Application of Treatment simulation Software for War Injury in Emergency Treatment Training on the Battlefield based on Chinese Visible Human Datasets

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Abstract

Background: Proficiency in self-help and mutual aid skills is correlated with the prognosis of injured patients, and this study aims to create treatment simulation software for war injuries that reflect the physical constitution of Chinese people and study its application in first aid training on the battlefield.

Methods: Based on thin-sectional, highly precise Chinese Visible Human (CVH) data with high resolution, combined with self-help and mutual medical aid measures such as digital pressure hemostasis, cricothyroid membrane puncture, pneumothorax puncture and bone marrow puncture for battlefield first aid, useing Amira and other softwares to building the simulation software for the technical training of military medical students and basic medical officers was constructed. Eighty medical service students were trained on battlefield first aid technology, and a new training mode for the treatment of war injuries was developed and optimized.

Results: Simulation software of hemostasis and puncture for battlefield first aid that was suitable for the technical training of military medical students and its supporting teaching materials 3D-PDF were established. The software included modules of hemostasis of the vertex, face, head-shoulder, shoulder-arm, forearm, upper forearm, lower limb and foot and puncture of the cricothyroid membrane , pneumothorax, and bone marrow cavity. Collaborating with interactive 3D-PDF, it was successfully used for on-site first aid training of military medical students. The questionnaire results showed that the trainees had a high recognition of the human-computer interactive performance of the software with a clear interface and easy operation.–The accuracy and richness of the three-dimensional model structure, knowledge of hemostasis and puncture and applied anatomy contained in this software were high, helping trainees to quickly master the knowledge points and operation techniques related to hemostasis and puncture.

Conclusion: The system can effectively mobilize the learning enthusiasm of students and fully improve the learning efficiency of the basic materials and applied anatomy of battlefield first aid, as well as the teaching efficiency of teachers. The training simulation of battlefield first aid, comprising a combination of various modes, effectively complemented each other, met many training needs, and achieved satisfactory training results. Additionally, this software could be used in the emergency training of traffic accident injuries and disaster-related injuries.

Key words: Chinese Visible Human; Military medicine; War trauma treatment; Sectional anatomy.

Background

According to the casualty data and related reports of the US and UK military forces during the wars in Iraq and Afghanistan, the rates of blood vessel injury were higher than those in previous wars, and the main site of the injury was the limbs [1, 2]. Eastridge BJ et al analyzed all combat-related mortality during Operation Ending Freedom (OEF) and Operation Iraqi Freedom (OIF), revealing that up to 25% of the deaths were salvageable [3]. Holcomb et al reported similar rates of 15% and 19% of US combat cases [4-6]. Further studies by E. Glassberg, Eastridge BJ and others showed that most (90%) of these deaths were attributed to blood loss, and airway injury (8%) and tension pneumothorax (1%) were also important major causes of death [3, 7].

Military medicine focuses on preventable death, emphasizing bleeding control, resuscitation strategies and evacuation improvement [7]. Timeliness is a major factor affecting treatment. The time from the beginning of trauma to approximately 10 minutes after injury is considered the key time of first aid; thus, it is defined as the "platinum 10 minutes". During this period, adopting correct emergency treatment can significantly shorten the rescue time and improve the rescue rate. The "platinum ten minutes" emphasizes the importance of self-help and mutual aid among warfighters. Large space, high mobility, complex environment, scarce resources and other tactical restrictions in modern war often delay the time for medical personnel to reach the wounded and delay the evacuation time, making it difficult for the wounded to obtain definitive treatment in the early period after the injury. Self-help and mutual aid among warfighters can help the wounded to gain time while waiting for professional treatment. Therefore, mastering self-help and mutual aid skills is crucial to warfighters.

The effective implementation of self-help and mutual aid requires the rescuer to acquire specific knowledge of basic anatomy, surgery, and military medicine. However, grassroots soldiers, most of whom are not medical professionals, have relatively poor knowledge of human anatomy, making it difficult for them to accurately judge the injuries and implement effective treatment. Therefore, the training of on-site self-help and mutual aid techniques must be strengthened. However, the effect of the traditional simulation dummy is limited, making it difficult to achieve a good learning effect. Digital technology provides various ways to train self-help and mutual aid skills. Using virtual simulation technology, simulation of treating casualties in a real war environment is attainable, which helps improve the effect of self-help and mutual aid training.

In this study, we constructed thin-sectional, highly precise, high resolution, sectional anatomy images (Chinese visible human (CVH)) data, combined with hemostasis (digital pressure hemostasis), ventilation (cricothyroid membrane puncture), pneumothorax puncture and intraosseous infusion for venous collapse in self and mutual medical aid, and simulation software to treat war injury in any computer terminal and reflect the physical constitution of the Chinese human body. The software is used to train and teach self-help and mutual aid skills to observe its learning effect.

Methods

Establishment of treatment simulation software for war injury

CVH data have the characteristics of a thin section, high precision and high resolution and have been widely used in the research and teaching of anatomy [8-11]. In this study, the second CVH dataset (image resolution: 3072 × 2048, pixel size: 0.15 mm × 0.15 mm, layer thickness: 0.5 mm) was selected as the experimental dataset. The experimental data were segmented using AMIRA 5.2.2 software (Visage Imaging, Inc. San Diego, California, USA) to obtain three-dimensional digital models of human muscle, bone, blood vessels, nerves and some organs. Autodesk Maya 2018 (Autodesk. San Rafael, California, USA) and Unfold3d (POLYGONAL DESIGN. MARSEILLE, French) were used for pre-processing, such as smoothing and simplifying, texture mapping and rigging. Unity3D (Unity Technologies, San Francisco, CA, USA)) was used to program and output the treatment simulation software of war injuries. The process is shown in Figure 1.

User interface and injury modules

User interface

The user interface of the software was designed as a four-level interface (Figure 2). The first-level interface was the login interface. The second-level interface was the interface of the selected injury module, which provided the function of injury module selection. Users could enter the learning interface of the corresponding module by clicks. The third-level interface was the learning interface of basic knowledge of injury, providing learning function of anatomy knowledge of injury and learning function treatment knowledge of injury. The fourth-level interface was the interactive learning interface of 3D digital anatomy and sectional anatomy, providing 3D digital anatomy learning, video teaching, sectional anatomy learning (the combination of 3D model and sectional anatomy), assessment model and other functions.

Injury modules

According to the needs of first aid on the battlefield, the injury module was divided into two parts: digital pressure hemostasis and puncture modules (Figure 2). The digital pressure hemostasis modules included the following: 1. hemostasis module of the vertex; 2. hemostasis module of the face; 3. hemostasis module of the head-shoulder; 4. hemostasis module of the shoulder-arm; 5. hemostasis module of forearm or upper forearm; 6. hemostasis module of the lower extremity; 7. hemostasis module of the foot. The puncture modules included the following: 1. cricothyroid membrane puncture; 2. pneumothorax puncture; 3. marrow cavity puncture.

3D-PDF of the treatment of war injuries

Using Deep Exploration (Right Hemisphere, Inc) and Adobe Acrobat(Adobe Systems Incorporated, San Jose, CA, USA) the 3D-PDF document of the treatment of war injuries, including the hemostasis modules and puncture modules, was obtained by adding 3D model data, graphic interpretation and video teaching of the treatment of war injuries into the PDF document.

Verification of the software

The development of the software was completed under repeated communication among experts in anatomy, emergency and software engineering. To verify its feasibility and effectiveness, the software was transplanted to the Intranet of the campus network and was used in the browser by downloading relevant plug-ins. The military medical students at our school were invited to participate in testing of the software, and the operation and use of the software were briefly explained to them. Once the military medical students clicked the corresponding module, the animation of the wounded individual would be played, and the injury situation and treatment measures would be explained to the trainees by voice to help them understand the characteristics of the injury and treatment points. Thus, the trainees could accurately identify the hemostasis point or puncture point in subsequent activities and become familiar with the whole emergency treatment process.

Curriculum design

The course design of the hemostasis and puncture simulation treatment on the battlefield was as follows: a course on basic theory (0.5 class hours) and a practice course (1.5 class hours). The participants completed 3 class hours of study. The basic theory course explained the operation method of the simulation software of hemostasis and puncture and 3D-PDF for trainees. The software was used to explain the key points of knowledge and caution during digital pressure hemostasis, cricothyroid membrane puncture, pneumothorax puncture and marrow cavity puncture. A 3D-PDF download service was provided to trainees via the Intranet cloud disk. During the practice course, the trainees could freely operate the software to learn and master relevant knowledge of hemostasis and puncture and verify knowledge on the real human body by self-study or with the help of trainees sitting beside them.

Performance evaluation of the software

The “teaching satisfaction questionnaire for the simulation software of hemostasis and puncture on the battlefield” was designed to evaluate the application effect of the software, and trainees participated in the evaluation anonymously. Eighteen items were in the questionnaire, which was designed by referring to a Likert scale, and the scoring standard was based on a 5-point system. Arabic numbers “5, 4, 3, 2, and 1” represented "strongly agree, agree, neutral, disagree, and strongly disagree", respectively (Table 1).

Results

In this study, the CVH data were used to construct a war injury model that could accurately and intuitively reflect the spatial position, three-dimensional morphology and adjacent relationship of vital organs, muscles, blood vessels and bone of Chinese people. Using Unity3D, the data on CVH tomography, teaching video of first aid, images and texts of first aid teaching and model of war injury were integrated, and first-aid teaching software applicable to the battlefield was developed (Figure 3-6). This provided a training platform for trainees with good interactive anatomy teaching function, which controlled the functions of a concealable anatomical structure display, an optional pressing point or puncture point, clues for wrong pressing or puncture point, video teaching, and contrast learning of the sectional and injury models.

Application of 3D-PDF

The production of 3D-PDF (Figure 7) occurred earlier than the development of the software. In a previous study, this software was used to train 20 military medical personnel of medical majors in first aid techniques on the battlefield, achieving good results. In this study, 3D-PDF was used as a supplement to the simulation software of hemostasis and puncture for first aid on the battlefield to help trainees review the key points of the knowledge of first aid for war injury in an environment where the software could not be used (such as for out-of-class study), thus consolidating the training effect of the software.

Training model of the software

The training mode of combining theory with practice with software compensated for the shortcoming that the conventional training mode could not display the internal characteristics of the injury in multiple dimensions and levels. The teaching method of combining three-dimensional interaction, video explanation and section effectively aroused trainees' learning enthusiasm and subjective initiative, helped them better understand hemostasis and puncture and improved their learning efficiency, as well as teachers' teaching efficiency. By comparing with the software and teaching video, finding and verifying the body surface projection of the pressing and puncture point in the real body deepened the trainees' memory of knowledge points, thus effectively prolonging their memory cycle.

Performance evaluation of the software

Eighty questionnaires were issued to trainees who participated in the training, all were recovered and valid, resulting in a valid questionnaire rate of 100%. Limited by the enrollment quota of military schools and the student number of small classes, fewer trainees participated. The trainees had a high recognition of the human-computer interactive performance of the software, believing that the software interface was friendly and easy to operate (Table 1, Q1 and Q2). The accuracy and richness of the three-dimensional model structure, knowledge of hemostasis and puncture and applied anatomy contained in the software were unanimously recognized by trainees, helping them to quickly master the knowledge points and operation techniques related to hemostasis and puncture (Table 1, Q3-Q13). Some of the trainees affirmed the practical application significance of the software and believed that it presented the process of treatment for war injury vividly, and users could intuitively visualize the pressing point and puncture point. After mastering how to operate the software, the trainees believed they could repeatedly operate the software and learn the knowledge points without the teachers' explanation (Table 1, Q17). Regarding the deficiency of the software, they proposed that the bleeding effect should be added in the three-dimensional interactive area to simulate the arterial bleeding state and obtain a more realistic simulation effect, and that the radius of the pressing point should be expanded, with different hemostatic effects for different radii. Advice and suggestions on the learning module of first aid measures such as adding combat application tourniquets and dressings and fixation after first aid management were also proposed (Table 1, Q17-18).

Discussion

In this study, the CVH data were used to construct a war injury model that could accurately and intuitively reflect the spatial position, three-dimensional morphology and adjacent relationship of vital organs, muscles, blood vessels and bone of Chinese people. Using Unity3D, the data on CVH tomography, teaching video of first aid, images and texts of first aid teaching and model of war injury were integrated, and first-aid teaching software applicable to the battlefield was developed (Figure 3-6). This provided a training platform for trainees with good interactive anatomy teaching function, which controlled the functions of a concealable anatomical structure display, an optional pressing point or puncture point, clues for wrong pressing or puncture point, video teaching, and contrast learning of the sectional and injury models.

The period from the beginning of the trauma to within one hour after the injury is called the “golden hour”. It is based on successive pre-hospital emergency care and in-hospital care, with the main goal of providing wounds with definitive treatment within one hour after the trauma. Limited by the battlefield environment, tactical mechanism and mobility of troops, it is difficult for wounds to obtain definitive treatment within 1 hour after injury. Self-help and mutual aid within the "platinum time" provide curative effect guarantees for evacuation and in-hospital treatment within the "golden time". Timely and accurate emergency treatment within the "platinum time" can greatly shorten the rescue time and improve the success rate of rescue, thus reducing amputation and infection caused by bleeding, hypoxia and nerve injury. Self-help and mutual aid by the warfighters themselves at the occurrence of injury are considered crucial events by the armies of all countries. The "Buddy-Buddy" care system of the British Armed Forces emphasizes the provision of assistance immediately (including the use of hemostatic bandages and tourniquets) to wounded colleagues in combat units[2]. In the US Army, Echelon I of Echelon levels of military medical care includes a medic, self aid, buddy aid and battalion aid station[12]. TCCC guidelines of the U.S. Army simplify battlefield care into three phases. In the first phase, "Care under Fire", a tourniquet should be used first to control bleeding, rather than directly applying pressure or using hemostatic dressings [12]. Combat casualties treated with emergency tourniquets have a higher survival rate and a lower incidence rate[13]. However, Avishai Michael Tsur pointed out that the conventional training of tourniquet use did not improve the success rate of tourniquet use by non-medical personnel, with incorrect placement positions accounting for 62.30 of the failure cases. Lack of comprehension, flawed basic skills and skill acquisition might affect the training effect under combat pressure [14]. Therefore, correctly grasping the site, anatomy and adjacent spatial relationship of the bleeding point is crucial. Most warfighters do not have a medical background. If medical training is needed, problems such as a long training period and high cost will occur. Our virtual simulation training software helps to sort out and simplify the knowledge related to self-help and mutual aid techniques, such as anatomy, surgery, and military medicine, and helps non-medical professional soldiers understand the principle of self-help and mutual aid skills to effectively help warfighters master and correctly use the skills in a short time.

The software developed in this study provides trainees with a simulation platform for first-aid training on the battlefield with good interaction and teaching function for anatomy and positive significance to the training of first-aid techniques on the battlefield. In class, it can help trainees improve their learning efficiency and teachers improve their teaching efficiency. After class, it can help trainees independently review and consolidate the key points of first-aid technical knowledge on the battlefield.

Compared with the traditional training mode, such as medical simulation dummy, make-up wounded, sand-table exercises and animal experiments, our treatment simulation software for war injury is constructed based on CVH datasets, which can provide a realistic three-dimensional display effect of the injury, demonstrate the internal characteristics of the injury and simulate the whole treatment process. Compared with the physical data of the human body, the three-dimensional structure model created based on the segmentation of CVH datasets shows the three-dimensional morphology and adjacent spatial relationship of organs similar to the real human body for trainees and improves the realistic effect of simulation. However, the 3D effect display based on the 2D plane has some visual errors. When the view is adjusted to a certain angle, the position of the mouse click is visually within the radius of the pressure and puncture points, but the actual position of the mouse click is outside the radius of these points. VR, AR, MR and other technologies can effectively solve the problem of visual error to obtain a better 3D visual experience. This technology is one of the main development directions of medical simulation training in the future, but it is difficult to popularize in grassroots areas because of the limitations of high costs, long development cycles, high equipment requirements and complicated operation. This software has low requirements for equipment configuration and can be run on ordinary computers. Combined with the traditional first-aid training mode of war injury, it can help trainees learn and understand the anatomy knowledge related to first-aid techniques more effectively and improve the accuracy of injury judgment and proficiency of treatment operations.

War injuries have common features with traffic injury and disaster injury, of which instantaneity, mass and frequency are characteristics, and most are penetrating, blunt, blast and concussion injuries. Therefore, the experience of treatment training for war injury can be effectively applied to the treatment of traffic injury and disaster injury. Although few studies have investigated first aid provided by bystanders in traumatic situations caused by traffic accidents and disasters, Tannvik TD and Bakke HK et al.'s findings suggested that bystanders with experience of first aid training could provide better first aid than those with unknown first aid training[15, 16]. A two-level pre-hospital system in which nonprofessionally trained emergency personnel provide initial basic life support at the scene where the pre-hospital transport time is long and medical personnel provide advanced life support at the scene and during evacuation can reduce the mortality rate of trauma caused by serious road traffic accidents (RTAs)[17]. In a trauma event, the casualty or someone close to the scene is usually the first to provide emergency assistance. Therefore, training in first aid techniques of trauma should not be limited to specific professions but should be targeted at the general public, and the trained general public should be encouraged to participate in emergency rescue. The first aid training of war injury developed in this study comprises extensive knowledge of first aid techniques, which can be used in the training of military on-site treatment and that of self-help and mutual aid techniques of traffic and disaster injuries.

Benefiting from digital modeling and virtual simulation technology, this study completed the construction of the human body model and development of hemostatic treatment simulation software on the battlefield and realized the creation of the treatment atmosphere, simulation of the treatment process and multi-dimensional display of the injury and other functions. However, there are still some deficiencies in the functional richness and experience of the software. There are two main limitations:

1. This software must be further improved and enriched in terms of simulation fidelity and content. For example, adding bleeding animation, optimizing the radius range of pressing points, different pressing areas suggesting other treatment effects, and appropriate supplementation of treatment courses following emergency hemostasis (e.g., courses on bandages, tourniquets, and fixation). These problems will be improved in the subsequent development of the software.

2. The lack of real mechanical feedback is a limitation of this software that can be effectively remedied by learning from a real human body. A single training mode has difficulty meeting the requirements of satisfactory training. Therefore, various training modes, such as medical simulation dummies and wound make-up must be integrated.

Conclusion

The treatment simulation Software for War Injury developed based on the high-resolution thin-sectional anatomical images (CVH) dataset is able to help trainees to masterself-help and mutual aid skills, andto better understand the knowledge of the applied anatomical knowledge about self-help in trauma.

Abbreviations: Chinese Visible Human (CVH); Operation Enduring Freedom (OEF); Operation Iraqi Freedom (OIF); Virtual Reality (VR); Augmented Reality (AR); mixed reality (MR); Road Traffic Accidents (RTA);

Ethics approval and consent to participate: All CVH cadavers were enrolled in the body donation program of the CVH project, which follows the scientific and ethical rules of the Army Medical University (Third Military Medical University). The study was approved by the Ethics Committee of the Army Medical University (Third Military Medical University).

Consent for publication: Written informed consent for publication was obtained from all participants.

Availability of data: The datasets analyzed during the current study are not publicly available as they are part of an ongoing study.

Competing Interests: The authors declared no competing interests.

Funding: This study is supported by the Military Medical Scientific Research Program of Youth Cultivation Project (16QNP100); Project director of a basic research and frontier exploration project in Chongqing (cstc2018jcyjAX0537); Projector director of a State Natural Science Fund (31771324)

Author contributions: X Hu, Z Xu and JY Yang created the three-dimensional model of the human body, X Hu, HF Guo and Y Wu participated in the design and creation of software, L Liu, L Zhu and Y Wu participated in the design and teaching of the training course, X Hu, L Liu and Y Wu designed and wrote the paper.

Acknowledgments: Thanks to Jinan Zhong fei Technology Co. Ltd. for its help and support in the software development process

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Table 1 Questionnaire on learning satisfaction of the simulation software of hemostasis and puncture on the battlefield

number	Survey question	rms ±sd
1	This system is easy to operate and learn, and I can quickly master its usage.	4.40 ±0.608

2	The interface of this system is attractive and user-friendly.	4.49±0.675
3	The information on the three-dimensional morphology and adjacent relationship of the related anatomical structures in this system is accurate.	4.41±0.669
4	The operation information on pressing hemostasis and puncture is accurate in this system.	4.53±0.693
5	This system can help me quickly master the knowledge of applied anatomy and operation related to cricothyroid membrane puncture.	4.39±0.606
6	This system can help me quickly master the knowledge of applied anatomy and operation related to finger pressure hemostasis for lower limb hemorrhage.	4.46±0.655
7	This system can help me quickly master the knowledge of applied anatomy and operation related to finger pressure hemostasis for shoulder and arm hemorrhage.	4.54±0.615
8	This system can help me quickly master the applied anatomy knowledge and operation related to finger pressure hemostasis for forearm or upper forearm hemorrhage.	4.50±0.656
9	This system can help me quickly master the applied anatomy knowledge and operation related to finger pressure hemostasis for forehead and neck hemorrhage.	4.44±0.672
10	This system can help me quickly master the knowledge of applied anatomy and operation related to finger pressure hemostasis of facial bleeding.	4.47±0.595
11	This system can help me quickly master the knowledge of applied anatomy and	4.54±0.635

	operation related to finger pressing hemostasis of bleeding of the vertex.	
12	This system can help me quickly master the knowledge of applied anatomy and operation related to pneumothorax puncture for airway obstruction.	4.40 ±0.648
13	This system can help me quickly master the knowledge of applied anatomy and operation related to bone marrow puncture in hemorrhagic shock.	4.41 ±0.706
14	This system can effectively improve my learning initiative.	4.55 ±0.549
15	This system can effectively improve my interest in learning.	4.54 ±0.572
16	My satisfaction with this system	4.64 ±0.557
17	What are the advantages and disadvantages of this system compared with the training you have received before?	-
18	My comments and suggestions about this system	-

Figure 1. Flow chart of software construction

Figure 2. Frame diagram of treatment simulation software by hemostasis and puncture on the battlefield. A: First-level interface; B: Second-level interface; C: Third-level interface; D: Fourth-level interface.

Figure 3. Interface of the software. A. Interface of the user login. B. Interface of the module selection, providing the function of injury module selection. C. Module of learning basic knowledge of the injury. D. Interactive learning interface of the 3D digital anatomy and sectional anatomy. E. Interaction with the 3D model. F. Video teaching. G. Learning function of the sectional images. H. Learning function of CVH

and the 3D model. a. Click area of the 3D model structure control, video teaching and tips. b. Sectional image learning, CVH and 3D model learning button area.

Figure 4. Functional demonstration of the hemostasis of the foot by pressing. A. Observation of the injury. B. Pressing of the wrong position and observation of error clues. C. Transparency of the skin, observation of the injury deeply to identify the correct hemostatic pressing point. D. Selection of the correct pressing position. E. Animated demonstration of pressing and helping trainees observe the situation of vascular compression and adjacent relationship between the pressing position and injury. F. Teaching video of hemostatic pressing demonstrating the operation techniques.

Figure 5. Pressing to stop bleeding on the face. A. Observation of the injury. B. Pressing of the wrong position and observation of error clues.; C. Transparency of the observation of the injury deeply to identify the correct hemostatic pressing point. D. Selection of the correct pressing position. E. Animated demonstration of pressing and helping trainees observe the situation of vascular compression and adjacent relationship between the pressing position and injury. F. Teaching video of hemostatic pressing, demonstrating the operation techniques.

Figure 6. Bone marrow puncture. A. Observation of the injury; B. Selection of the wrong puncture position and observation of error clues. C. Transparency of the skin and observation of the injury deeply to identify the correct puncture point. D. Selection of the correct puncture position and confirmation to proceed to the next step.

E. Animated puncture demonstration to help trainees observe the angle, approach and depth of the puncture. F. Teaching video confirming the puncture point.

Figure 7. 3D-PDF interface of digital pressure hemostasis of the dorsal pedal artery and posterior tibial artery. A. Functional area of the model tree. B. Functional area of the video and image and text. C. 3D view area; D. Preset view area.