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Real Time Battlefield Casualty Care Decision Support

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ABSTRACT

The Trauma Triage Treatment and Training Decision Support (4TDS) system is designed to provide real time casualty data and trend indications to medics and clinicians in austere battlefield settings. Artificial intelligence (AI) models scan vital signs data to detect risk of internal hemorrhage, probability of need for massive transfusion, and likelihood of impending shock. Participatory design from initial development through field evaluation aligned 4TDS with needs to support Tactical Combat Casualty Cate (TCCC) and Prolonged Field Care (PFC).

Keywords: Decision support system, Artificial intelligence, Tactical combat casualty care, Prolonged field care

INTRODUCTION

Tactical Combat Casualty Care (TCCC 2012) involves care for casualties in armed conflict from one's own service and other services (i.e., U.S. Army, Air Force), allied forces, adversaries, and civilians. Medics minimize injury and preserve a casualty's life through retrieval, stabilization and documentation, transport, triage, and treatment. In the future, delays in evacuation are expected to require extended care including Prolonged Field Care (PFC WG 2015) over hours to days. Such delays can increase the potential for complications such as insufficient blood flow (shock), bloodstream infection (sepsis), internal bleeding (hemorrhage), and lead to performance of more complex treatment. Most medics have only simple equipment and essential medications and will need assistance at point of care to make decisions on how to handle more complex cases and procedures such as transfusion in an austere, remote, unsupported setting.

The Trauma Triage Treatment and Training Decision Support (4TDS) is a real-time decision support system (DSS) to monitor casualty health (Nemeth et al 2021). 4TDS includes two artificial intelligence (AI) models. One indicates the current risk of internal hemorrhage and probability of the need for a massive transfusion (more than one unit of red blood cells). The other indicates the future probability of shock. Both models rely solely on six vital signs to scan data for effects of trauma that can lead to morbidity and mortality if not detected.

The 4TDS software prototype operates on an Android smart phone or tablet configured for use in the Department of Defense (DoD) Nett Warrior program. The phone is connected to a VitalTag (Pacific Northwest National Laboratory, Richland, WA) vital signs monitor placed on a casualty at point of injury (PoI). The monitor streams real time patient vital signs, including heart rate, respiration rate, peripheral oxygen saturation (SpO2), and diastolic and systolic blood pressure. Nurses, technicians, and physicians can use the tablet to display expanded data including lab values while providing care at a Battalion Aid Station (BAS) and Field Hospital (FH). Medics who provide PFC may need to perform life-critical procedures that may not have been used for an extended period. 4TDS includes refresher training in how to perform, as well as whether to perform, such procedures.

RESEARCH DESIGN AND METHODS

The project used a triangulated multi-method approach to design, develop, and evaluate 4TDS and its algorithms. Applications for human subject research began the process with submissions to the Western Institutional Review Board (IRB) (field studies) and Mayo Clinic (shock model) and Stanford University (hemorrhage model). After IRB approvals, the applications were submitted to and approved by the Army Human Subjects Research Protection Office (HRPO).

Literature Review

A review of key TCCC publications [see Army MEDEVAC (2017), Hospital Corpsman (2019), TCCC (2012)] extracted protocols that define prehospital tasks a medic is to perform. Results formed the basis for two representations that military medical subject matter experts (SMEs) reviewed.

Rapid Prototyping

Development of quick prototypes can make initial concepts more concrete and elicit reactions to refine project direction (Woods and Dekker 2001, Hoffman et al., 2010). A workflow diagram reflected the team's expectations about how 4TDS would fit into TCCC. Use cases described in narrative form how the smart phone/vital signs sensor would be used at PoI, and how the tablet would be used at a BAS or FH. The team developed multiple examples of interface screens that detailed how the system would operate and presented them to SMEs to elicit responses about how the interface and procedures could be designed to support TCCC.

Subject Mater Expert (SME) Review

Design Requirements Review—A series of in-depth interview sessions lasting 45 to 90 minutes sought reactions to the initial rough prototypes from 17 SMEs from the Army (68W medics), Navy (Independent Duty Corpsmen), and Air Force (Independent Duty Medical Technicians). Participants had an average of 17 years of service in military medicine, including 4 deployments. Each session reviewed medic task workflow and procedures and interface examples. The SME recommendations guided prototype concept refinement.

Training Scenarios—Medics who provide TCCC and PFC may need to perform life-critical procedures (e.g., shock management, cricothyroidotomy). However, they may not be familiar with the procedure, or may not have used it for an extended period. Two SMEs shared recommendations for refresher training scenarios based on their extensive career experience providing deployed casualty care. 4TDS includes refresher training in how to perform, as well as whether to perform, such procedures.

Algorithm Development and Evaluation

Both AI models were developed in parallel with the 4TDS prototype.

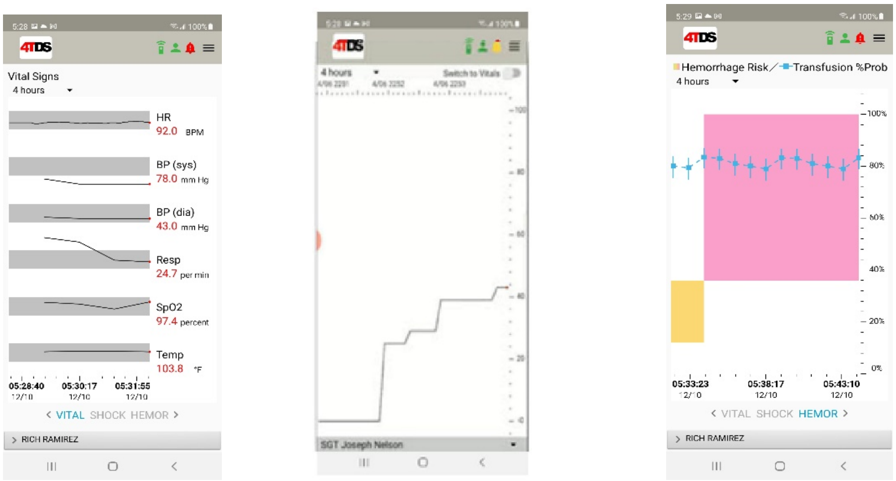
Hemorrhage Risk/Massive Transfusion Probability—The hemorrhage model indicates low, medium, or high risk of internal bleeding. The Biotechnology High Performance Computing Software Applications Institute (BHSAI) at Fort Detrick, MD developed the Automated Processing of the Physiologic Registry for Assessment of Injury Severity (APPRAISE) hemorrhage detection model, which uses standard heart rate and blood pressures vital signs and was designed to be easily interpretable and understood even by novice medics. BHSAI had previously used data retrospectively collected on adult trauma patients (>18 years old) from three independent clinical studies performed at three different sites to develop the reference for the final model of the Hemorrhage Risk Index (APPRAISE-HRI) algorithm (Reifman et al., 2015).

APPRAISE can initiate assistance from the Massive Transfusion Protocol (MTP) that incorporates several clinically relevant, immediately available data that are too complex for manual calculation at PoI. The Uniformed Services University of the Health Sciences (USUHS) developed the MTP algorithmm with Emory University from clinical findings gathered in a literature review of the Joint Traunma System (JTS) Clinical Practice Guidelines (JTS 2021) and tested in large military and civilian trauma data sets. Their neural network approach consistently proved to be sensitive, specific, and well calibrated to predict a combat casualty's the need for massive transfusion.

Shock Probability Model—The shock model was trained on Mayo Clinic Intensive Care Unit (ICU) patient data, then evaluated in a 6-month "silent test" comparing shock prediction with actual clinician diagnoses. The model only uses 6 vital signs, which is suited to battlefield care and is designed to predict shock up to 90 minutes ahead of shock onset. Model performance was evaluated using the Receiver Operating Characteristic (ROC) Curve, a plot that depicts the diagnostic ability of a binary classifier system (e.g., shock/no shock) as its criterion (discrimination threshold) is varied. Plotting the true positive rate (TPR) against the false positive rate (FPR) at various threshold settings creates a ROC. The Area Under Curve (AUC) is the percentage of randomly drawn pairs for which this is true (correctly classifies the two patients in the random pair) and represents true and false positive tradeoffs.

Protype Development

Based on results from design requirements reviews, the team used agile development (Paetsch, Eberlein, and Maurer, 2003) to program both phone



Casualty vital signs | Shock probability | Hemorrhage risk/massive transfusion probability

Figure 1: 4TDS interface screens. (Copyright © 2022 Applied Research Associates. Used by permission).

(Figure 1) and tablet interface prototypes. Repeated, recursive development of 4TDS concepts provided an early version for users and stakeholders to review and provide comments that were used to improve later versions. Prototypes demonstrated phone user interface design and function, ability to stream data from an external sensor to monitor patient vital signs, displays indicating shock probability and hemorrhage risk, training scenarios, and BAS/FH patient data displays on the tablet. Reviews made it possible to collect user responses on what 4TDS does, how it fits TCCC, and to guide improvements.

Usability Assessment/Acceptance Test

Two rounds of field assessments at Joint Base San Antonio, TX (JBSA) in December 2020/January 2021 and November 2021 enabled the team to determine user acceptance and how well use of the decision support aligned with TCCC and PFC.

4TDS/Shock Model—Twenty-eight exceptionally qualified SMEs evaluated 4TDS in December 2020 (1 USN and 23 USA) and January 2021 (4 USAF). Four different scenarios included tasks for the participant to perform. One script called for evaluating the phone interface and shock management using de-identified actual patient data. Three sought to evaluate medic and clinician use of the BAS/FH and training interfaces on the tablet. Participants used response sheets to give comments and respond to statements on a scale from 1 (strongly disagree) to 7 (strongly agree) on criteria such as suitability for prehospital care, confidence in decisions, speed finding and using information, ease of use, and more.

HDATS/MTP/VitalTag—Field evaluation in November 2021 included a range of novice through expert military healthcare providers. Forty-seven

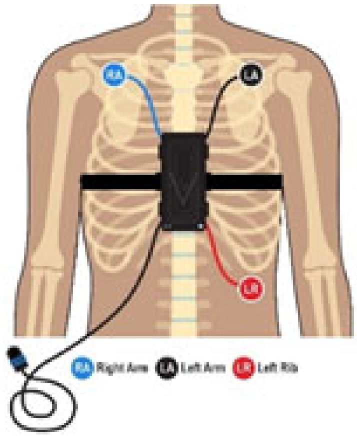


Figure 2: VitalTag sensor. (Copyright © 2022 Applied Research Associates. Used by permission).

medics from the Army, Navy, and Air Force evaluated use of the VitalTag sensor (Figure 2) and HDATS/MTP algorithm displays. Years of experience favored more junior (23) and more senior (14) medics. Participants donned the VitalTag's 3-EKG lead and SPO2 finger cuff, viewed their vital signs in real time on the 4TDS phone display, then removed the leads. Two casualties were then presented in the HDATS app in a PFC scenario, and the participant was asked to evaluate hemorrhage risk and probability of the need for a massive transfusion. Each participant provided comments and scale ratings to statements like they did in the earlier field assessment.

RESULTS

4TDS and VitalTag Sensor—Usability assessments in November 2021 with healthcare providers from the Army, Navy, and Air Force at JBSA demonstrated medics and clinicians find 4TDS and its capabilities align with TCCC/PFC practice.

Table 1 shows mean ratings for responses to statements on the user response form. A mean score of 4.0 indicates neutral on a 7-point scale. None were below 5.0.

All participants were able to accurately assess casualty condition and successfully complete the scenario. Participant comments also enabled the team to refine display and scenario details.

Shock Model—While other published results include lab tests (e.g., lactate), the 4TDS model only uses 6 vital signs, which is suited to battlefield care in an austere setting. Test results produced a receiver operating characteristic (ROC) curve of 0.83 at shock onset and decreased to 0.78 when detecting shock 90 minutes ahead of onset. Medics had indicated during the Design Requirements Review that a 30-minute advance warning would be more than sufficient to initiate preventive care.

Hemorrhage Risk Model/Massive Transfusion Probability—Validation tests use data from both Stanford University Medicine and Linking

Table 1. November 2021 sample mean ratings (Nemeth, et al.2022).

Mean rating	
	Hemorrhage Risk
6.2	The HDATS hemorrhage risk display fits with TCCC practice
6.1	The display is useful as a way to gauge the risk of hemorrhage
5.4	I am better prepared to manage hemorrhage in a casualty using this display.
5.6	I am confident about my patient care decisions using the HDATS hemorrhage risk display
	Transfusion Probability
5.9	The massive transfusion probability display fits with TCCC practice
5.8	The display is useful as a way to gauge the need for a massive transfusion
5.5	I am better prepared to manage massive transfusion in a casualty using this display
5.6	I am confident about my patient care decisions using the massive transfusion display
	The 4TDS App/Sensor
6.0	Use of 4TDS fits with TCCC practice
5.8	The Vital Tag sensor was easy to use
5.6	The 4TDS smartphone app was easy to use
5.8	Using the 4TDS smartphone app, I could ***find*** the information I needed to make a decision
5.6	Using the 4TDS smartphone app, I could find the information I needed to make a decision ***quickly***
	Comparison
5.4	I can find the information I need *more* ***easily*** in HDATS than I can using current tools.
5.4	I can find the information I need *more* ***quickly*** in HDATS than I can using current tools.
5.5	HDATS better supports the way I do my work than current tools (*e.g., checklists, blood pressure cuff*)
5.1	I would feel *more* ***confident*** making future clinical decisions using HDATS than using current tools
5.0	HDATS supports *the way I do my work* better than current tools

Investigations from Trauma and Emergency Services (LITES 2021). Successful demonstration of APPRAISE should result in the 95% CI upper bound LR for HRI I < 0.60 and the 95% CI lower bound LR for HRI III >2.0. These results would also demonstrate that the 95% CI upper bound LR for HRI I < the 95% CI lower bound LR for HRI II and the 95% CI upper bound LR for HRI II < the 95% CI lower bound LR for HRI III.

CONCLUSION

Participatory design ensured 4TDS and its AI models reflected medic and clinician mental models and work processes. It also built support among potential users should the system transition to operational use. Consultation with TCCC and PFC SMEs during training and interface development ensured close alignment with both standard of care and practical considerations of actual care in the field. Usability assessments with healthcare providers from the Army, Navy, and Air Force at Joint Base San Antonio, TX confirmed 4TDS and its capabilities align with TCCC practice.

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