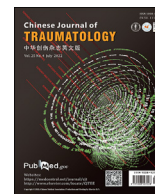




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## Original Article

## Establishment of a combat damage control surgery training platform for explosive combined thoraco-abdominal injuries

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## ABSTRACT

**Purpose:** It is challenging to prepare military surgeons with the skills of combat damage control surgery (CDCS). The current study aimed to establish a damage control surgery (DCS) training platform for explosive combined thoraco-abdominal injuries.

**Methods:** The training platform established in this study consisted of 3 main components: (1) A 50 m × 50 m square yard was constructed as the explosion site. Safety was assessed through cameras. (2) Sixteen pigs were injured by an explosion of trinitrotoluene attached with steel balls and were randomly divided into the DCS group (accepted DCS) and the control group (have not accepted DCS). The mortality rate was observed. (3) The literature was reviewed to identify the key factors for assessing CDCS, and testing standards for CDCS were then established. Expert questionnaires were employed to evaluate the scientificity and feasibility of the testing standards. Then, a 5-day training course with incorporated tests was used to test the efficacy of the established platform. In total, 30 teams attended the first training course. The scores that the trainees received before and after the training were compared. SPSS 11.0 was employed to analyze the results.

**Results:** The high-speed video playback confirmed the safety of the explosion site as no explosion fragments projected beyond the wall. No pig died within 24 h when DCS was performed, while 7 pigs died in the control group. After a literature review, assessment criteria for CDCS were established that had a total score of 100 points and had 4 major parts: leadership and team cooperation, resuscitation, surgical procedure, and final outcome. Expert questionnaire results showed that the scientific score was  $8.6 \pm 1.25$ , and the feasibility score was  $8.74 \pm 1.19$ . When compared with the basic level, the trainees' score improved significantly after training.

**Conclusion:** The platform established in this study was useful for CDCS training.

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## Introduction

The survival rate of injured combat casualties has been improved greatly in Operation Iraqi Freedom and Operation Enduring Freedom compared with the past wars. Multiple factors,

including the implementation of tactical combat casualty care, rapid in-theater evacuation and early access to damage control surgery (DCS), have contributed to this improvement.<sup>1</sup> Of those factors, the early DCS plays a key role in reducing the incidence of death related to wounds (i.e., death occurs after the casualties have been transferred into military medical facilities<sup>2</sup>). Derived from military experience, DCS now is the well-established standard of care for severely injured civilian patients worldwide. Damage control trilogy is the basis of DCS, which comprises an abbreviated operation, intensive care unit resuscitation, and a return to the operating room for the definitive operation, with the intention to avoid the lethal triad comprised of the vicious cycle of hypothermia, acidosis, and coagulopathy.<sup>3,4</sup> It is generally accepted that DCS

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consists of emergency surgical procedures and treatment by a surgical team to stabilize severely injured casualties to save life, limb or function.<sup>3,4</sup> DCS techniques are applied when the magnitude of tissue and organ damage are such that definitive surgery is likely to exceed the casualty's physiologic limits. Examples of emergency DCS procedures include cricothyrotomy for definitive airway control, laparotomy or thoracotomy for control of exsanguinating hemorrhage, laparotomy to control enteric spillage and temporary restoration of blood flow to a limb using vascular shunts.<sup>3,4</sup>

It is a great challenge to prepare a military surgeon with the skills for combat environment,<sup>1,5</sup> especially with the skills for DCS. The principles for combat damage control surgery (CDCS) are similar to those of the civilian setting; however, the limited resources, the constantly occurring mass casualties, the more severely injured patients and the need for the evacuation of the patients between medical facilities make the CDCS paradigm different from that of the civilian DCS paradigm.<sup>1,5</sup> Many courses and simulation trainings have been developed in civilian trauma centers for CDCS training, but there remains a large gap between operational medical needs and training opportunities in peacetime.<sup>6</sup> Typical civilian training and practice do not provide adequate exposure to the broad set of surgical skills required for combat casualties.<sup>7</sup> To fill this gap, Back et al.,<sup>7</sup> Gaarder et al.,<sup>8</sup> Jacobs et al.<sup>9</sup> and Hansen et al.<sup>10</sup> developed gunshot penetrating injury models on live animals for DCS training. It was revealed that this training could significantly increase the participants' perceived competence. However, these animal models were based on gunshot wounds, which is different from the epidemiology of modern war. It has been revealed that explosion is the main injury mechanism of modern war, and the causes of lethal injuries in the interval between October 2001 and June 2011 during Operation Iraqi Freedom and Operation Enduring Freedom were explosive wounds (73.7%), gunshot wounds (22.1%), and other wounds (4.2%).<sup>2</sup> The injury mechanisms, injury patterns, pathological changes and care procedures of explosive wounds are different from those of gunshot wounds.<sup>2</sup> To make the training closer to the real combat environment, we have established a training platform for CDCS based on explosive combined thoraco-abdominal injuries in live pigs. The platform established in this study was composed of 3 main components: an explosion site, explosive thoracic-abdominal combined injury model, and objective test standard. Then, a 5-day training course was carried out to test the feasibility of the platform, and it was found that the platform could not only improve the DCS ability of trainees but also improve the trainees' ability to cope with a mass casualty incident (MCI).

## Methods

All procedures involving animals were approved by the Ethics Committee of Army Medical University of China PLA and were performed in accordance with relevant regulations of Ethics Committee of the PLA Army Medical University of China.

### *Construction of the explosion site and the DCS training site*

Explosion is the main mechanism in modern war.<sup>2</sup> Thus, an explosion site was constructed for the establishment of a DCS animal model. Two engineers from Army Corps of Engineers were asked to help us to build the explosion site and to make the animal models. One hundred gram trinitrotoluene (TNT) would be employed to produce animal model based on their experience and references.<sup>11–14</sup> One hundred gram of TNT belong to low-order explosive, and the travel distance of positive-pressure shock wave and negative-pressure suction wave are about 2 m, and the travel

distance of blast wind is about 30 m. The travel distance of fragment is less than 15 m. Thus, in the current study, a 50 m × 50 m square yard was constructed in a rural mountain area with no habitats within a 500 m diameter.

At the center of the yard, a 10 m (length) × 10 m (width) × 2 m (height) square steel frame was constructed. Outside of the frame, a 1.2-m-high sandbag wall was constructed to prevent blast form traveling too far away and to prevent bomb fragments from projecting out. During an explosion, the top of the frame was attached with tree branches and quilts to prevent the bomb fragments from projecting out and to prevent blast form traveling too far away. High-velocity cameras were fixed at the corner of the wall to record the explosions process, the projectile and training process. Four pressure sensors (Chongqing Degu Technology Co., Ltd., Chongqing, China) were attached to the four lateral walls and the pressure was monitored when explosion took place.

Approximately 1.2 km from the explosion site, tents were constructed for DCS training. Each tent was equipped with an operation bed, light source, surgical instruments, reagents for damage control resuscitation (DCR), ventilator, physiological monitor, and other necessary facilities for DCS. Next to the tents for DCS training was a tent containing lab instruments that was constructed for routine blood examination, blood coagulation, blood gas examination, and thromboelastography examination.

### *Establishment of a CDCS animal model*

Fifty-kg mini-musk pigs of either sex were fixed in a homemade fixator, with only the abdomen and right thorax exposed. Rectangular explosive made of 100g 2, 4, 6-TNT was used to produce the animal model. The explosive, 6 cm long, 4 cm wide, and 1.5 cm thick, was attached with 20 steel balls (0.3 cm in diameter) and placed 1.2 m (to injure the pigs more severely) or 3 m (to injure the pigs less severely) away from the animal. The height from the TNT to the ground was 0.6 m. After the pigs were sedated with an intramuscular injection of 20 mg/kg ketamine and 2 mg/kg xylazine, the TNT was detonated by a remote-controlled primer.

The distance (1.2 m or 3 m) between the animal and the explosive was determined by preparatory experiments. Briefly, 24 pigs weighing 50-kg were evenly divided into 4 groups, of which the TNT attached with steel balls was placed at 0.6 m, 1.2 m, 3 m and 5 m away from the animals. The same procedure as mentioned above was performed. Then thoracic and abdominal exploration were performed to reveal the extent of injuries. It was found that when explosion took place at 0.6 m away from the animals, all 6 pigs died within 30 min after injury and the injury severity score (ISS)<sup>15</sup> was 50; when explosion took place at 1.2 m away from the animal, most of the pigs (5 out of 6) could survive more than 2 h after injury without treatment and the ISS was 27 for 5 pigs or 32 for the rest pig; when explosion took place at 3 m away from the animals, all the animals could survive more than 6 h after injury without treatment, and ISS was 8 for 4 pigs or 13 for 2 pigs; when explosion took place at 5 m away from the animals, all the pigs could survive more than 24 h after injury without treatment, and ISS was 2 for 4 pigs or 5 for 2 pigs. So, the distance of 1.2 m and 3 m were selected to produce severely injured animal models and less severely animal models, respectively.

To observe the effect of DCS on the outcome of injured animals, 16 pigs were randomly divided into the DCS group and the control group. Both groups accepted explosion injury at the distance of 1.2 m. The DCS group accepted both DCS and DCR. Intravenous access was established within 10 min after injury to initiate fluid resuscitation. The resuscitation fluid consisted of 500 mL hydroxyethyl starch and 1000 mL Ringer's lactate. The control group only accepted DCR. The type and amount of resuscitation fluid were the

same as that in the DCS group. Animals can survive if appropriate DCS is performed, but those without DCS at high risk of death.

#### *Establishment of the test standard for CDCS*

An extensive literature review was performed to identify the key factors for assessing the procedure and outcome of CDCS, and the testing standards for CDCS were then established. Keywords including “combat casualty”, “damage control”, “damage control surgery”, “combat damage control surgery”, “damage control resuscitation”, “blast”, “explosion”, “gunshot”, “testing”, and “test standard” were used to search on PubMed. Literature directly related to the training, testing and assessment of DCS were preferentially selected, while papers containing key elements of DCS were also selected. All the parameters were extracted for the establishment of a test standard for CDCS. Based on the importance of each parameter, 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 standard. 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; for the evaluation of feasibility, scores of 1, 3, 5, 7 and 9 indicate that the testing standard was non-feasible, fairly non-feasible, feasible, fairly feasible and highly feasible, respectively. In addition, experts were asked to evaluate whether the points given to the parameters was reasonable. In total, 20 well-known experts from 12 military hospitals were invited to complete the questionnaire.

#### *General description of the training course*

To test the feasibility of the platform, a 5-day training course was carried out. On day 1, didactic lectures covering the whole design of the course, the pathophysiology of DCS, the basic principles of CDCS, the principles and methods of DCR, and other details of DCS (especially damage control laparotomy, damage control thoracostomy, and tube thoracostomy) were delivered. In addition, basic information and knowledge, including the anatomical differences between humans and pigs, first-aid methods, and basic information about combat casualty care, such as military evacuation chains, were also taught. On day 2, the participants were trained on DCS. On day 3, single injured pigs were assigned to one team to test the participants' DCS ability. On day 4, 3 injured pigs were assigned to one team to test the participants' ability to cope with MCI along with DCS. On day 5, the testing of DCS and MCI care was performed.

Between 20th and 24th of May, 30 teams (150 persons) attended the training course. All teams were trained and tested according to the standard protocol as described below.

#### *Training of CDCS*

For simple DCS ability training, severely injured animals (TNT was placed 1.2 m away from the animals) were assigned to one team to test the participants' DCS ability. A team generally consisted of 2 surgeons, 2 nurses, and 1 anesthesiologist. After the explosion, the team was asked to practice orotracheal intubation, ventilation via bag-valve masks, peripheral intravenous access establishment, and wound dressing. Then, the pigs were transferred to DCS training tents where damage control laparotomy and tube thoracostomy were practiced. Key components and steps of tube thoracostomy and damage control laparotomy were trained. For chest tube drainage, a horizontal skin incision was made anterior to the mid-axillary line at the 4th or 5th intercostal space, and blunt dissection was continued through the intercostal muscles and the

parietal pleura. Then the tip of the clamped chest tube is grasped with a curved hemostat and introduced in a cephalad and posterior direction. The tube is advanced into the thoracic cavity until the side holes are well inside the pleural space and then rotated 360°. Finally, the tube was connected to a closed drainage system and was secured in place. For laparotomy, the surgeons should follow a routine for the proper exploration of the contents of the abdomen to inspect all intraperitoneal and retroperitoneal organs. If there was no overt bleeding, the surgeon should pass a hand quickly over the liver, spleen, and pulling the intestines first towards him and then away, inspect the retroperitoneum. Attention then turns to any contamination by a meticulous inspection of the entire gastrointestinal tract. If it is thoraco-abdominal injury, a chest tube should have been placed prior to laparotomy; if not done, one is inserted intra-operatively and the diaphragm repaired to re-establish proper ventilation. Once exploration of the peritoneal cavity has been accomplished, further control of hemorrhage and contamination and definitive repair should be conducted depended on the patient's physiological status.

For MCI care training, 3 injured pigs were assigned to one team at the same time. For one animal, the TNT was put 1.2 m away from the animal to produce severe injuries; for the other 2 animals, the TNT was put 3 m away from the animal to produce less severe injuries. In addition to the abovementioned practices, the team was asked to practice triage, the stabilization of the injured animals, the arrangement of the surgeries in the proper sequence, and cooperation.

During the training process, a score was given to each team, which served as the basic level of each team.

#### *Testing of CDCS*

On day 5, the testing of CDCS and MCI care was performed. Three injured pigs were assigned to one team at the same time, and the injury patterns were the same as that mentioned above. Three judgment referees were assigned to each team, and an assistant was assigned to each team whose responsibility was to video record the whole process with a hand-held camera. Before the explosive injuries and 1 h after the operation, both arterial and venous blood samples were obtained and tested for the abovementioned parameters to observe the physiological effect of CDCS and DCR.

The referees gave scores to each team during the process, and necessary revision was made after reviewing the video. The average score was the score that the tested team eventually received.

#### *Statistics*

All data are expressed as the means  $\pm$  SE. SPSS 11.0 was employed to analyze the results. Statistical significance was evaluated using unpaired Student's *t*-tests for comparisons between the two groups, and the confidence interval was set at 95% (95% CI). A  $p < 0.05$  was considered significant.

## **Results**

#### *Safety of the explosion site*

The explosion site was constructed in a rural mountain area (Figs. 1A&B). In total, 148 explosions were carried out throughout the training process. During the explosion, no obvious blast pressures were found by the pressure sensor attached to the 4 lateral walls. The video results showed that only a small amount of fragments and debris formed by the explosion was projected out of the central explosion area; due to a large amount of dust caused by the explosion (Figs. 1C&D), high-speed video playback did not show





**Fig. 1.** Explosion site established in the current study. (A) The outside wall; (B) The square steel frame at the center of the explosion site; (C&D) Large amounts of dust and smoke caused by the explosion.

steel balls, explosion fragments, debris, etc. projecting beyond the wall. Because no person was allowed to stay inside of the wall, the results of the high-speed video playback indicated that the explosion site constructed in this study was safe.

#### Validity of the animal model

During the establishment of the CDCS animal model, the pigs were fixed in a homemade fixator with only the abdomen and right thorax exposed (Fig. 2A), and 100 g of TNT attached with 20 steel balls was used for explosion (Figs. 2B&C). The distance between the animals and the explosives was set at 1.2 m based on the preparatory experiment results. It was found that no animal died within 24 h when DCS and DCR were carried out after the explosion, while 7 animals died within 24 h after injury without corresponding measures, with a mortality rate of 87.5%. The number of dead animal was 1 at 30 min after injury, 1 at 1 h after injury, and 2 at 2 h after injury, 3 at 3 h after injury. These results indicated that the animals could survive when DCS was performed, while the animals were at high risk of death if no DCS was performed.

After the explosion, there was no obvious thoracic and abdominal bleeding (Fig. 3A) and the physiological condition of the

injured animal was stable. Intraoperative exploration (the operation group) or postmortem exploration (the control group) revealed that the range of injuries after injury was extensive (Figs. 3B–F). Each animal had lung contusion and laceration, liver injury, intestinal injury, and gastric injury; 87.5% of the animals had spleen injury; and 50% had bladder injury. The number of injured organs in each animal was between 5 and 6, and the ISS scores were 27 in 15 animals and 32 in 1 animal. These results indicated that the live porcine model established in this study was consistent, and could be used as a good model for CDCS training.

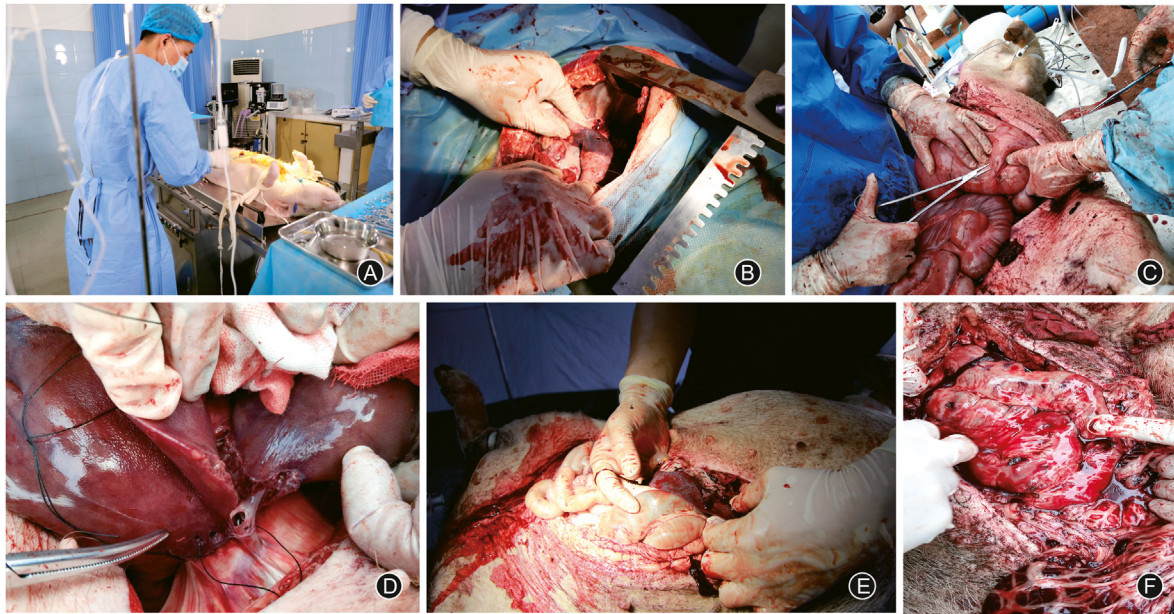
#### Establishment of the test standard for CDCS

A literature search found that there were no studies directly related to CDCS assessment and evaluation, whereas there were 262 studies related to the organization and implementation of CDCS, team cooperation, operation process, resuscitation process, outcome and effect. Due to limitations of length, this paper lists only 9 of the most closely related documents in the references.<sup>11,16–22</sup>

By thorough analysis of the literature retrieved, the core indicators reflecting DCS and CDCS included organizational ability,



**Fig. 2.** Establishment of the animal model. (A) Homemade fixator; (B) The explosion instrument was placed in front of the porcine, which was detonated by a remote-controlled primer; (C) Explosion instrument consisting of 100 g of TNT attached with 20 steel balls.



**Fig. 3.** (A) Preparation of the animal. Extensive injuries were caused to the (B) lung, (C) stomach, (D) liver, (E) liver and (F) intestine.

team cooperation ability, injury assessment, injury classification, the judgment of whether DCS was needed, the ability to perform concise surgery, operation time, the establishment of a resuscitation lines as soon as possible, the selection of appropriate resuscitation fluid, the use of an appropriate amount of resuscitation liquid, whether there was the lethal triad of hypothermia, coagulation dysfunction, and acidosis, whether the vital signs were stable, and so on. On this basis, we formulated the CDCS assessment criteria (Table 1). The evaluation method has a total score of 100 points, which is divided into 4 major parts: leadership and team cooperation, resuscitation, surgical procedure, and final outcome and effect.

A total of 20 expert questionnaires were sent out, and all the questionnaires were collected. The scientific score was 8.6 (+1.25), and the feasibility score was 8.74 (+1.19). All experts considered that the points given to the parameters were reasonable.

These results revealed that the experts agreed with our determined assessment criteria.

#### Application of the platform

In total, 30 teams (150 persons) attended the training course. Among the scores given for each team, the score from each of the 3 experts deviated little from the average score, which indicates that this standard is very objective. In the process of judging, the index set by each determinant was easy to judge, and there were few subjective factors. There were no complaints or objections to the criteria.

When compared with the basic level score, the participants' scores improved significantly after training (Fig. 4).

#### Discussion

DCS is one of the key skills that military surgeons should master, however, it is much more challenging and complicated to prepare military surgeons with DCS than other relatively skills, such as first aid techniques. To make these surgeons more prepared for war, the U.S. Army Trauma Training Center was established in 2001 at the University of Miami Miller School of Medicine/Ryder Trauma

Center as the only pre-deployment mass casualties and clinical trauma training center for all forward surgical teams.<sup>23</sup> The U.S. Navy began a similar program at the University of Southern California/Los Angeles County Medical Center, and the U.S. Air Force initiated Centers for the Sustainment of Trauma and Readiness Skills at busy academic medical centers, i.e., the R. Adams Cowley Shock Trauma Center at the University of Maryland and Saint Louis University.<sup>23</sup> Similar measures have been taken in France.<sup>1</sup> As far as training methods are concerned, rotations in clinical practice, didactic sessions, case presentations, experience with surgical simulators, cadaver dissections, live tissue surgical procedures, and live animal surgical training are currently the most often used methods for DCS training.<sup>24</sup> Rotations are a useful and basic way to improve DCS skills, however, typical civilian training and practice do not provide adequate exposure to the broad set of surgical skills required for combat casualties because even surgeons in level I trauma centers have limited experience with CDCS.<sup>7</sup> Didactic sessions and case presentations are necessary and useful but cannot provide hands-on practice. Simulators are a valuable training tool to increase patient safety and improve provider ability and competence in nearly every aspect of medicine.<sup>25</sup> Initially, simulators were not so advanced and were used for training for relatively simple skills, such as trauma resuscitation,<sup>26</sup> establishment of vascular access,<sup>25</sup> treatment of disorders of the airway, and difficulty with breathing.<sup>27</sup> With the progress of techniques, many advanced simulators have been developed, such as virtual reality-based simulator, first aid-focused simulator, and damage control surgery - focused simulator, etc.<sup>28</sup> This kind of simulator involves the computer-generated simulation of 3D images or environments so that the learner can interact in a seemingly real or physical way. Currently, there are more than 400 models available. However, these simulators now mainly focus on the particular surgical skills involved in one of the abovementioned skills, and there are no simulators for DCS training.<sup>28</sup> Because cadaver dissections and live tissue surgical procedures cannot simulate real injury situations, such as hemorrhage and organ injuries, their usage in DCS training is less promising.<sup>8</sup> In comparison, the use of live animal models can simulate various kinds of combat casualties and provide the opportunity for hands-on management in a safe situation.



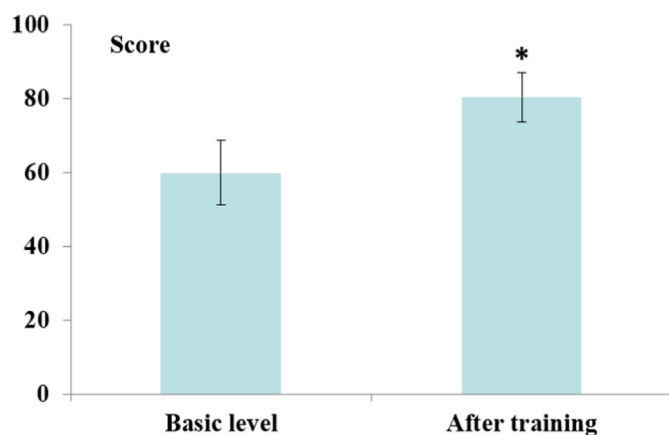
**Table 1**  
**Test standards for combat damage control surgery established in the current study.**

Major parts	General requirements	Score indicators and score standards	Points
Leadership and team cooperation (Total score: 10 points)	Team leader organizes the whole process in an orderly manner, and team members work together to ensure an orderly treatment procedure.	Five team members had a clear division of labor and performed their respective duties (3 points). The team leader coordinated well to ensure the smooth flow of treatment material (3 points). Language communication between team members in on-site care and during the operation was smooth. If there were arguments, the team members could discuss and reach an agreement (4 points).	
Damage control resuscitation (Total score: 20 points)	The venous channel should be established, and fluid resuscitation should be initiated during the stage of on-site care. In addition, the continuity of resuscitation should be maintained at the point-of-care and during the simulated patient transfer to the operation room.	Correct assessment of the injuries and whether there was a shock was made during the on-site care stage (3 points). The venous channel was established at the stage of on-site care (3 points). Fluid resuscitation was initiated at the stage of on-site care (3 points). No slippage of the infusion lines, falling off of the tracheal tube or falling off of stretcher during the transportation of the porcine (3 points). Effective vital signs monitoring was established during the operation (2 points). Appropriate fluid resuscitation was performed based on the results of vital signs monitoring during operation (3 points). Stable and reasonable levels of blood pressure and heart rate were maintained (3 points).	
Damage control surgery (Total score: 50 points)	Choosing the appropriate anesthesia method according to the condition of the wounded and performing a reasonable and effective damage control operation. The time of the operation should be limited to within 1 h.	Choice of an appropriate incision was made (2 points). Adoption of corresponding damage control operations according to the injury condition (such as direct suture of single intestinal perforation; ligation after the resection of severe intestinal injury; direct suture for mild liver injury; resection of severely damaged liver injury) (15 points). The sequence and method of damage-controlled laparotomy was correct (3 points). The method of searching for the source of major bleeding was appropriate, and the source of major bleeding was found in short time (usually in less than 3 min after the abdomen was opened (3 points). Appropriate methods were taken to control major bleeding (3 points). Vital abdominal injuries were not missed during exploration and were not left without treatment (6 points). For every missed or untreated vital injury, 2 points will be deducted out of 8 points maximum. Effective tube thoracostomy was performed for thoracic injuries (3 points). The time of the operation was limited to within 1 h (5 points). For every 10 min over the required time (60 min), 1 point will be deducted out of 5 points maximum. No obvious violation of aseptic operation during the operation (3 points). Measures such as flushing with large amounts of saline were implemented to prevent infection (3 points). Using an electric blanket to keep the porcine warm (2 points). Heating the infused fluid with an infusion pump during resuscitation (2 points).	
Final outcome and effect (Total score: 20 points)	No animal deaths should occur, and there should be no hypothermia, coagulation dysfunction, acidosis or other physiological disorders.	Animal should be alive for at least 2 h after the operation. If death occurs, a total of 20 points will be deducted. Appropriate body temperature was kept (4 points). For cases in which the body temperature drops below 35° Celsius, 4 points will be deducted; for those cases in which the body temperature drops to between 35 and 36.9° Celsius, 2 points will be deducted. Arterial and venous blood with good quality and in proper amount were acquired and available for laboratory testing (2 points). No coagulation dysfunction occurred (5 points). If INR is greater than 1.5, 5 points will be deducted; if INR is between 1.2 and 1.49, 3 points will be deducted. The base deficit (BE) was in the normal range (5 points). If the value of the BE is less than -5 mmol/L, 5 points will be deducted; if the value of the BE is between -2.5 mmol/L to -4.9 mmol/L, 3 points will be deducted. The value of the hemoglobin was in the accepted range when compared with the baseline value of the porcine itself (4 points). When the value of the hemoglobin is 50 g/L below the baseline value of the porcine itself, 4 points will be deducted; when the value of the hemoglobin is 20–49 g/L below the baseline value of the porcine itself, 2 points will be deducted.	

Total score

Signature of referee or evaluator:

Date of evaluation:



**Fig. 4.** Scores that the teams received before and after the training.  
\*:  $p < 0.05$  when compared with basic level. A  $p < 0.05$  was considered significant.

In previous studies, Back et al.,<sup>7</sup> Gaarder et al.,<sup>8</sup> Jacobs et al.<sup>9</sup> and Hansen et al.<sup>10</sup> have developed gunshot penetrating injury models in live animal models to train DCS. It was revealed that this training could significantly increase the participants' perceived competence. However, these animal models are based on gunshot wounds, so these wounds are different from explosive wounds, which are the main mechanism in modern war.<sup>2</sup> Intraoperative exploration and postmortem exploration have revealed that the range of injuries after explosion is more severe and extensive than those of gunshot wounds (Figs. 3C–E), and these injuries are critical and validated for DCS training, i.e., the animal can survive when DCS is performed, while the animal is at high risk of death if no DCS is performed.

Various methods, including questionnaires and post-training surveys, an objective structured assessment of technical skills, a global rating scale of performance scoring systems, structured assessments using video recording, and motion tracking software, have been designed for the assessment of simulation-based training.<sup>29</sup> Previously, the most commonly used methods have been questionnaires and post-training surveys.<sup>29</sup> In the present study, we established an objective assessment method for DCS. In the process of establishing the assessment criteria, we selected core indicators that can reflect the process and outcome of DCS, such as organizational ability, team cooperation ability, injury assessment, injury classification, the judgment of whether DCS is needed, the ability to perform concise surgery, operation time, the establishment of a resuscitation pathway early, an appropriate resuscitation fluid, the appropriate use of the resuscitation fluid, whether there is a low body temperature, coagulation dysfunction and acidosis lethal triad, whether the vital signs are stable, and so on (Table 1). Hand washing, wound preparation and dressing, etc., which are common surgical skills, 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 DCS but also avoid subjective factors. In the process of training and testing, it was found that the scores from the 3 experts deviated little from the average score of them, which indicates that this standard is very objective. In the process of judging, the index set by each determinant was easy to judge, and there were few subjective factors. There were no complaints or objections to the criteria.

In addition, the platform established in the present study provided a way to train MCI management. By assigning 3 animals to each team, triage, the stabilization of the injured animals, the

arrangement of the surgeries in the proper sequence, cooperation, and team leadership were practiced. In addition, after practice, cooperation was the part that improved the most. Communication during teamwork is the most important factor,<sup>30</sup> and the present study showed that by training, team communication improved significantly.

There are several limitations of the current study, and there are several aspects that need to be improved in the future. First, the animal model developed in the current study consisted only of thoraco-abdominal combined injuries and did not include all kinds of injuries. In the future, we will establish different types of injuries, such as cranial explosive injury, limb explosive injury, and combined injuries of different types, to train wartime DCS more comprehensively. Second, the safety requirements of our platform are relatively high. For example, to construct the explosion site, it is required a area that no habitants within a 500 m-diameter. This fact makes the spreading of the platform difficult. Third, regardless of how effective the platform is, a hybrid training model should be used to improve the training effect.<sup>25</sup> In the future, a hybrid training system with the current platform as a core element will be established to improve the training effectiveness.

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## Ethical statement

All procedures involving animals were approved by the Ethics Committee of Army Medical University of China PLA and were performed in accordance with relevant regulations of Ethics Committee of PLA Army Medical University of China

## Declaration of competing interest

The authors declare no conflicts of interest.

## Author contributions

Zhao-Wen Zong was responsible for study design, supervision, and drafting of the article. Ren-Qing Jiang and Xin Zhong were responsible for the construction of the explosion site and the DCS training site, establishment of a CDCS animal model, and establishment of the test standard for CDCS. Wen-Qiong Du and Lin Zhang contributed to the organization of the training and test. Zhao Ye was responsible for the data collection and data analysis Yi-Jun Jia was involved in organization of the training course.

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