Augmented Reality and Telestrated Surgical Support for Point of Injury Combat Casualty Care: A Feasibility Study

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Abstract. Providing surgical care in remote environments presents a significant challenge. Telepresence and telesurgery have the potential to bridge the gap between definitive care and nonsurgical critical care for prolonged field care scenarios. This feasibility study investigated several key questions regarding the suitability of these technologies for this application. First, what are the technology requirements and minimum specifications for telestration capabilities between a surgical specialist at a Medical Treatment Facility and a remote non-surgeon in a far-forward environment using existing telecommunication systems within the US Army? Second, what training requirements are needed to prepare surgeons and non-surgeons to control lower extremity junctional hemorrhage, and to use associated telestration hardware, software and communications systems? Third, what is the transferability of this training paradigm and technology suite to a wider range of medical care and clinical procedural skills to anticipated future military medical care needs and environments? Our initial feasibility study indicates that telementoring and telestration using augmented reality (AR) systems appears well suited to providing surgical support and training across dispersed groups of medical providers. Forward surgical support using AR and telestration technologies are viable for point of injury surgical support and may be essential to filling this "missing middle" in the Combat Casualty Care continuum. We anticipate that the life and limb saving capabilities supported by this approach will be necessary in future Multi-Domain Battlefield Concept and in cases of remote and dispersed operations.

Keywords: Augmented reality · Telestration · Telementoring Modeling · Simulation · Combat casualty care

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1 Introduction

Providing surgical care in remote environments presents a significant challenge. Dispersed medical operations and Anti-Access/Area Denial environments place casualties at risk of extended delays to forward surgical care sites. Postponed surgical care exposes casualties to avoidable suffering, loss of function or even loss of life [1]. Delayed emergency surgical care increases complications to damaged tissue and infection rates [2]. Unnecessary complications increase the cost of providing care to wounded service members [3]. Far-forward telestrated surgery support promises to mitigate these risks by stabilizing combat trauma in situations where this care would otherwise not be available.

Military trauma treatment has shown remarkable improvement in survival rates from World War II through Operations Enduring and Iraqi Freedom, where "died of wounds" rates decreased from 19% to 9%. Much of the recent improvement in survival is attributable to the liberal use of tourniquets and to rapid evacuation from the point of injury to locations offering damage control surgery. Although tension pneumothorax and airway compromise are in the top three causes of preventable death on the battlefield, hemorrhage remains the top cause of preventable casualty death [4]. Current and anticipated military operating environments threaten access to the forward surgical care necessary for damage control surgery that controls this hemorrhage. The lack of sufficient forward surgical resources has emerged as a critical capability gap.

The current U.S. military situation involves lower numbers of troops dispersed over a vast operating area. Additionally, near peer military rivals threaten U.S. air supremacy and military overmatch to the point that Area Denial and Anti-Access environments are expected in future conflicts [5]. Currently, Special Operation Forces in Africa operate across such great distances that providing rapid access to a field surgical facility is impossible in many cases. These military factors lead to the anticipation that many future casualties will need aspects of their initial damage control interventions, including some surgical procedures and intensive resuscitation, performed in the field. Telemedicine and telepresence promise the ability to move subspecialty resuscitation far forward to field units that are too separated geographically or too dangerous due to enemy activity [6].

Telepresence and telesurgery have the potential to bridge the gap between definitive care and nonsurgical critical care for prolonged field care scenarios. AR telementoring for surgery has been demonstrated to be effective for craniotomy and for carotid endarterectomy on cadavers [7]. The first transatlantic telerobotic surgery was performed in 2002 by a surgeon in New York City who removed the gallbladder on a patient in France [8]. Remote telerobotic proctoring was shown to be effective for life and limb saving procedures on cadavers between specialty surgeons and residents [9]. We anticipate that the life and limb saving capabilities augmented by these technologies will be necessary in the approaching Area Denial and Anti-Access environments. U.S. Special Operations Forces are already requesting these capabilities for their operational needs.

For the reasons and rationale stated previously, our research team reviewed potential candidate systems to begin to bridge this surgical capability gap. A concept of operations (see Fig. 1) was developed to provide a high-level view of the capability need and guide research and development of forward surgical support solutions. A demonstration study was conducted to evaluate candidate technologies, training requirements, and process model testing, leading to a focused research investigation into the effectiveness of AR and telestrated surgical support for point of injury combat casualty care.

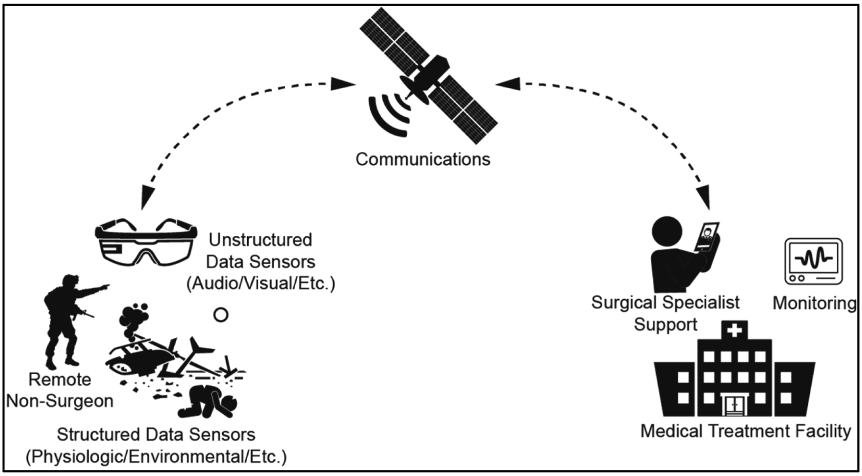

Fig. 1. Augmented reality forward surgical support concept of operations

2 Methods

An active-duty staff U.S. Army orthopaedic surgeon guided a U.S. Navy Physician Assistant (PA) through anterior exposure of the common femoral and external iliac arteries on a realistic surgical manikin using an AR wearable display. The surgeon was in a separate building, so he could not be seen or heard by the PA performing the procedure. The surgeon communicated with the PA using a Windows based personal computer with bidirectional voice communications and full motion video broadcast from the AR glasses. The PA used the AR glasses for all communication with the surgeon. The surgeon used the telestration capability of the glasses to superimpose instructions on the PA's visual field. These instructions appeared in the PA's surgical field, superimposed on the anatomy of the hyper-realistic surgical manikin. The telestrated instructions and voice communications were used to guide the PA through this damage control procedure.

Osterhout Design Group (ODG) R-7 Smartglasses (San Francisco, CA), a lightweight wearable on-visual-axis display, were furnished by BioMojo LLC (Cary, NC) with preloaded Librestream (Winnipeg, Manitoba, Canada) "Onsite Connect" telestration software and NuEyes® (Newport Beach, CA) magnification kits. The glasses were connected to a desktop workstation in a nearby building using an available wireless network. Surgical kits used were typical of what is available in a field surgery setting. Forceps, Mayo scissors, Metzenbaum scissors, ring forceps, scalpels, Army-Navy retractors and Weitlaner retractors were available for the PA to use during the procedure. An Operative Experience Inc. (North East, MD) realistic anatomically correct manikin was used to simulate the anatomy and injury of a high femoral gunshot wound. A training classroom from the Fort Bragg Medical Simulation Training Center was mocked-up to represent an austere medical care environment. The PA and an additional nonsurgical assistant wore surgical gloves only for simulation purposes, as no infection control issues were presented by the manikin.

Prior to performing the procedure, the PA underwent crawl-walk-run pre-training sessions. The surgeon and PA received training with the ODG-R7 glasses (see Fig. 2). The training also contained a review of the indications, anatomy and technique for the procedure (see Fig. 3). These training sessions were performed to simulate actual training that would be conducted for selected telestration procedures if this technology were applied in a real-world situation. Other procedures selected could be fasciotomy and craniotomy.

Fig. 2. Technology training focusing on human interface with visualization and communication hardware and software. (Photo Credit: U.S. Army photo by Eve Meinhardt)

2.1 Feasibility Testing and Verification

Intensive, focused education and simulation-based training on anterior approach to the external iliac artery was provided. Verification of surgical skill competence was assessed on a newly developed surgical manikin. The PA and Surgeon were trained to perform the procedure while wearing the head-mounted display, to develop understanding and use of the augmented reality and telestration technologies. The team practiced the procedure, using the remote support technologies repetitively to assure

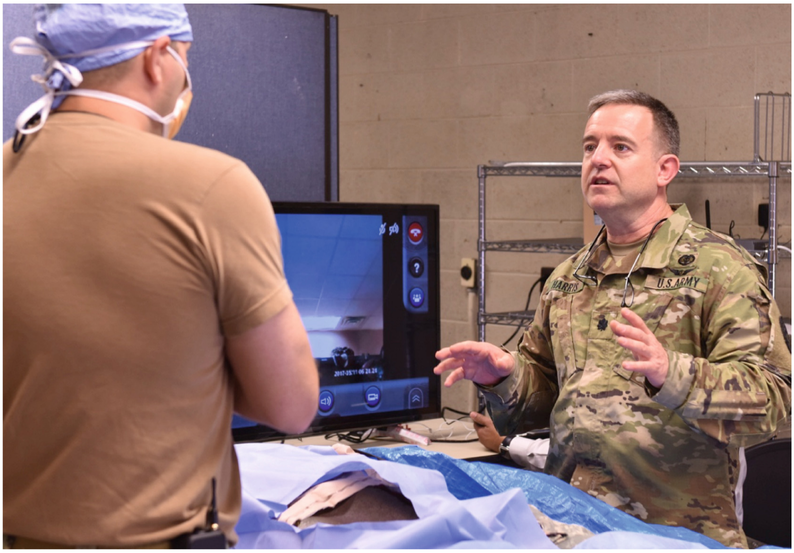

Fig. 3. Simulation-based procedural training between surgeon and non-surgeon. (Photo Credit: U.S. Army photo by Eve Meinhardt)

mastery of both the technology and procedure. Feasibility was assessed by a final demonstration and assessment in a simulated environment representing a remote, improvised surgical environment with a non-surgeon operator and a surgical specialist at a separate location.

2.2 Technical and Human Factors

Technical and human factors assessments will be conducted to evaluate the application, role and appropriateness of this surgical telestration and augmented reality capability. Assessments will be conducted to evaluate the usability of the system, workload and the comfort/confidence of the telestrating surgeon and the operating non-surgeon. Areas of assessment will include usability, ease of procedure, task load assessment, safety, efficiency, and operative time. Additional qualitative data will be collected through participant interviews and free-response instruments. Since this is an integration study we do not plan a control group.

Successful performance of this study and data analysis will guide submission of performance improvement strategies and follow-on studies that include field environment settings and a list of procedures considered by the United States Army Special Operations Command Deputy Chief of Staff-Surgeon. This list includes deep vessel access for control of junctional hemorrhage, abdominal cavity packing with temporary closure, upper extremity fasciotomies, lower extremity fasciotomies, advanced burn care resuscitation, burr hole craniotomy, resuscitative endovascular balloon occlusion of the aorta, external fixator placement, extremity vascular repair with shunt placement, and open fracture irrigation with debridement.

The feasibility study will focus on Navy Independent Duty Corpsman, Army Special Forces medics, Air Force Para-Rescue Jumpers and equivalents for the non-surgeon operators. These individuals are targeted for this study as they are prepared to provide medical services in austere environments, without ancillary, physician, logistic or medical evacuation support [10]. The surgical specialists will be recruited from military treatment facilities surgical specialties. Since this is a feasibility study we do not plan a control group. However, future studies will use control groups and additional procedures to deeply investigate telestrated surgery for study on human patients.

3 Results

Using AR, the surgeon remotely guided (see Fig. 4) the PA via telestration through anterior exposure of the femoral artery and external Iliac arteries (see Fig. 5). An additional non-surgeon held retractors, functioning as a surgical assistant. The surgical assistant only took direction from the PA and did not offer any guidance. The PA performed exposure and clamping of the proximal common femoral artery, which represented success for this procedure.

Fig. 4. Surgical specialist operating telestration console to guide anterior exposure of the femoral artery for bleeding control by a non-surgeon at a remote location. (Photo Credit: U.S. Army photo by Eve Meinhardt)

We successfully demonstrated a simulated, proof-of-concept use of lightweight wearable on-visual-axis display for surgical control. The PA/remote surgeon team, using augmented reality and telestration, were able to successfully perform junctional hemorrhage control, demonstrating the ability to project on-time, on-demand surgical expertise in a forward environment.

Fig. 5. U.S. Navy PA performing anterior exposure of the common femoral and external iliac arteries on a realistic surgical manikin using a wearable display with AR telestration connected to a remote surgical specialist. (Photo Credit: U.S. Army photo by Eve Meinhardt)

4 Discussion

Current military medical studies show there is a clear need for surgical capabilities within 60 min of injury in most deployed locations, regardless of how basic this capability may be [11]. Military medical specialists are in increasing need to perform damage control procedures to far forward environments when timely access to in-person surgical care is not possible due to distance or tactical considerations. Surgeons cannot be present in the far-forward area with each operational detachment team, increasing the need for advanced medical training and supportive telementoring and telestration technologies for specialized military medical care providers.

Telemedicine is defined as a set of medical practices without direct physician-patient interaction, via interactive audio-video communication channel employing tele-electronic devices [12]. Telestration, is defined as a technique for drawing freehand annotations over an image or video. Telestration has been found to be an essential functionality of telementoring systems [13]. An increasing body of knowledge is investigating the use of telementoring and telestration [12, 14, 15]. Telementoring has been reported in this literature as a natural fit in surgery demonstrating improved surgical practice, education, treatment and postoperative care [14]. While there has been much investigation into the technologies, cost effectiveness and safety of telementoring and telemedicine, there is little evidence regarding the rigorous study of clinical and educational outcomes [14]. The educational aspects of telestrated surgical support using augmented reality are a key focus of this study.

Telemedicine has advanced substantially from its initial use of telephone conversations to current advanced, real-time videoconferencing equipment, telementoring and telestration making it well suited to supporting a means of transferring surgical knowledge across geographically dispersed individuals [15]. Advances in visualization and communication technologies offers the opportunity to train, equip and connect non-surgeon military medical providers with remote surgical experts to provide high quality emergency surgical care to far forward remote areas where access to evacuation to advanced surgical expertise may not be immediately available. However, clinical, user and mentor, technological and future research aspects of telementoring and telestration require further investigation and development.

In telestration-supported surgery, supervising surgeons draw or place virtual instruments on a device held over or remotely located to demonstrate procedures to assisted surgeons. The drawings or devices then appear superimposed on the surgical field, demonstrating procedural steps or important anatomy. Many current technologies present telestrated information off the central visual axis requiring the operative surgeon to look away from the operative field, compromising visual orientation for open procedures. Other devices held over the surgical field impair direct visualization of the field, degrading depth perception from loss of stereopsis. The size, weight, and requirement for fixed positioning further limits the field utility of these devices. We have demonstrated the use of a new lightweight wearable display with improved telestration capability to explore the feasibility of projecting surgical expertise forward in a field-able commercial-off-the-shelf device.

5 Future Directions

The next phases of our research and development of telestration for forward surgical support and telementoring will focus on evaluating the clinical benefits of these technologies on surgical interventions (including accuracy of clinical procedural skill performance as compared to telestrated targets, task completion and duration, and levels of mentoring and telestration required for procedure completion), educational benefits of the training programs and processes, quality of telestration and telementoring, and user satisfaction with both the remote telementoring and telestration aspects, and human-computer aspects. A mixed methods study has thus been designed to accomplish this purpose. This protocol was developed to evaluate the following aspects of providing surgical support to remote environments:

1. Technology requirements and minimum specifications for telestration capabilities between a surgical specialist at a Medical Treatment Facility and a remote non-surgeon in a far-forward environment using existing telecommunication systems within the US Army.
2. Training requirements to prepare surgeons and non-surgeons to control lower extremity junctional hemorrhage, and to use associated telestration hardware, software and communications systems.
3. Transferability of this training paradigm and technology suite to a wide range of medical care and clinical procedural skills to anticipated future military medical care needs and environments.

5.1 Training Protocol

A "Mastery Learning" model approach [16] will be employed to train and assess the surgical procedural skill performance of trainees (non-surgeons) and trainers (surgeons). Two surgical skills, anterior exposure of the femoral artery for bleeding control, and four-compartment fasciotomy, are the targeted procedures for the second phase of this project. The American College of Surgeons, Advanced Surgical Skills for Exposure in Trauma (ASSET) curriculum [17] will be used to teach the candidate surgical procedures.

The essential steps of this model include the following:

1. Establishment of a minimum passing mastery standard for each surgical procedural task, based on evidence-based or best practice standards,
2. Baseline assessment to determine appropriate level of difficulty of initial training activity needs,
3. Establishment of clear learning objectives, and performance indicators, sequenced as units ordered by increasing difficulty,
4. Engagement in training activities (e.g. skills practice, data interpretation) that are focused on reaching the objectives, and performance indicators,
5. Formative assessment and feedback to gauge surgical procedural task completion at the defined minimum mastery standard (e.g., repetitive error-free performance),
6. Advancement to the next surgical procedural training task when repeated measured performance meets or exceeds the standard, or
7. Continued practice or study on the surgical procedural training task until the mastery standard is reached.

This feasibility study will focus on Navy Independent Duty Corpsman, Army Special Forces medics, Air Force Para-Rescue Jumpers and equivalents for the non-surgeon operators. These individuals are targeted for this study as they are prepared to provide medical services in austere environments, without ancillary, physician, logistic or medical evacuation support [10]. The surgical specialists will be recruited from MTF surgical specialties. Since this is a feasibility study we do not plan a control group. However, future studies will use control groups and additional procedures to deeply investigate telestrated surgery for study on human patients.

Once surgeons and non-surgeons have completed the training component and achieved the mastery standard, they will advance to the surgical telestration environment and participate in technology training and simulation-based telestration scenarios focused on the surgical procedural training tasks. Simulation-based surgical telestration performance will be compared to the mastery learning training model and performance standard to evaluate the reliability (accuracy and consistency) of this model, as well as retention and transfer of training to the simulated environment.

6 Conclusions

Telementoring and telestration using AR systems appears well suited to providing surgical support and training across dispersed groups of medical providers. Forward surgical support using augmented reality and telestration technologies are viable for point of injury surgical support and may be essential to filling this “missing middle” in the Combat Casualty Care continuum. We anticipate that the life and limb saving capabilities supported by this approach will be necessary in future Multi-Domain Battlefield Concept and in cases of remote and dispersed operations. Continued rigorous investigation is needed to ensure safe and appropriate medical care in this environment as well as to inform the development and improvement of new and future technologies to support this capability.

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