Chinese Journal of Traumatology 26 (2023) 41–47

Contents lists available at ScienceDirect

Chinese Journal of Traumatology

journal homepage: http://www.elsevier.com/locate/CJTEE

Original Article

Animal model-based simulation training for three emergent and urgent operations of penetrating thoracic injuries

Wen-Qiong Du [a, 1], Xin Zhong [b, 1], Ren-Qing Jiang [a], Zhao-Wen Zong [b, *], Yi-Jun Jia [a], Zhao Ye [a], Xiao-Lin Zhou [a]

[a] *State Key Laboratory of Trauma, Burn and Combined Injury, Department for Combat Casualty Care Training, Training Base for Army Health Care, Army Medical University, Chongqing, 400037, China*

[b] *State Key Laboratory of Trauma, Burn and Combined Injury, Department for Combat Casualty Care Training, Training Base for Army Health Care & Department of Orthopedics, Xinqiao Hospital, Army Medical University, Chongqing, 400037, China*

A R T I C L E I N F O

Article history:
Received 28 December 2021
Received in revised form
31 May 2022
Accepted 30 June 2022
Available online 2 August 2022

Keywords:
Penetrating thoracic injuries
Emergent operations
Urgent operations
Simulation training
Animal model

A B S T R A C T

Purpose: To develop animal models of penetrating thoracic injuries and to observe the effects of the animal model-based training on improving the trainees' performance for emergent and urgent thoracic surgeries.

Methods: With a homemade machine, animal models of lung injuries and penetrating heart injuries were produced in porcine and used for training of chest tube drainage, urgent sternotomy, and emergent thoracotomy. Coefficient of variation of abbreviated injury scale and blood loss was calculated to judge the reproducibility of animal models. Five operation teams from basic-level hospitals (group A) and five operation teams from level III hospitals (group B) were included to be trained and tested. Testing standards for the operations were established after thorough literature review, and expert questionnaires were employed to evaluate the scientificity and feasibility of the testing standards. Tests were carried out after the training. Pre- and post-training performances were compared. Post-training survey using 7-point Likert scale was taken to evaluate the feelings of the trainees to these training approaches.

Results: Animal models of the three kinds of penetrating chest injuries were successfully established and the coefficient of variation of abbreviated injury scale and blood loss were all less than 25%. After literature review, testing standards were established, and expert questionnaire results showed that the scientific score was 7.30 ± 1.49, and the feasibility score was 7.50 ± 0.89. Post-training performance was significantly higher in both group A and group B than pre-training performance. Post-training survey showed that all the trainees felt confident in applying the operations and were generally agreed that the training procedure were very helpful in improving operation skills for thoracic penetrating injury.

Conclusions: Animal model-based simulation training established in the current study could improve the trainees' performance for emergent and urgent thoracic surgeries, especially of the surgical teams from basic-level hospitals.

Introduction

Trauma continues to be a major public health problem worldwide as it is associated with high morbidity and mortality both in developed and developing countries. Trauma is also reported to be the leading cause of death, hospitalization, and long-term disabilities in the first four decades of life.[1] Thoracic trauma comprises 10%–15% of all traumas in civilian setting,[2] and 8.6%–11.7% during wartime depending on the weapons used and the intensity of the war.[3–7] Fortunately, over 80%–90% of thoracic injuries can be managed non-operatively utilizing tube thoracostomy, appropriate analgesia and aggressive respiratory therapy.[8,9] Only 10%–20% will require operative intervention. However, since there are so many important tissues and organs in the chest cavity, operations needed for thoracic injuries are always emergent or urgent.

There are many different classification systems for thoracic operations as far as the urgency is concerned. It can be an emergent

* Corresponding author.
E-mail address: zongzhaowen@163.com (Z.-W. Zong).
Peer review under responsibility of Chinese Medical Association.
[1] Wen-Qiong Du and Xin Zhong contributed evenly in this manuscript.

https://doi.org/10.1016/j.cjtee.2022.07.004

procedure performed as part of emergency room resuscitation, an urgent operation as a way of damage control strategy, or a late intervention usually due to complications.[10] Emergency department thoracotomy (EDT) was performed immediately for casualties alive at the initial assessment who lost signs of life during transport or during management in shock room. A quick left thoracotomy or clamshell thoracotomy was used aiming to open pleura and pericardium, and achieve an internal cardiopulmonary resuscitation.[10,11] In contrast to EDT, urgent thoracotomy (UT) is generally defined as a surgical thoracic intervention performed in the operating room within the first 48 h after admission.[10–12] UT is usually carried out as a mean of damage control, and the indications of it are as following: (1) penetrating thoracic injury with large hemothorax; (2) evacuation of more than 1000 mL of blood immediately after tube thoracostomy; (3) repeated blood transfusions required to maintain hemodynamic stability.[10–12] UT is also considered as a life-saving tool for penetrating cardiac injury and critically injured patients "in extremis" such as traumatic cardiac arrest.

As far as injury mechanism is concerned, chest injuries can be generally been divided into blunt injuries and penetrating injuries. The formers are more common in civilian setting, whereas the latter are more common in combat settings.[5,8,10] Although not universal, the average injury severity of penetrating chest injuries is usually higher than that of blunt chest injuries, and the former is more urgent than the latter.[5–7] As far as we know, proper EDT and UT procedures help to save lives, however, the mastery of EDT and UT skills are not so sufficient. In civilian settings, the incidence of penetrating chest injuries is rare and thus it is difficult for the surgeons to be familiar with its treatment and have less chance to practice this kind of injuries. The military settings are also facing the similar challenges. Thus, training in surgeries for penetrating thoracic injuries is obviously needed.[13–16]

Due to such reasons as limited patient encounters and a focus on patient safety, simulation training has gained popularity and has shown a promising outcome in recent years.[17] Currently, there are various kinds of simulation training methods in medical education, and the most often used ones include live tissue, live animal model, high-fidelity training simulators, trained live actor-patients, virtual reality, etc. Each method has its own advantages and disadvantages,[17,18] and until now, animal model-based simulation training is the most ideal method for training of surgery because it can carry out a practical procedures.[19,20] However, there is not an ideal animal model for training of EDT and UT. The current study aimed to develop animal models of penetrating thoracic injuries with a custom-made machine that can simulate gunshot and blast-fragment injury mechanisms. Then the effects of the developed animal models on improving the trainees' performance were explored.

Methods

All procedures involving animals were approved by the Ethics Committee of Army Medical University of Chinese People's Liberation Army and were performed in accordance with relevant regulations of Ethics Committee of Army Medical University of Chinese People's Liberation Army.

The development of animal models of penetrating thoracic injuries

After extensive literature reviews, it was found that the 3 commonest emergent and urgent operations for penetrating thoracic injury were chest tube drainage for moderate lung injury, urgent thoracostomy for major intrathoracic bleeding and air leakage in severe lung injury, and thoracostomy for penetrating heart injury.[3–7,10,11,20] Thus, totally 3 kinds of penetrating chest injuries included moderate lung injuries, severe lung injuries and penetrating heart injuries were produced by the homemade machine in the present study (Supplementary Fig. 1A), and were used for training of chest tube drainage, urgent thoracostomy, and emergent thoracotomy, respectively.

The mechanism of the machine was that the air was highly compressed and the pressure could increase from 20 kPa to 600 kPa. The pressure then was guided through the thin-plaster coned steel tube to produce blast injury, or guided through thin-plaster coned steel tube containing simulated fragments to produce combined blast-fragment injury (Supplementary Fig. 1B). An infrared based targeting system was embedded into the machine to ensure the precision of wounding (Supplementary Fig. 1C).

Eighteen adult mini-musk swine of either sex were randomly and evenly divided into 3 groups to produce the above mentioned 3 kinds of injury patterns. The body weight of the swine was (25.6 ± 1.59) kg, and their age was (7.2 ± 0.4) months. After the swine were sedated with an intramuscular injection of 20 mg/kg ketamine and 2 mg/kg xylazine, the animals were exposed to different kinds of injures as abovementioned. One author who accepted veterinary training for 3 days in Center of Animal Experiment, Army Medical University was responsible for managing the animals.

Different from human, the heart of which is located on left side, swine's heart locates in the middle of the body. And the upper boundary locates in the upper border of sternum, and the lower boundary locates in the 4th/5th intercostal space of swine. Thus, when penetrating cardiac injuries were intended to be produced, the animal was targeted at the middle line of the sternum and 3 cm below the upper edge of the sternal notch. After firing, the projectile penetrated the sternum and pericardium, forming penetrating heart injury and pericardial tamponade. When moderate lung injury was intended to be produced, the right lung was targeted and injured by simulated fragment and pipe outlet pressure of 100 kPa was applied. When severe lung injuries were intended to be obtained, both side of the lung were targeted and injured by combined blast-fragment mechanisms; and the pipe outlet pressure of 300 kPa was applied. A small-sized pressure sensor was placed at the abovementioned targeted areas to measure the actual loading pressure over the animal.

Before the injuries were produced and 10 min after injury, peripheral vein blood was harvested and routine blood test were measured using an automatic blood analyzer (BC-5180 CRP, Mindray Inc, Shengzhen, China). The amount of blood loss was calculated according to formula: blood loss (mL) = (hematocrit before the injuries were produced - hematocrit after the operations were performed) ÷ hematocrit before the injuries were produced × weight of the animal (kg) × 8% ×1000. After taking of blood samples, the swine were sacrificed by intravenous injection of overdose potassium chloride, and autopsy was performed. Pictures of the injured tissues were taken, and were used to assess the abbreviated injury scale (AIS).[21] The AIS scores in the swine were recorded and the cumulative AIS scores were used for analysis.

Then coefficient of variation (CV) of cumulative AIS scores and blood loss was calculated to judge the reproducibility of animal models. A CV value less than 25% was considered to be significant.[22] The lower the CV value, the higher the reproducibility of the animal model. The CV value of AIS score was calculated as follows:

$$CV = \frac{\sigma}{M} \times 100\,\%$$

where M was the arithmetic mean, and σ was the standard deviation. The calculation formula of M was:

$$M = \frac{1}{m}\sum_{i=1}^{m} C\,i$$

where *C* were the AIS score, and m was the number of animals. The calculation formula of σ was:

$$\sigma = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}(Ci - M)^2}$$

Establishment of the test standards for emergent and urgent operations of penetrating thoracic injuries

An extensive literature review was performed to identify the key factors for assessing the procedure and outcome of main emergent/urgent surgeries of thoracic penetrating injuries, and testing standards for main emergent/urgent surgeries of thoracic penetrating injuries were then established. Keywords were the same as those used in the part “The development of animal models of penetrating thoracic injuries”. Literature directly related to the training, testing and assessment of emergent/urgent surgeries of thoracic penetrating injuries were preferentially selected, while papers containing key elements of emergent/urgent surgeries of thoracic penetrating injuries were also selected. All the parameters were extracted for the establishment of test standards for emergent and urgent operations of penetrating thoracic injuries, and different points were given to each parameter and all the weighted coefficient factors were put at 1.0.

Expert questionnaires were employed to evaluate the scientificity and feasibility of the testing standards. For the evaluation of scientificity, scores of 1, 3, 5, 7 and 9 indicate that the scientificity was very low, low, fair, high, and very high, respectively, which simultaneously indicate that the testing standards were non-feasible, fairly non-feasible, feasible, fairly feasible and highly feasible, respectively. In total, 20 well-known experts from 12 military hospitals were invited to complete the questionnaire.

Training procedure and test procedure

In May 2019, 5 operation teams from basic-level hospitals (group A) and 5 operation teams from level III hospitals (group B) were trained and tested to observe the effect of the animal model-based training. Each group consisted of 1 anesthetist, 2 surgeons and 1 nurse.

The training process consisted of 2 parts: half day for theory training and 2 days for practice training. In the theory lecture, epidemiology, indications, and procedures of emergent/urgent thoracic operations along with basic principles and procedure of damage control resuscitation were taught. In animal model-based simulation training, each injury model was trained 3 times. All teams were tested before the training, and the scores got were set as baseline. Tests were carried out after the training. The group were trained 3 times and tested as a whole, and the performance was assessed based on the test standards established in the present study.

Based on different animal models, emergent or urgent operations were trained of the standard operation procedure.[10,11,22,23] For chest tube drainage, a horizontal skin incision was made just anterior to the mid-axillary line at the 4th or 5th intercostal space, and blunt dissection was continued through the intercostal muscles. Then a finger was inserted to make certain that pleuropulmonary adhesions were not present, and then the tip of the clamped chest tube was introduced and advanced into the thoracic cavity until the side holes were well inside the pleural space. While an assistant holded the chest drain in place, it was connected to bubble tubing leading to a closed drainage system with an underwater seal containing normal saline. Then the tube was secured by suture. For emergent thoracotomy, midline incision was made, and the sternum was cut either by electric saws to expose the heart quickly. Cardiac massage and cardiac suture were exercised. For urgent thoracostomy for severe lung injuries, after entering the chest cavity through intercostal space, the lung wound was explored and quickly searched, and direct suturing or packing was performed according to the injury. During the training process, enough hydroxyethyl starch and Ringer's lactate were available for resuscitation. The trainees were allowed to select the type and amount of fluid by themselves based on their own judgment to ensure satisfying resuscitation outcome. One hour after the operation, 6 mL arterial blood were taken to test blood coagulation using automatic coagulation analyzer (Rayto, Shenzhen, China) and blood gas using parameters I-STAT Analyzer (Flextronics Manufacturing, Singapore), respectively.

Post-training survey

After the training and testing, all participants rated agreement to a series of survey items on a 7-point Likert scale (1 = strongly agree, 2 = agree, 3 = somewhat agree, 4 = undecided, 5 = somewhat disagree, 6 = disagree, 7 = strongly disagree).[24] The research measures and questions are shown in Table 1.

Statistics

All data were expressed as the mean ± standard deviation. Kolmogorov–Smirnov test was used for the normal distribution of all data. Multi-group comparisons were conducted by one-way ANOVA. Statistical analysis was performed using SPSS statistics software, version 17.0 (SPSS Inc., Chicago, IL, U.S.A.). The confidence interval was set at 95% (95% *CI*). A $p < 0.05$ was considered significant.

Results

Animal models of penetrating thoracic injuries were successfully developed

When pipe outlet pressure of 100 kPa was applied, the actual pressure applied on the chest was (78.32 ± 4.52) kPa. Under this injury condition, there was a small entry and small area of contusion in the lung. The AIS score was 3.00 ± 0.63, and the CV value was 21.1%; the volume of blood loss was (58.45 ± 4.74) mL, and the CV value was 8.11%. When pipe outlet pressure of 300 kPa was applied, the actual pressure applied on the chest was (258.36 ± 13.24) kPa. Under this injury condition, there was a large entry and large area of contusion in the lung (Fig. 1A). The AIS score was 4.00 ± 0.63, and the CV value was 15.8%; the volume of blood loss was (248.68 ± 17.74) mL, and the CV value was 7.14%. When the heart was targeted, a hole could be found in heart (Fig. 1B), and a large amount of blood and clot were found in pericardium (Fig. 1C), resulting in cardiac tamponade. The AIS score was 4.67 ± 0.52, and the CV value was 11.1%; the volume of blood loss was (322.47 ± 20.34) mL, and the CV value was 6.31%. These data indicated that animal models of the 3 kinds of penetrating thoracic injuries were successfully developed with high reproductivity.

Table 1
Post-training survey rating for evaluation of confidence, helpfulness and usefulness.

Research measures	Questions
Confidence helpfulness and simulation effect	1. I feel confident in performing emergent and urgent surgeries of penetrating thoracic injuries after training. 2. I feel the animal model established in the current study could simulate the main thoracic penetrating injury types. 3. I feel the training procedure is close to the actual operations in human. 4. I feel the test standards are reasonable. 5. I feel the whole training procedures are very help in improving operation skills for thoracic penetrating injury.

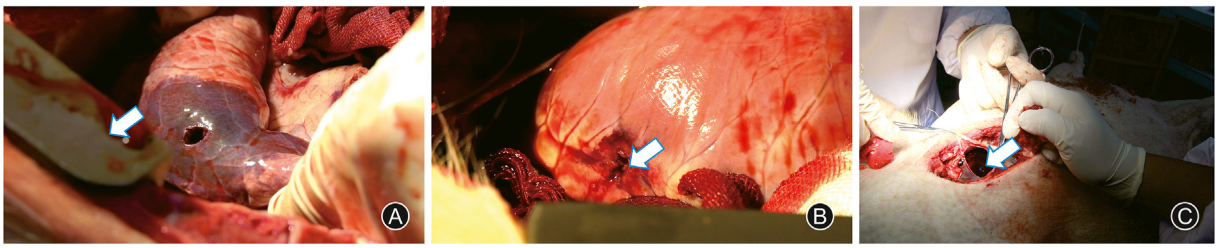

Fig. 1. Representative pictures of animal models. (A) Combined blast-fragment mechanism resulted in penetrating lung injury (arrow) and extensive lung contusion. In animal model for penetrating heart injuries; (B) a hole could be found in heart (arrow) and (C) a large number of clots were found in pericardium (arrow).

Establishment of the test standards for emergent and urgent operations of penetrating thoracic injuries

A literature search found that there were no studies directly related to test standards for emergent and urgent operations of penetrating thoracic injuries, however, there were 189 studies related to the procedure of emergent and urgent operations of penetrating thoracic injuries. Thorough analysis of the literature retrieved, the core indicators reflecting emergent and urgent operations of penetrating thoracic injuries, i.e., team cooperation, operation procedure, resuscitation, and final outcome.[3–7,10,11,19,20] On this basis, we formulated the assessment criteria for emergent and urgent operations of penetrating thoracic injuries (Table 2). The evaluation method has a total score of 100 points, which is divided into 4 major parts: leadership and team cooperation, surgical procedure of emergent and urgent operations, resuscitation effect, and final outcome and effect.

A total of 20 questionnaires were sent out to 20 experts, and all the questionnaires were collected. The scientific score was 7.30 ± 1.49, and the feasibility score was 7.50 ± 0.89. These results revealed that the experts agreed with the assessment criteria.

Training outcomes and post-training survey

All the 5 operation teams from 5 basic-level military hospitals made a huge improvement after 3 rounds of training (Table 3). All the trainees had no or little experience in thoracic or cardiac trauma surgery, and they scored 46.04 ± 9.27 before training, indicating that they barely knew how to perform emergent and urgent operations for penetrating thoracic injuries. After 3 rounds of training, they scored 80.42 ± 6.44, significantly higher than the score they got before training. The pre-training scores in group B was significantly higher than that in group A; and the post-training scores in group B was higher than that in group A, however, the difference did not show statistically significance (Table 3).

Post-training survey showed that all the trainees felt confident in applying emergent and urgent operations for penetrating thoracic injuries (Fig. 2). As for simulation effect, the trainees agreed that the animal model established in the current study could simulate the main thoracic penetrating injury types and the training procedure was close to the actual operations in human (Fig. 2). And they agreed that the whole training procedure were very helpful in improving skills of thoracic penetrating injury (Fig. 2).

Discussion

Over 80% of thoracic injuries can be managed non-operatively, and only 10%–15% will require operative intervention. However, since there are so many important tissues and organs in chest cavity, operations needed for thoracic injuries are always emergent or urgent. However, it is hard for surgeons to master the emergent or urgent surgeries for thoracic wound because of the low incidence of thoracic injuries, especially penetrating thoracic injuries. As a result simulation training with a focus on patient safety has gained popularity and shown a promising outcome in civil medical education in recent years. Currently, there are various kinds of simulation training methods in medical education, and the most often used ones for surgery training include cadaver dissections, live tissue surgical procedures, and live animal surgical training, high-fidelity training simulators, trained live actor-patients, and virtual reality.[17–19,24–30] Each method has its own advantages and disadvantages. Using live tissues or organs such as the chest wall or trachea of swine covering with skin of swine is employed to train invasive first aid skills such as needle decompression and thyrocricocentesis.[25,26] The main advantage of this method is that it can carry out practical operation, and the operation feel is similar to the actual operation on human body, which is also economical and affordable. It is suitable for the training of basic first aid skills, but not suitable for surgical procedure. Virtual reality technology can simulate the real environment and scene, and has advantages of real scene, immersion, and simple operation,[17,27] however, the disadvantages are also obvious, e.g., it cannot perform actual skill training.[17,27,28] With the introduction of biomedical engineering, computer technology, information technology and other new technology, many kinds of high-fidelity training simulators such as SimMan, SimBaby, and Emergency Care Simulator, etc., were developed.[18,29] These mannequins have real physical examination findings, such as bleeding, spinal fluid leaks with skull fracture, and abnormal lung, heart, and bowel sounds, and the simulators permit the performance of invasive procedures. Additionally, simulators physiologically model human responses to intervention, permitting real utilization of monitoring equipment in medical training.[30] More recently, many more advanced simulators have been

Table 2
Test standards for emergent and urgent thoracic surgeries established in the current study.

Major parts	General requirements	Score indicators and score standards	Points
Leadership and team cooperation (Total score: 10 points)	Team leader organized the whole process in an orderly manner, and team members worked together to ensure an orderly treatment procedure.	Team members had a clear division of labor and performed their respective duties (5 points). Language communication between team members was smooth. If there were arguments, the team members could discuss and reach an agreement (5 points).	
Surgical procedure of emergent and urgent surgeries (Total score 60 points)	Chest tube drainage (Total score: 20 points): performed the procedure smoothly and correctly.	All the materials and equipment needed were well prepared and placed in order. One point was deducted for each missing item; 5 points were deducted if items were placed disorderly or if operation was negatively affected by these disorders. Selected the right incision, e.g., at the 4/5 intercostals space in the axillary midline. Deduct 5 points if the position of incision was incorrect. Correct and smooth separation procedure, e.g., separated muscles bluntly to enter the pleural cavity; and used fingers to penetrate the pleural cavity and separated the potential gaps upward. Deduct 1–5 points if the separation method was incorrect. Connected the end of the rubber tube with the long tube of the water seal bottle, placed the water seal bottle at a lower level than the wounded, loosened the hemostatic forceps, and observed the fluctuation of the liquid level of the water seal bottle. Deduct 5 points if the drainage was blocked or the drainage effect was bad.	
	Emergency department thoracotomy for penetrating cardiac injury (Total score: 20 points): perform the procedure smoothly and correctly.	All the materials and equipment needed were well prepared and placed in order. One point was deducted for each missing item; 5 points were deducted if items were placed disorderly or if operation was negatively affected by these disorders. Selected the right incision, e.g., midline incision was selected. Deduct 5 points for wrong choice of surgical incision. Right procedure for different kinds of injury states: if there was a cardiac tamponade, cut the pericardium and removed the hematoma or blot; if there was a cardiac penetrating injury, sutured the wound; if there was a cardiac arrest, performed cardiac massage. Deduct 5–10 points if the injury was not handled properly. The whole procedure should be as fast as possible, and usually was completed in less than 30 min. For every 5 min over the required time, 1 point was deducted out of 5 points maximum.	
	Urgent thoracotomy for severe lung injuries (Total score: 20 points): perform the procedure smoothly and correctly.	All the materials and equipment needed are well prepared and placed in order. One point was deducted for each missing item; 5 points were deducted if items are placed disorderly or if operation was negatively affected by these disorders. Select the right incision, e.g., intercostal incision is selected. Deduct 5 points for wrong choice of surgical incision. Right procedure for different kinds of injury states: suture, packing and lobectomy could be carried out for large lung injury. Deduct 5–10 points if the injuries were not handled properly. The whole procedure should be as fast as possible, and usually was completed in less than 40 min. For every 5 min over the required time, 1 point was deducted out of 5 points maximum.	
Resuscitation (Total score: 10 points)	No coagulation dysfunction and acidosis developed.	No coagulation dysfunction occurred (5 points). If international ratio is greater than 2, 5 points were deducted; if international ratio is between 1.5 and 2, 3 points were deducted. The base deficit was in the normal range (5 points). If the value of the base deficit is less than −5 mmol/L, 5 points were deducted; if the value of the BE is between −2.5 and − 4.9 mmol/L, 3 points were deducted.	
Final outcome and effect (Total score: 20 points)	No preventable deaths occur.	If the animal died due to preventable deaths, deduct 20 points.	
Total score			

Signature of referee or evaluator.
Date of evaluation.

Table 3
Pre- and post-training performance in group A and group B

Variables	Group A	Group B	*p* value
Pre-training	46.04 ± 9.27	60.18 ± 7.48	0.032
Post-training	80.42 ± 6.44	86.21 ± 8.23	
p value	0.006	0.024	

developed, such as virtual reality simulators. This kind of simulator involves the computer-generated simulation of three-dimensional images or environments with which the learner can interact in a seemingly real or physical way. Currently, there are more than 400 models available. However, most operations procedure cannot be performed on these simulators and there are currently no specific training simulators for the emergent or urgent operations of penetrating thoracic injuries. Because cadaver dissections and live tissue surgical procedures cannot simulate real injury situations, such as hemorrhage and organ injuries, their usage in surgery training is less promising. In comparison, the use of live animal models can simulate various kinds of injury and provide the opportunity for hands-on management in a safe situation.

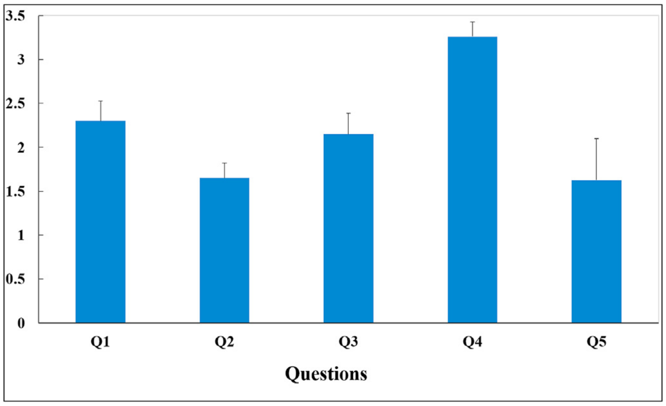

Fig. 2. Post-training survey. Scores of the trainees gave to each question listed in Table 1.

The current study intended to establish series animal models for the training of emergent and urgent operations for penetrating thoracic injuries. Based on the epidemiology data from both civilian and military settings, it was found that the most often performed procedure for penetrating thoracic injuries were chest tube drainage, urgent thoracostomy for massive lung contusion, EDT for penetrating heart injury and pericardium. By employing a home-made machine, these animal models were successfully developed with high productivity. All the trainees highly agreed that the animal model could highly simulate emergent or urgent thoracic injures, and are suitable for training the relative skills. And it was found that these live animal model-based trainings effectively improved the trainees' performance (Table 3). And all the trainees felt more confident in performing related surgeries after training (Fig. 2).

There are several advantages of the current training method. Firstly, the animal models are close to the real human injury state, and the live animal could react to the operation and resuscitation. Unlike the high-fidelity simulator of which the reaction was programmed and simulated, the reactions of animal to treatment are real and are closer to human being. Secondly, the assessment criteria are objective and could reflect the key steps of the whole procedure. In the process of establishing the assessment criteria, we selected core indicators that can reflect the process and outcome of the operations, such as organizational ability, team cooperation ability, the ability to perform concise surgery, operation time, whether there are coagulation dysfunction and acidosis, and so on (Table 2). Common surgical skills such as hand washing, wound preparation and dressing were not included in the assessment indicators. At the same time, we tried to use objective indicators as much as possible, such as alkali residue, an international standardized ratio and other laboratory indicators, which can not only reflect the effect of operation but also avoid subjective factors. In addition, the trainees were allowed to select the type and amount of fluid for resuscitation based on their own judgement, and the outcome of resuscitation was assessed by lab tests. Different resuscitation protocols that the trainees used will have different effects on the parameters of lab examinations, such as coagulation test and full blood count, reflecting the outcomes for the different resuscitation protocols. This provides an objective test of the trainees' real ability of resuscitation and mastery of relevant knowledge.

There are several limitations of the current study. Firstly, thoracic penetrating injuries are usually caused by gunshot, fragment and sharp weapons such as knife. Animal models established in the current study were based on simulated fragment, and were not based on sharp weapons. The mechanisms, pathophysiological changes and treatment of sharp weapons might be different from fragment.[31] Secondly, due to lack of other methods for surgical procedures training for penetrating thoracic injuries, there was no positive control group in the current study. Furthermore, it was impossible to test the training effects in clinical practices. Only pre- and post-training performances were compared in the present study, which is an inherent shortcoming. Fourthly, the present study mainly focused on the technical skills and only parts of non-technical skills such as leadership and team cooperation. Other parts of non-technical skills such as situation awareness and decision making are also important for the training of emergent and urgent operations of penetrating thoracic injuries[31] and were not included in the current study. We will include these parameters into the test standards when the technical skills improved to a satisfactory level in the basic-level hospitals.

In summary, animal models of moderate lung injuries, severe lung injuries and penetrating heart injuries were developed, and test standards for emergent and urgent thoracic surgeries were established in the current study. These animal model-based simulation trainings could improve the performance of the trainees, especially of the surgical teams from basic-level hospitals.

Funding

This work was supported by Key logistics scientific project of the "Thirteenth Five Year Plan" of Medical Research of PLA (ALJ19J001), Key Clinical Innovation Project of Army Medical University and Xinqiao Hospital (CX2019JS107/2018JSLC0023).

Ethical statement

All procedures involving animals were approved by the Ethics Committee of the Army Medical University of China PLA (AMU-WEC2019471) and were performed in accordance with the relevant regulations of the Ethics Committee of the Army Medical University of China PLA, P. R. China.

Declaration of competing interest

The authors declare no conflicts of interest.

Author contributions

Wen-Qiong Du and Xin Zhong were responsible for the production of animal model and the training process; Ren-Qing Jiang contributed to the production of animal model; Zhao-Wen Zong designed the study, established the test standards and wrote the manuscript; Yi-Jun Jia and Zhao Ye were responsible for arrangement of the training and testing, and data collection; Xiao-Lin Zhou contributed to data analysis. All authors read and approved the final manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cjtee.2022.07.004.

References

1. Mulima G, Purcell LN, Maine R, et al. Epidemiology of prehospital trauma deaths in Malawi: a retrospective cohort study. *Afr J Emerg Med.* 2021;11: 258–262. https://doi.org/10.1016/j.afjem.2021.03.011.
2. Ajayi B, Guthrie H, Trompeter A, et al. The rising burden of penetrating knife injuries. *Inj Prev*. 2021;27:467–471. https://doi.org/10.1136/injuryprev-2020-044016.

3. Lichtenberger JP, Kim AM, Fisher D, et al. Imaging of combat-related thoracic trauma - review of penetrating trauma. *Mil Med*. 2018;183:e81–e88. https://doi.org/10.1093/milmed/usx034.
4. Keneally RJ, Meyers BA, Shields CH, et al. Pediatric thoracic trauma mortality in Iraq and Afghanistan compared to the United States national trauma data bank. *Mil Med*. 2022;187:e338–e342. https://doi.org/10.1093/milmed/usab020.
5. Senanayake EL, Poon H, Graham TR, et al. UK specialist cardiothoracic management of thoracic injuries in military casualties sustained in the wars in Iraq and Afghanistan. *Eur J Cardio Thorac Surg*. 2014;45:e202–e3207. https://doi.org/10.1093/ejcts/ezu076.
6. Poon H, Morrison JJ, Apodaca AN, et al. The UK military experience of thoracic injury in the wars in Iraq and Afghanistan. *Injury*. 2013;44:1165–1170. https://doi.org/10.1016/j.injury.2013.01.041.
7. Keneally R, Szpisjak D. Thoracic trauma in Iraq and Afghanistan. *J Trauma Acute Care Surg*. 2013;74:1292–1297. https://doi.org/10.1097/TA.0b013e31828c467d.
8. Huang JF, Hsu CP, Fu CY, et al. Is massive hemothorax still an absolute indication for operation in blunt trauma? *Injury*. 2021;52:225–230. https://doi.org/10.1016/j.injury.2020.12.016.
9. Heus C, Mellema JJ, Giannakopoulos GF, et al. Outcome of penetrating chest injuries in an urban level I trauma center in The Netherlands. *Eur J Trauma Emerg Surg*. 2019;45:461–465. https://doi.org/10.1007/s00068-015-0533-9.
10. Christos G, Marco B, Asa M. *War Surgery: Working with Limited Resources in Armed Conflict and Other Situations of Violence. Volume 2*. Geneva: International Committee of the Red Cross; 2013.
11. Matthew M, Alec B. *Front Line Surgery. A Practical Approach*. New York, NY: Springer; 2010.
12. Refaely Y, Koyfman L, Friger M, et al. Clinical outcome of urgent thoracotomy in patients with penetrating and blunt chest trauma: a retrospective survey. *Thorac Cardiovasc Surg*. 2018;66:686–692. https://doi.org/10.1055/s-0037-1608899.
13. Søreide K, Petrone P, Asensio JA. Emergency thoracotomy in trauma: rationale, risks, and realities. *Scand J Surg*. 2007;96:4–10. https://doi.org/10.1177/145749690709600102.
14. Bonnet S, Gonzalez F, Mathieu L, et al. The French advanced course for deployment surgery (ACDS) called CoursAvancé de Chirurgieen mission extérieure (CACHIRMEX): history of its development and future prospects. *J Roy Army Med Corps*. 2016;162:343–347. https://doi.org/10.1136/jramc-2015-000528.
15. Bonnet S, Gonzalez F, Poichotte A, et al. Lessons learned from the experience of visceral military surgeons in the French role 3 Medical Treatment Facility of Kabul (Afghanistan): an extended skill mix required. *Injury*. 2012;43:1301–1306. https://doi.org/10.1016/j.injury.2012.03.002.
16. Doll D, Eichler M, Vassiliu P, et al. Penetrating thoracic trauma patients with gross physiological derangement: a responsibility for the general surgeon in the absence of trauma or cardiothoracic surgeon? *World J Surg*. 2017;41:170–175. https://doi.org/10.1007/s00268-016-3703-y.
17. Nielsen RP, Nikolajsen L, Paltved C, et al. Effect of simulation-based team training in airway management: a systematic review. *Anaesthesia*. 2021;76:1404–1415. https://doi.org/10.1111/anae.15375.
18. Lv M, Jia Y, Zong Z, et al. Method for teaching life-saving combat first-aid skills with live-actor patients using a wearable training apparatus. *Mil Med*. 2022;187:757–763. https://doi.org/10.1093/milmed/usab286.
19. Izawa Y, Hishikawa S, Muronoi T, et al. Ex-vivo and live animal models are equally effective training for the management of a penetrating cardiac injury. *World J Emerg Surg*. 2016;11:45. https://doi.org/10.1186/s13017-016-0104-3.
20. Hansen KS, Uggen PE, Brattebø G, et al. Training operating room teams in damage control surgery for trauma: a follow up study of the Norwegian model. *J Am Coll Surg*. 2007;205:712–716. https://doi.org/10.1016/j.jamcollsurg.2007.06.015.
21. García Cañas R, Navarro Suay R, Rodríguez Moro C, et al. A comparative study between two combat injury severity scores. *Mil Med*. 2021. https://doi.org/10.1093/milmed/usab067. usab067.
22. Thangjai W, Niwitpong SA, Niwitpong S. Confidence intervals for the common coefficient of variation of rainfall in Thailand. *PeerJ*. 2020;8, e10004. https://doi.org/10.7717/peerj.10004.
23. Garcia AF, Manzano-Nunez R, Bayona JG, et al. A clinical series of packing the wound tract for arresting traumatic hemorrhage from injuries of the lung parenchyma as a feasible damage control technique. *World J Emerg Surg*. 2019;14:52. https://doi.org/10.1186/s13017-019-0273-y.
24. Xu J, Kwan C, Sunkara A, et al. Dynamic visual feedback during junctional tourniquet training. *J Surg Res*. 2019;233:444–452. https://doi.org/10.1016/j.jss.2018.08.044.
25. da Luz LT, Nascimento B, Tien H, et al. Current use of live tissue training in trauma: a descriptive systematic review. *Can J Surg*. 2015;58:S125–S134. https://doi.org/10.1503/cjs.014114.
26. Goolsby C, Branting A, Ausman J, et al. Systematic review of live tissue versus simulation education for prehospital trauma providers. *Mil Med*. 2017;182:e1824–e1833. https://doi.org/10.7205/MILMED-D-17-00026.
27. Bielsa VF. Virtual reality simulation in plastic surgery training. Literature review. *J Plast Reconstr Aesthetic Surg*. 2021;74:2372–2378. https://doi.org/10.1016/j.bjps.2021.03.066.
28. Kivlehan SM, Tenney K, Plasmati S, et al. Humanitarian training with virtual simulation during a pandemic. *Disaster Med Public Health Prep*. 2021:1–5. https://doi.org/10.1017/dmp.2021.152.
29. Roy E, Quinsat VE, Bazin O, et al. High-fidelity simulation in training dental students for medical life-threatening emergency. *Eur J Dent Educ*. 2018;22:e261–e268. https://doi.org/10.1111/eje.12284.
30. Lichte P, Oberbeck R, Binnebösel M, et al. A civilian perspective on ballistic trauma and gunshot injuries. *Scand J Trauma Resuscitation Emerg Med*. 2010;18:35. https://doi.org/10.1186/1757-7241-18-35.
31. Casali G, Lock G, Novoa NM. Teaching non-technical skills: the patient centered approach. *J Thorac Dis*. 2021;13:2044–2053. https://doi.org/10.21037/jtd.2019.01.48.