Scientific Research Publishing

Open Journal of Anesthesiology, 2020, 10, 190-202
https://www.scirp.org/journal/ojanes
ISSN Online: 2164-5558
ISSN Print: 2164-5531

Simulation of Bleeding Airways in Cadavers: New Models for Experiential Learning

Rajkumar Chandran[1], Asadi Negar[2], Seok Hwee Koo[3], Yin Yu Lim[4], Juen Bin Lai[5], Alvin Kah Leong Tan[6], Prit Anand Singh[1]

[1]Department of Anesthesia and Surgical Intensive Care, Changi General Hospital, Singapore, Singapore
[2]Department of Anaesthesiology, Singapore General Hospital, Singapore, Singapore
[3]Clinical Trials & Research Unit, Changi General Hospital, Singapore, Singapore
[4]Ministry of Health Holdings, Singapore, Singapore
[5]Department of Oral & Maxillofacial Surgery, Changi General Hospital, Singapore, Singapore
[6]Department of Otorhinolaryngology, Head and Neck Surgery, Changi General Hospital, Singapore, Singapore
Email: chandran.rajkumar@singhealth.com.sg

How to cite this paper: Chandran, R., Negar, A., Koo, S.H., Lim, Y.Y., Lai, J.B., Tan, A.K.L. and Singh, P.A. (2020) Simulation of Bleeding Airways in Cadavers: New Models for Experiential Learning. *Open Journal of Anesthesiology*, **10**, 190-202.
https://doi.org/10.4236/ojanes.2020.105017

Received: April 17, 2020
Accepted: May 15, 2020
Published: May 18, 2020

Abstract

Background: Healthcare education models have recently shifted from the traditional reliance on the apprenticeship model, where trainees learn on real patients in actual clinical settings, to one based on simulation models. Education in airway management is a fundamental component of anesthetic training programs, and airway modification to simulate difficult airways increases the fidelity of airway management training. **Objective:** The study goal was to determine the feasibility of simulating difficult airways such as mandibular fracture and post-tonsillectomy bleed in cadaver models by surgical modification for the use in enhanced experiential learning of difficult airway management. **Methods:** Two cadaver heads were modified surgically to simulate a mandibular fracture and post-tonsillectomy bleed. Workshop facilitators conducted directed one-to-one learning and provided feedback to participants. A paper-based feedback was obtained from the participants on their confidence level, and the realism, attractiveness, beneficial levels, and difficulty levels of the simulation models used. **Results:** The modified cadavers were reliable in simulating difficult airways. The majority of participants (83.3% for fractured mandible and 87.1% for post-tonsillectomy bleed) reported an increase in confidence level for management of the difficult airway after the experience with the modified cadavers, and found both models realistic, attractive, and beneficial for difficult airway training. **Conclusions:** Surgical modifications of cadavers to simulate difficult airways such as fractured mandible and post-tonsillectomy bleed may be incorporated into advanced airway management courses to

enhance experiential learning.

Keywords

Airway, Simulation, Hemorrhage, Tonsillectomy, Experiential Learning

1. Introduction

Education in airway management is a fundamental component of anesthetic training programs, but the conventional teaching of anesthesia falls short of exposing trainees to the vast spectrum of difficult airways potentially encountered in clinical practice. Airway management training emphasizes on teaching skills for airway management such as the use of flexible fiber-optic bronchoscopy, laryngeal mask airway, and rigid fiber-optic laryngoscopes [1]. It, however, lacks the emphasis on the exposure to rare but complex cases of difficult airways such as congenital defects, infections, tumors, obesity, acromegaly, acute burns, or facial, cervical, laryngeal, or tracheal injury [2].

Patient safety in anesthesia has improved tremendously in the past few decades [3]. An increased commitment to patient safety has resulted in a shift in healthcare education models from the traditional reliance on the apprenticeship model, where trainees learn on mannequins and then on real patients in actual clinical settings, to one based on simulation models [4]. Simulation is defined as a guided experience that evokes the real-world scenario in an interactive fashion to replace real-life experiences. Simulation enhances training in both technical and non-technical skills to improve professional practice and crisis management. Non-technical skills are an inherent part of human factors as they relate to situational awareness, communication, leadership, decision making, prioritization, and task management. These are essential in promoting patient safety, productivity, and efficiency [3].

Experiential learning refers to the construction of knowledge and meaning through the transformation of real-life experience [5]. Experiential learning is now increasingly used in medical education, as simulation models adhere to their principles by providing opportunities for hands-on experiences and guided reflection in a safe environment [4], thereby enhancing the transition from novice to expert professional practice [3].

Available simulation models are limited and do not encompass the entire spectrum of difficult airways. Practice on models simulating different pathologies of difficult airways increases the fidelity of airway management training by exposing trainees to real-life challenges in airway visualization and ventilation, challenging them to progress through an airway algorithm, and generate backup plans in the event of failed ventilation [6].

Difficult airways which can progress to life-threatening scenarios include conditions such as post-tonsillectomy bleed and bleeding mandibular fracture.

There are currently no studies in the literature which attempt to simulate models of these pathologies for training purpose. This study explores the simulation of these two scenarios and its use in an advanced airway workshop for enhanced experiential learning.

Mandibular fractures increase the difficulty in airway management due to airway obstruction, possible cervical spine injury, difficult mask ventilation, and competing needs of the airway and surgical access. Further airway visualization is impaired where severe hemorrhage, vomitus, secretions, soft tissue edema, fractured or exfoliated teeth, bone fragments, and foreign bodies obstruct the airway [7] [8]. The effective removal of blood is impaired when the risk of spinal injury outweighs the risk of airway compromise, resulting in the choice not to position the patient sitting up with his neck flexed and head down [9]. Any associated trauma to the larynx and trachea displaces the epiglottis, arytenoid cartilages, or vocal cords [8] [10]. Tongue base prolapse due to bilateral fracture of the anterior mandible [9] results in obstruction of the oropharynx in a supine patient [8]. Anesthetic concerns of these patients also include regurgitation of stomach contents and its sequelae [7]. Also, proper fitting of ventilation masks to the face is difficult in the event of disrupted oral cavity or oropharynx anatomy [7], facial edema, or restricted mouth opening [10].

Post-tonsillectomy bleeding poses a unique set of challenges to the anesthetist: Associated airway obstruction and pulmonary aspiration increase difficulty in airway management. Blood, clots [11], and edema from previous airway instrumentation associated with recent surgery or repeated attempts due to poor visualization may obstruct visualization for intubation in the oral cavity. These may increase the failure rate of intubation at the first attempt, need for alternative airway devices, and the duration of intubation [12].

Severe bleeding in these patients has the potential to result in anemia, hypovolemia, and even death [11]. Furthermore, patients tend to swallow large volumes of blood. During induction of general anesthesia when protective airway reflexes are diminished, patients are susceptible to pulmonary aspiration of sequestered intra-gastric blood or post-operative oral intake [11]. This can result in further hypoxia by physical obstruction or pneumonitis.

Given the complexity associated with fractured mandibles and post-tonsillectomy bleeding, and the subsequent effects on airway management, it is imperative to simulate models of these pathologies for the learning of the management of difficult airways in emergencies. There is currently limited information in the literature which describes the construction of these models, which can be used for the purpose of training and learning.

The objectives of this study were to create a novel model with features of a difficult airway such as fractured mandible and post-tonsillectomy bleed, and to assess the suitability of the surgically modified cadaver models for enhanced experiential learning of the management of difficult airways. To the best of our knowledge, there are no publications in the literature simulating the pathology described in this article.

2. Methods

2.1. Ethical Considerations

The research study protocol was submitted to the SingHealth Centralized Institutional Review Board (CIRB Reference Number: 2017/2960) and was exempted from review based on the nature of the study. The research study was conducted over two sessions of the Advanced Airway Management Workshop in our tertiary care hospital in 2016 and 2017.

2.2. Cadaver Models

Cadaver models cut at the mid-thorax level and included the head, neck, and upper thorax were procured for surgical modifications. They were certified to be negative for hepatitis B, hepatitis C, and human immunodeficiency virus 1 and 2 based on serology testing. Maxillofacial specialists carried out the surgical procedure on the cadaver heads to simulate difficult airways, namely fractured mandible and post-tonsillectomy bleed.

2.3. Simulation of Fractured Mandible

The body of the mandible was approached via submandibular approach. The fracture of the mandibular body distal to the mental foramina was accomplished using an oscillating saw. A bleeding tube was tunneled from the submandibular incision site and secured in the subperiosteal plane in the mandibular body fracture site to simulate the bleeding vessel (Figure 1).

2.4. Simulation of Post-Tonsillectomy Bleed

For simulating per-oral bleeding, a catheter was placed through a small neck incision and tunneled via blunt dissection to connect to the oropharynx via the ipsilateral tonsillar fossa. A silk suture was placed through the tip of the catheter to anchor it to the anterior tonsillar pillar to avoid dislodgement.

For simulating esophageal regurgitation of stomach contents, a catheter was

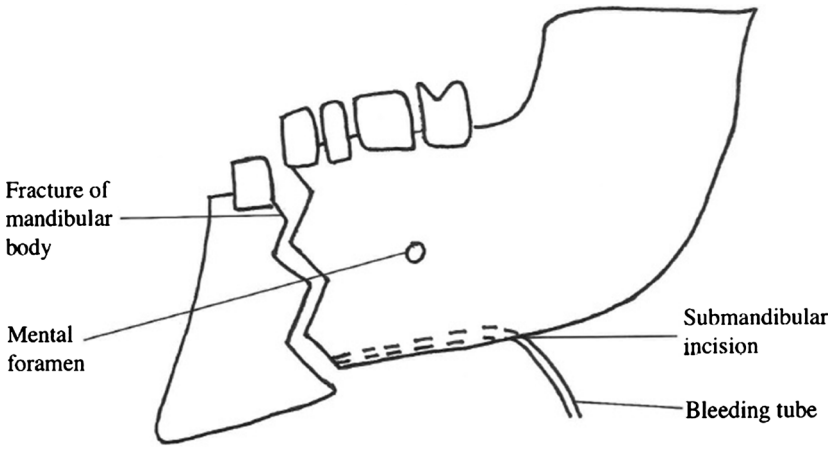

Figure 1. Schematic representation of modification of cadaver head to simulate mandibular fracture.

placed via the distal cut end of the esophagus of the cadaver (upper thorax level) and inserted along the lumen of the esophagus until the esophageal inlet (pyriform fossa) in the hypopharynx. This catheter was also anchored with a silk suture distally at the cut end of the cadaver to avoid dislodgement (Figure 2).

2.5. Participant Experience

During the advanced airway workshop, tutors facilitated directed one-to-one learning by way of direct feedback to participants. Maxillofacial specialists carried out the surgical procedure on the cadaver heads to simulate difficult airways, namely fractured mandible and post-tonsillectomy bleed.

2.6. Assessment by Participants

The models were assessed by consented participants of the advanced airway training workshop. All participants were required to don personal protective equipment as a precautionary measure. Participants were asked to provide information about seniority rank (specialist or non-specialist) and years of airway management experience. They were requested to rate their confidence level in managing a patient with difficult airway before and after training with the modified cadavers. An improvement in confidence level by at least one point on the Likert scale in higher than 75% (arbitrarily defined) of the participant population was considered clinically significant.

Feedback was also obtained on the difficulty level, realism, attractiveness, and beneficial level of the cadaver models for use in enhanced experiential learning of the management of difficult airways. The performance indicators were assessed using a 7-point Likert scale (Table 1). Simulated models were evaluated

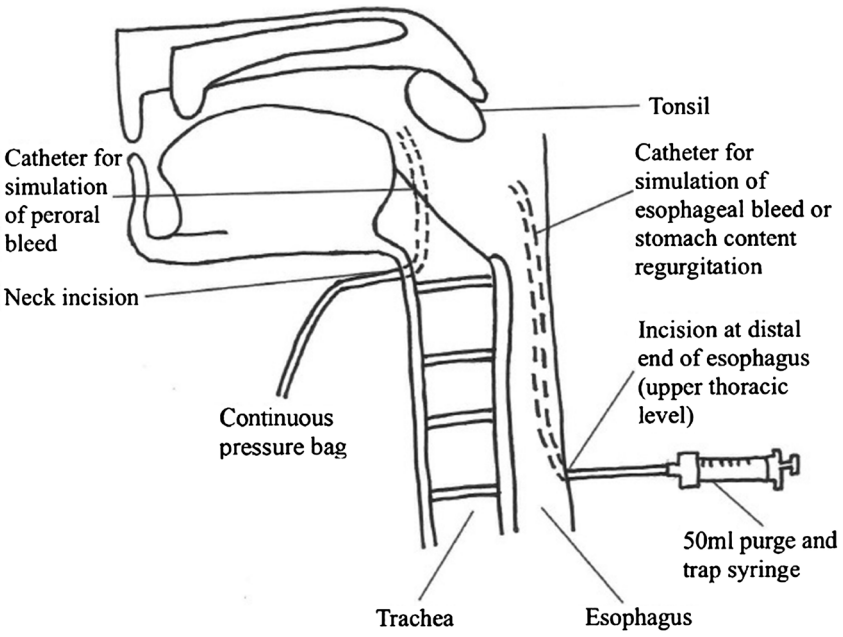

Figure 2. Schematic representation of modification of cadaver head to simulate post-tonsillectomy bleed.

Table 1. Likert scale.

Likert Scale	Difficulty	Realism	Attractiveness	Benefits
1	Very easy	Absolutely unrealistic	Absolutely unattractive	Absolutely non-beneficial
2	Moderately easy	Unrealistic	Unattractive	Non-beneficial
3	Slightly easy	Slightly unrealistic	Slightly unattractive	Slightly non-beneficial
4	Neutral	Neutral	Neutral	Neutral
5	Slightly difficult	Slightly realistic	Slightly attractive	Slightly beneficial
6	Moderately difficult	Realistic	Attractive	Beneficial
7	Very difficult	Absolutely realistic	Absolutely attractive	Absolutely beneficial

by participants as follows: post-tonsillectomy bleeding (n = 34), mandibular fracture (n = 19). Achievement of Likert scores of 5, 6 or 7 in higher than 75% (arbitrarily defined) of the participant population was considered clinically significant in the assessment of, difficulty, realism, attractiveness and benefits for skill training. All interactions with the participants took place during the course of the workshops.

2.7. Statistical Analysis

Categorical data were presented as frequency and percentage. Numeric data were presented in median and interquartile range. Pre- and post-confidence levels of participants were compared using the Wilcoxon Signed Rank test. Associations between seniority, years of airway management experience with outcomes were examined using Fisher's Exact Test. A one-sided binomial test was used to test the model difficulty, realistic, attractiveness and beneficial rates (based on Likert scale of 5, 6 or 7) with the thresholds of 75%. All comparisons were two-sided and a P value of <0.05 was considered statistically significant. Analyses were performed with SPSS statistical software, version 19.0 (IBM Corp. Armonk, NY).

3. Results

3.1. Participant Characteristics

The participants enrolled for the advanced airway workshops on their own initiative. Among them, 23.5% (8/34) were specialists, 61.8% (21/34) were non-specialists and the remaining 5 participants chose not to indicate their rank. Further, 44.1% (15/34) of the participants had <5 years of airway management experience, 47.1% (16/34) had ≥5 years of experience, and the experience level was not known for 3 participants.

3.2. Confidence Level

Our study revealed that the advanced airway workshops using modified cadavers resulted in statistically significant ($P \leq 0.001$) improvement of participants' con-

fidence level for fractured mandible model and post-tonsillectomy bleed model. The median confidence level went up from 4.0 (interquartile range (IQR), 2.0 - 5.0) to 5.0 (IQR, 3.3 - 6.0) and from 3.5 (IQR, 2.3 - 5.0) to 5.0 (IQR, 4.0 - 6.0) respectively.

The confidence level improved by at least one point on the Likert scale in 83.3% (20/24) (95% confidence interval (CI), 64.1 to 93.3) of participants using the fractured mandible model, and in 87.1% (27/31) (95% CI, 71.2 to 94.9) using the post-tonsillectomy bleed model. An improvement in confidence level by at least one point on the Likert scale in higher than 75% (arbitrarily defined) of the participant population was considered clinically significant. Improvement in confidence level was seen in all categories of participants (non-specialists and specialists, and participants with <5 years of experience and those with ≥5 years of experience), with no significant difference between them, for both fractured mandible and post-tonsillectomy bleed models (Table 2).

3.3. Feedback on Difficulty, Realism, Attractiveness and Benefits of Models

The majority of participants found both surgically modified cadaver models realistic (fractured mandible model: 79.0% (15/19); 95% CI, 56.7 to 91.5; post-tonsillectomy bleed model: 78.8% (26/33); 95% CI, 62.3 to 89.3), and attractive (fractured mandible model: 83.3% (15/18); 95% CI, 60.8 to 94.2; post-tonsillectomy bleed model: 79.4% (27/34); 95% CI, 63.2 to 89.7) in simulating a difficult airway. 88.2% (30/34) (95% CI, 73.4 to 95.3) of the participants found the models to be beneficial. In comparison, a lower percentage of participants rated the models to have a difficult anatomy (fractured mandible model: 47.4% (9/19); 95% CI, 27.3 to 68.3; post-tonsillectomy bleed model: 51.5% (17/33); 95% CI, 35.2 to 67.5). Among those who rated the fractured mandible model as difficult (Likert scale ≥ 5), 8 participants found it to be slightly difficult, 1 moderately difficult and none

Table 2. Percentage of participants whose confidence level improved by at least one point of the Likert scale.

Confidence Level Improved by at Least One Level of Scale	Fractured Mandible	Post Tonsillectomy Bleed
All	83.3% (20/24), 95% CI 64.1% - 93.3%	87.1% (27/31), 95% CI 71.2% - 94.9%
Seniority		
Non-specialist	80.0% (12/15)	85.0% (17/20)
Specialist	80.0% (4/5)	83.3% (5/6)
P value	>0.999	>0.999
Years of experience		
<5	81.8% (9/11)	86.7% (13/15)
≥5	81.8% (9/11)	84.6% (11/13)
P value	>0.999	>0.999

very difficult. For the post-tonsillectomy model, 10 participants felt it was slightly difficult, 6 moderately difficult and 1 very difficult. There was no significant difference in levels of difficulty, realism, attractiveness, and benefits between non-specialists and specialists, and between participants with <5 years of experience and those with ≥5 years of experience (Table 3). All participants (100%) expressed their desire for more of such stations in training workshops, found cadaver simulations to be an innovative interface for learning, and were immersed in the scenario.

4. Discussion

Difficulty in intubation occurs in 1.7% of patients with maxillofacial fractures [13], and in 2.7% of patients who underwent operative intervention for post-tonsillectomy bleed [11]. Although the majority of patients with fractured mandible or post-tonsillectomy bleed present with a stable airway, the life-threatening nature of airway compromise mandates high fidelity airway management training. Simulation of the fractured mandible or post-tonsillectomy bleeding via cadaver modifications enhances competence in technical and

Table 3. Assessment of levels of difficulty, realism, attractiveness, and benefits of models using a Likert scale.

Fractured Mandible	Difficulty	Realism	Attractiveness	Benefits[a]
All	47.4% (9/19), 95% CI 27.3% - 68.3%	79.0% (15/19), 95% CI 56.7% - 91.5%	83.3% (15/18), 95% CI 60.8% - 94.2%	88.2% (30/34), 95% CI 73.4% - 95.3%
Experience				
Non-specialist	46.2% (6/13)	76.9% (10/13)	91.7% (11/12)	90.5% (19/21)
Specialist	33.3% (1/3)	100.0% (3/3)	66.7% (2/3)	75.0% (6/8)
P value	>0.999	>0.999	0.371	0.300
Years of Experience				
< 5	33.3% (3/9)	77.8% (7/9)	87.5% (7/8)	93.3% (14/15)
≥ 5	62.5% (5/8)	87.5% (7/8)	87.5% (7/8)	81.3% (13/16)
P value	0.347	>0.999	>0.999	0.600
Post Tonsillectomy Bleed	**Difficulty**	**Realism**	**Attractiveness**	
All	51.5% (17/33) 95% CI 35.2% - 67.5%	78.8% (26/33) 95% CI 62.3% - 89.3%	79.4% (27/34) 95% CI 63.2% - 89.7%	
Experience				
Non-specialist	55.0% (11/20)	80.0% (16/20)	85.7% (18/21)	
Specialist	37.5% (3/8)	75.0% (6/8)	62.5% (5/8)	
P value	0.678	>0.999	0.305	
Years of Experience				
<5	46.7% (7/15)	80.0% (12/15)	80.0% (12/15)	
≥5	53.3% (8/15)	80.0% (12/15)	81.3% (13/16)	
P value	>0.999	>0.999	>0.999	

[a]Respondents were to rate the beneficial level of the station in improving their skill set, regardless of the models.

non-technical skills—both of which are essential in ensuring safe care of complicated or acutely sick patients [3].

Simulation enhances the proficiency of technical skills by providing an experiential learning experience through Kolb's Experiential Learning Cycle. Simulation of bleeding airways in cadavers is an emotionally charged, challenging, and stressful training experience, inducing learners to experience a significant change in body state which enables meaningful reflection to rationalize their behavior and subsequently adapt their mental model. It is a crucial platform for learners to actively experiment with their new mental model within a short period after it is formulated [4]. As such, experiential learning enables better grasp and retention of clinical motor skills compared to the conventional model. In a study conducted by Ti *et al.* comparing learning to intubate via experiential model versus conventional learning, 64.5% of the experiential group and 36.9% of the guided group successfully intubated three months after the training module [14]. Conventional training might result in cognitive bias formation, comfort in key airway processes, and neglect of an airway algorithm [6].

Simulation integrates human factors into education and clinical practice [3]. Weaver *et al.* revealed that simulation practice improved team performance and patient outcomes, and reduced medication and transfusion errors [15]. As the management of a single patient often involves a multidisciplinary team, and healthcare professionals within each team are expected to perform well despite limited knowledge of the skills or competencies of other team members, it is crucial to conduct training of different disciplines together to improve human factors and thus patient safety [3].

The findings from this study clearly show that the surgically modified cadaver models were realistic, attractive, and beneficial. This is consistent with the positive reviews of similar attempts of simulating bleeding in cadavers. It is of note that among the participants who rated the models as difficult, the majority felt they were slightly to moderately difficult. This level of difficulty was appropriate as the airway management workshop was designed to cater to a broad spectrum of participants of various ranks and specialties. The intent was not to create an excessively difficult model which might discourage learning. Given the shift towards competency-based learning in medical training today, these results present implications for all procedural and surgical specialties [15]. Greene *et al.* showed that simulated bleeding cadaver models (*i.e.* bleeding secondary to internal mammary artery break down) garnered high reviews for both authenticity and utility for increasing knowledge, teaching new skills, and improving patient safety. This was also viewed as a high-fidelity simulation of coronary anastomosis, valvular cardiac surgery, and cardiopulmonary bypass [16]. Compared to mannequins, cadavers are of higher realism, as they maintain the texture of live humans [17], are a better representation of airway anatomy and spatial relationships [18] and showcase real human anatomy and tissue [19]. Cadavers are also better suited for psychomotor skill training [17] and are appreciated as a link

between simulated training on mannequins and training using patients [19]. Compared to patients, cadavers are better suited for teaching as they eliminate ethical and safety concerns of practicing techniques on patients and allow for systematic teaching of emergency or uncommon techniques [18].

To the best of our knowledge, there are no existing models reported in the literature for fractured mandible or post-tonsillectomy bleed for use in simulation training of anesthetists. However, previous attempts at bleeding simulations have proven useful in training for other specialties. For instance, Inglez de Souza *et al.*'s bleeding simulation of embalmed cadavers provided high-fidelity simulation training for the practice of multiple surgical interventions [20]; while Sarkar *et al.*'s continuous flow perfused cadaver model replicated many aspects of advanced endovascular procedures with haptic feedback [21].

Our study involved a multidisciplinary team consisting of anesthetists, oral and maxillofacial surgeons, and otolaryngologists to formulate novel cadaver modifications for experiential learning in airway management. Both the surgically modified cadaver models constructed by our team are easily replicable and have the potential to promote the shared interest of anesthetists and surgeons in improving their skill sets and thus improved patient outcome and safety. Furthermore, effective teamwork is important in airway management to avoid intraoperative conflicts arising from competing needs of anesthetists for airway access and oral and maxillofacial surgeons and otolaryngologists for surgical access [9]. The non-technical skills of communication and teamwork inculcated through our simulations play a role in reducing conflicts and promoting patient safety [3].

Multiple studies have used confidence level in defining the levels of success of training programs, such as Van Dillan *et al.* in evaluating the effectiveness of simulation training in tourniquet use and needle decompression [22]. However, the correlation between confidence level and competence is debatable, with Augustine *et al.* revealing a positive correlation between confidence and competence level [23], but Leopold *et al.* revealing an inverse relationship between confidence and competence level due to an overestimation of skill level with increased confidence [24]. Confidence level was positively associated with competency after training [14], with increased confidence levels resulting in effective decision making and improved clinical performance [25]. In our opinion, the confidence level is representative of the overall comfort level of physicians for performing difficult interventions, hence is reflective of their level of knowledge, skill sets, experience, and training. To increase the robustness of future studies, we recommend the investigation of the suitability of cadaver models in experiential learning to involve an objective metric to deduce if training with bleeding cadavers increases the skill levels of our workshop participants. We also recognize that it might be difficult for clinicians in hospitals where research and training are not supported by the management to engage themselves in these high-fidelity simulation activities. In such scenarios, simulation with other mod-

els such as partial-task trainer, high-fidelity mannequins, virtual reality, or computer software [26] would still be beneficial and should be encouraged.

The use of simulation models in medicine is a relatively new concept but is in need of further exploration as it offers potential opportunities to improve the competence and confidence of medical professionals and increase patient safety [27]. Participants reported an increased confidence level to face challenging airway scenarios after the training on surgically modified cadavers in this study. These surgically modified cadavers were deemed to be realistic, attractive and beneficial.

For supporting competency-based anesthesia training programs, it is essential for airway management workshops to provide challenging real-world scenarios to increase proficiency levels of the participants in dealing with difficult airways [28]. We recommend the use of cadaver modifications to strengthen further the experiential learning in management of difficult airways facilitated by airway training courses.

5. Conclusion

In conclusion, the advanced airway workshops using modified cadavers improved participants' confidence level for the fractured mandible model and post-tonsillectomy bleed model. The models were deemed to be of an appropriate level of difficulty, realistic, attractive, and beneficial for enhancing experiential learning.

Acknowledgements

We would like to express our appreciation to the following for the conduct of the study: 1) Ms Carmen Jia Wen Kam for her help in the statistical analysis, 2) Ms Chor Kim Lee for procurement and maintenance of cadavers at Centre for Advanced Clinical and Surgical Skills, Changi General Hospital, Singapore 3) Clinical Trials & Research Unit, Changi General Hospital, Singapore for general assistance, 4) Cadaveric Advanced Airway Workshop Organizers 2016 and 2017, 5) Operating Theatre staff, and 6) Radiology Services, Changi General Hospital, Singapore.

The modification of cadaver heads was carried out as development work for the conduct of research study supported by a grant from the National Medical Research Council (NMRC/CG/002/2013 – CG12Aug02-11), Singapore.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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