 2
A, Comparisons of different levels of trainees for SEK. B, Comparisons of different levels of trainees for SEC. C, Comparisons of different levels of trainees for SES. D, Comparisons of different levels of trainees for K.
perform in an emergency” or “uncomfortable and would never perform”) with performing certain potentially lifesaving pediatric procedures, including chest tube placement. The residency training of these physicians included internal medicine, family practice, surgery, general practice, pediatrics, and emergency medicine. A survey of 50 junior doctors working in adult wards (medicine, surgery, accident and emergency, and anesthesia) in the United Kingdom found that only 44% knew the correct location to insert a chest drain.

Given the limited opportunities to even attempt chest tube placement, there is a need for an appropriate model for trainees to experience familiarity with the equipment, practice key steps of the procedure, and achieve competence, without compromising patient safety. Animal models used in the past to teach chest tube insertion procedure have included anesthetized cats, dead rabbits, pork ribs, and fryer chicken. These models are unrealistic for many reasons: absence of skin in the dead rabbit model, thick texture of skin and muscle in pork ribs, and lack of simulated pneumothorax and appropriate anatomic landmarks in the fryer chicken and cat models. There has been a phase-out of live animal laboratories in teaching institutions in the United States and around the world, partly because of the cost of maintaining animals and veterinary staff, but also because of ethical concerns over the killing of animals when there are suitable alternatives. There are currently limited simulation models available for the chest tube insertion procedure in infants.

We developed a chest tube insertion model that is realistic, allowing the trainee to see and feel landmarks to determine the appropriate site for chest tube insertion and use standard equipment for a lifelike experience, from skin incision, dissection of the muscle layer, to the slight popping sensation felt when entering the pleural space. The model also was inexpensive, and made with readily available material from a hardware store, for a total cost of <$50.00. We placed the “chest” model in the chest cavity of a discarded polyurethane resuscitation infant model, but it could be easily substituted by any plastic infant doll of an appropriate size. Both sides of the chest can be used for teaching purposes. The inflated sandwich bags simulating the pneumothorax need to be replaced after every procedure (cost <10 cents), and the “skin” and “muscle” layers, made of shelf liners, need replacement after 2 attempts on each side (4 procedures).

In our study, only 8 of the 60 residents had ever attempted placement of a chest tube, and only 1 of them had successfully placed a chest tube in an infant. Because of the lack of experience in chest tube placement, we did not evaluate clinical skills before teaching the procedure. Senior residents rated themselves higher in self-evaluations, but their knowledge and skill levels were similar to those of the junior residents and interns. The lack of association between self-evaluation and objective performance measures is consistent with other studies of medical students and junior doctors. Residues felt more confident and were more knowledgeable about the chest tube placement procedure after the training program using our model, and this confidence and knowledge was retained even after 1 month.

One of the limitations of the study is that the preceptor who tested the residents throughout the study remained the same and was not blinded. However, the residents’ clinical skills were scored by using an objective checklist, which should eliminate bias. CS acquired postteaching was retained well after 1 month. There was a slight decrease in the CS scores, which was not statistically significant. Another limitation of our study was that retention was tested only at 1 month, for reasons of feasibility. Testing at longer intervals...
would have provided a better idea of retention of knowledge and skills. Other simulation studies have shown decay in skills within 3 months, signifying that simulation training may be most effective in temporal proximity to the time when the skills are likely to be used and that frequent refresher training should be considered to prevent skills decay. Given the unpredictability of pneumothorax in infants, “just-in-time” training would not be possible or appropriate. Our model can be used for repeated practice to maintain skills.

There is a concern that improved performance after a simulation training session does not necessarily translate into improved performance at the bedside. Although this is not definitive, we have anecdotal evidence that after the simulation training, 3 residents performed chest tube insertions in the NICU successfully, and reported that the simulation training had helped them tremendously.

CONCLUSIONS
An educational intervention using a simple, easily constructed and inexpensive nonanimal chest tube insertion model can effectively teach pediatric residents the chest tube insertion procedure and increase their knowledge, comfort level, and skills about chest tube placement. Trainees retained the knowledge and skills after 1 month of the teaching session. Our model can be used repeatedly to maintain proficiency. Further study is needed to determine the long-term retention of knowledge and skills, and whether these improvements translate into proficiency in the clinical setting.

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