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# The marriage of surgical simulation and telementoring for damage-control surgical training of operational first responders: A pilot study

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**BACKGROUND:** Hemorrhage is the leading cause of preventable posttraumatic death. Many such deaths may be potentially salvageable with remote damage-control surgical interventions. As recent innovations in information technology enable remote specialist support to point-of-care providers, advanced interventions, such as remote damage-control surgery, may be possible in remote settings.

**METHODS:** An anatomically realistic perfused surgical training mannequin with intrinsic fluid loss measurements (the "Cut Suit") was used to study perihepatic packing with massive liver hemorrhage. The primary outcome was loss of simulated blood (water) during six stages, namely, incision, retraction, direction, identification, packing, and postpacking. Six fully credentialed surgeons performed the same task as 12 military medical technicians who were randomized to remotely telementored (RTM) (n = 7) or unmentored (UTM) (n=5) real-time guidance by a trauma surgeon.

**RESULTS:** There were no significant differences in fluid loss between the surgeons and the UTM group or between the UTM and RTM groups. However, when comparing the RTM group with the surgeons, there was significantly more total fluid loss ($p = 0.001$) and greater loss during the identification ($p = 0.002$), retraction ($p = 0.035$), direction ($p = 0.014$), and packing($p = 0.022$) stages. There were no significant differences in fluid loss after packing between the groups despite differences in the number of sponges used; RTM group used more sponges than the surgeons and significantly more than the UTM group ($p = 0.048$). However, mentoring significantly increased self-assessed nonsurgeon procedural confidence ($p = 0.004$).

**CONCLUSION:** Perihepatic packing of an exsanguinating liver hemorrhage model was readily performed by military medical technicians after a focused briefing. While real-time telementoring did not improve fluid loss, it significantly increased nonsurgeon procedural confidence, which may augment the feasibility of the concept by allowing them to undertake psychologically daunting procedures. (*J Trauma Acute Care Surg*. 2015;79: 741–747. Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.)

**KEY WORDS:** Operational medicine; tactical medicine; telemedicine; damage-control surgery; surgical simulation.

Most battlefield casualties die of their injuries before ever reaching a surgeon.[1–3] Before recent conflicts in Iraq and Afghanistan, studies found that traumatic hemorrhage resulted in more than 50% of all battlefield deaths.[2] However, these recent conflicts have been characterized by a different type of warfare, asymmetric warfare against nontraditional combatants and small unit engagements instead of the set piece battles of the last century.[1] As a result, hemorrhagic deaths have become even more prominent. Eastridge et al.[1] reported that during Operation Iraqi Freedom and Operation Enduring Freedom, 87% of all battlefield injury fatalities occurred in the pre–medical treatment facility environment. Most (67%) of these were truncal injuries, with extremity (14%) and junctional (19%) injuries being less common sites.[1] Much progress has been made in addressing both extremity and junctional hemorrhage, including improvements in techniques, system design, and pharmacology.[4–6] With the aggressive training and dissemination of tourniquet use, an 85% decrease in peripheral extremity hemorrhage mortality has been documented.[1] While junctional hemorrhage has been long considered a treatment gap in hemorrhage control, much attention and energy has been directed to addressing this challenge with a number of novel devices being introduced and trialed such as the Combat Ready Clamp (CRoC)[7] and the iTClamp.[8] However, there

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**Figure 1.** Remote mentor's screen illustrating the surgical simulator as viewed through the MedTechs head-mounted camera.

has been limited progress in developing techniques to control exsanguinating truncal hemorrhage in the pre–medical treatment facility environment, other than admonitions to decrease the time from point of injury to surgical intervention.[1]

Damage-control surgery refers to abbreviated techniques used when either the patient's physiologic reserve or the "local capabilities" of a care setting are inadequate.[9,10] Placing packs around bleeding solid organs and leaving the abdomen open are basic elements of damage-control surgery. Recently, remote damage-control resuscitation (RDCR) has been conceived as a method of extending damage-control principles to point of injury.[11] Of all the important concepts embraced by RDCR, control of compressible hemorrhage and rapid surgical control of bleeding are the most difficult to achieve in the prehospital setting. However, we believe that these concepts require urgent study. In terms of mechanics, performing a laparotomy by incising the anterior abdominal wall to access the peritoneal cavity is technically practical especially in healthy young subjects with normal to lean body mass and no previous surgery.[12] Nonphysicians have been previously reported to perform this successfully,[13] although this would be predicted to be very intimidating and stressful to a nonsurgeon. It is possible, however, that recent information technology advances may facilitate this.

Telemedicine is defined as providing medicine at a distance.[14] Remote telementoring is a specific telemedical technique wherein a remote expert is able to guide a novice in performing medical procedures outside his or her normal scope of practice in an urgent medical situation, using information technology.[15] Remote telementoring has global applications, essentially enabling providers to deliver advanced medical care via remote guidance anywhere on (or above the) earth, which has internet connectivity or satellite coverage.[16–19] Much work in this area has already been done by NASA investigators, who have successfully demonstrated the ability to remotely telementor emergency ultrasound examinations.[20,21] Furthermore, reports of the telementoring of surgical procedures have described there being no obvious differences in skill acquisition among telementored versus locally mentored surgeons.[22,23] Thus, we sought to explore the practicalities of mentoring surgically naive but motivated first responders to perform damage-control laparotomies and packing of exsanguinating liver injuries as a means of obtaining surgical control of truncal injuries in austere circumstances.

## PATIENTS AND METHODS

Ethical approval for this study was obtained from the University of Calgary (REB14-0634) and the National Research Council of Canada. This was a randomized nonblinded trial where medical technicians (MedTechs) in the Canadian Armed Forces were randomized to perform a trauma laparotomy with or without telementoring on a human patient simulator.

### Study Participants

All participants were volunteers who were free to withdraw from the study at any time without consequence. Military MedTechs were recruited from the 1 Canadian Field Hospital, a national-level element that reports directly to the Canadian Forces Health Services and provides deployable tertiary-level medical and surgical assets in support of the Canadian Armed Forces. A separate control group of fully credentialed surgeons performed the same task as military MedTechs to establish a benchmark for the primary outcomes of the study. None of these surgeons were telementored.

### Independent Variable

MedTechs were randomized to an unmentored (n = 5) (UTM) or remotely telementored (n = 7) (RTM) group, which included real-time guidance by a trauma surgeon. Those allocated to the RTM group received continuous instructions and feedback from an experienced trauma surgeon with previous telementoring experience.

### Equipment and Methods

Mentored MedTechs wore a USB audio headset with built-in microphone (Logitech, Romanel-sur-Morges, Switzerland) and wore a head-mounted 1.3-Megapixel video camera (Logitech Webcam 2 Megapixel Autofocus, Karl-Zeiss lens 2.0/3.7, Lausanne, Switzerland), which captured their point of view of the operative procedures required. This video capture was thereafter displayed on the mentor's laptop computer (HP Probook 4520s, Hewlett Packard, Palo Alto, CA) through the use of Skype (Luxembourg City, Luxembourg), which provided for one-way visual and two-way audio communication over an encrypted Internet connection (Fig. 1). All study procedures were conducted in a ground floor room of a research building for all mentored procedures, with the remote mentor residing within a separate room on a separate floor of the same building using the internal wireless network.

### Outcome

The primary outcome was "simulated blood loss" during a staged laparotomy on a surgical simulator with fluid loss measurement capabilities.

**TABLE 1.** Compartmentalized Stages of the Standardized Laparotomy and Hepatic Packing

| Surgical Task | Goal | Objective Evaluation |
|---|---|---|
| Incision | Open the abdominal cavity without inadvertent visceral injury | Completely open (y/n) If incomplete, (%) open |
| Retraction | Insertion of a self-retaining surgical retractor | Placed correctly (y/n) |
| Direction | Direction of a surgical assist to place and manipulate a handheld abdominal retractor to augment visualization. | Visualization augmented (y/n) |
| Identification | Correctly identify the site of surgical bleeding | Site of bleeding correctly identified (y/n) |
| Hemostasis | Control of the visceral bleeding through the manual application of gauze sponges | The volume of shed fluid for 60 s after completion of the packing phase |
| Closure | Performance of a skin-only suture closure | Completely closed (y/n) If incomplete, (%) closed |

## Surgical Task

All participants were asked to perform a laparotomy with midline incision into the peritoneal cavity followed by sponge packing of an exsanguinating liver hemorrhage (see Video, Supplemental Digital Content 1, http://links.lww.com/TA/A630). These surgical tasks were performed on the torso and viscera of a customized "Cut Suit" Human Worn Partial Task Surgical Simulator (Strategic Operations, San Diego, CA), without a human actor. The standardized laparotomy was compartmentalized into six different phases, each with a 60-second time limit, with specific objective goals to be accomplished within each task (Table 1). This compartmentalization was intended to allow study of the various subtasks required within the overall laparotomy and to facilitate comparisons with future studies in the weightless windows of parabolic flight. The primary outcome was the amount of fluid loss for 60 seconds after the hemostasis phase.

The specially modified Cut Suit torso was equipped with a sensitive fluid flow meter that recorded both total fluid loss and fluid loss velocities and was equipped with a remote control fob for accurate measurement of simulated hemorrhage (Fig. 2). The pressure setting of the Cut Suit pump was consistently set to the maximum flow rate of 12 psi (82.74 kPa). A senior surgeon (university professor and former command military surgeon) acted as a dual surgical assistant and safety surgeon for all participants. He was instructed to assist only as requested by the UTM MedTechs and surgeons and responded only to remote direction from the mentor for the RTM cohort of MedTechs. He did not handle any instruments or packs and only retracted as directed. He had, however, the authority to terminate all procedures by any participant he felt potentially unsafe.

## Randomization

After enrollment but before group allocation, all participants (including surgeons) were given a standardized introduction to the study, which included an introduction to damage-control surgery, the Cut Suit surgical trainer, and a tutorial on the basics of visceral packing for hemorrhage control (see Supplemental Digital Content 2, http://links.lww.com/TA/A631). After responding to questions and reinforcing the teaching, MedTechs were then randomized through random number generation to either laparotomy without telementoring (UTM) or laparotomy with remote telementoring (RTM).

The detailed study protocol is available online (see Supplemental Digital Content 3, http://links.lww.com/TA/A632). Prestudy questionnaires concerning demographics and previous surgical experience was administered to all participants (see

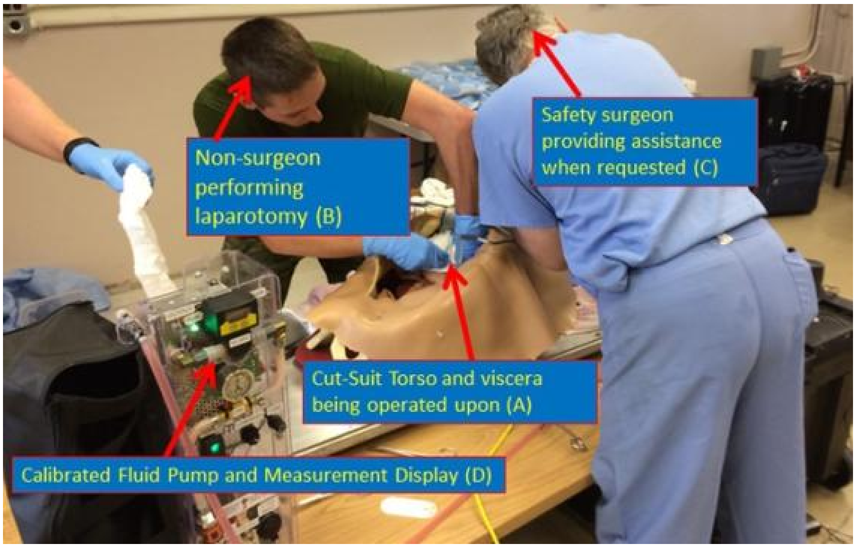


**Figure 2.** Simulated surgical suite for damage-control laparotomy and perihepatic packing. The torso and viscera of a customized Cut Suit (*A*) is being operated on by a nonsurgeon (*B*). Assistance is being provided only after a direct request from the experienced "safety surgeon" (*C*). Fluid loss representing the degree of massive hemorrhage is being measured by the calibrated fluid pump (*D*).

**TABLE 2.** Study Group Performance During Simulated Laparotomy and Hepatic Packing

| Task | Surgeons Median (IQR) | RMT Median (IQR) | UTM Median (IQR) |
|---|---|---|---|
| Incision fluid loss, mL | 303 (397) | 669 (400) | 444 (463) |
| Incision time, s | 23.97 (27.87) | 57.53 (28.44) | 34.38 (34.10) |
| Incision visceral Injury | 0 | 0 | 0 |
| Retraction time, s | 7.72 (22.43) | 20.50 (10.11) | 11.08 (22.68) |
| Retraction fluid loss, mL | 88 (291) | 255 (141) | 151 (291) |
| Direction time, s | 6.27 (6.55) | 11.25 (10.82) | 8.03 (12.15) |
| Direction fluid loss, mL | 73 (50) | 150 (126) | 108 (165) |
| Identification time, s | 3.33 (5.26) | 6.21 (26.18) | 4.63 (4.71) |
| Identification fluid loss, mL | 51 (87) | 58 (50) | 81 (354) |
| Packing time, s | 34.19 (40.20) | 60 (6.14) | 49.93 (28.84) |
| No. sponges | 7 (10) | 9 (7) | 5 (8) |
| Packing fluid loss, mL | 454 (552) | 785 (128) | 666 (350) |
| After packing fluid loss, mL | 801 (48) | 770 (210) | 790 (70) |
| Percentage skin incision closed | 0.19 (.22) | 0 (.09) | 0 (.03) |
| Total fluid loss, mL | 1,819 (675) | 2,721 (922) | 2,144 (874) |

Supplemental Digital Content 4, http://links.lww.com/TA/A633), as were posttest questionnaires (see Supplemental Digital Content 5, http://links.lww.com/TA/A634).

## RESULTS

Six credentialed surgeons and 12 MedTechs were recruited. The MedTechs were randomized to unmentored (n = 5) (UTM) or remotely telementored (n = 7) (RTM) real-time guidance by a trauma surgeon. When comparing age and sex among the three groups, there was no significant difference. RTMs were mostly male, 5 (71.4%) of 7, and had a mean (SD) age of 32 (7) years. The UTM also consisted mainly of males, with 80% (4 of 5) being men. The mean (SD) age for the UTM was 31 (11) years. The surgeon group was mostly men (5 of 6, 83.3%), with a mean (SD) age of 37 (7) years. None of the MedTechs had a valid license to practice surgery or had training on intra-abdominal surgery, although the majority (12 of 13) had advanced trauma training such as Advanced Trauma Life Support. All of the surgeons in the study possessed a valid specialty certification from the Royal College of Physicians and Surgeons of Canada and held an independent license to practice surgery in a province of Canada. Moreover, all of the surgeons had been trained on intra-abdominal surgery, had taken advanced trauma training, and had been trained in and performed trauma laparotomies. Detailed specific procedure-related training that was captured is presented in Supplemental Digital Content 6 (http://links.lww.com/TA/A635).

All participants, notably all the MedTechs, were able to perform all steps of the trauma laparotomy and to place hemostatic packs around the liver. There were no instances that were considered unsafe by the safety surgeon, and no procedures required termination. However, no participant was able to complete the skin closure within 1 minute. The overall fluid lost by the surgeons was a mean of 1,819 mL, versus 2,144 mL for the UTM and 2,721 mL for the RTM MedTechs (Tables 2 and 3). This was significantly different between surgeons and RTM MedTechs ($p$ = 0.005), but not between surgeons and UTM MedTechs ($p$ = 1.000) or between the two groups of MedTechs ($p$ = 0.432). When comparing surgeons with the RTM group, there was significantly greater loss during the identification ($p$ = 0.002), retraction ($p$ = 0.035), direction ($p$ = 0.014), and packing ($p$ = 0.022) stages. There were no significant differences in fluid loss after packing between the groups despite differences in the number of sponges used. The RTM MedTechs used more sponges under direction than surgeons and significantly more than UTM MedTechs ($p$ = 0.048).

Mentoring significantly increased nonsurgeon procedural confidence when asked if damage-control laparotomy was a realistic task for them to perform ($p$ = 0.030), if they felt confident in their current abilities to perform a damage-control laparotomy ($p$ = 0.004), and if damage-control laparotomy would be less dangerous for the patient than beneficial in their hands ($p$ = 0.004) for the RTM MedTechs compared with the UTM MedTechs. Surgeons were significantly more confident in their current ability to perform a damage-control laparotomy when compared with either RMT ($p$ = 0.002) or UTM ($p$ = 0.004) groups. The telementored group also felt strongly that telementoring was beneficial. When asked if they would want to be telementored again if they were asked to perform another laparotomy or if telementoring would increase their confidence when performing another laparotomy, subjects strongly agreed, answering a median of 5 of 5 on a Likert scale. When asked if telementoring would decrease their stress when performing another laparotomy, mentored subjects felt it would help, answering a median of 4 of 5 on the same scale (Table 2).

## DISCUSSION

The Cut Suit is an anatomically accurate simulator that can be safely worn by humans and allows for the performance of a variety of complex, realistic surgeries and procedures as encountered in real casualties.[24] After a relatively brief period of instruction, all nonsurgically trained military MedTechs

**TABLE 3.** Table of $p$ Value (Mann-Whitney U-Test) for the Study Group Performance During Simulated Laparotomy and Hepatic Packing

| Task | Surgeon vs. RMT | Surgeon vs. UTM | RMT vs. UTM |
|---|---|---|---|
| Incision fluid loss, mL | 0.002 | 0.177 | 0.106 |
| Incision Time, s | 0.002 | 0.177 | 0.106 |
| Retraction time, s | 0.035 | 0.177 | 0.268 |
| Retraction fluid loss, mL | 0.035 | 0.177 | 0.268 |
| Direction time, s | 0.035 | 0.082 | 0.639 |
| Direction fluid loss, mL | 0.014 | 0.247 | 0.639 |
| Identification time, s | 0.022 | 0.792 | 0.202 |
| Identification fluid loss, mL | 0.073 | 0.662 | 0.432 |
| Packing time, s | 0.022 | 0.329 | 0.048 |
| No. sponges | 0.731 | 0.329 | 0.048 |
| Packing fluid loss, mL | 0.022 | 0.662 | 0.010 |
| After packing fluid loss, mL | 0.073 | 0.429 | 0.432 |
| Percentage skin incision closed | 0.001 | 0.004 | 0.872 |
| Total fluid loss, mL | 0.001 | 0.177 | 0.073 |

were able to understand the basic principles and steps of a damage-control laparotomy and were able to perform one using a Cut Suit with simulated massive hemorrhage. Furthermore, after the completion of a surgical packing task, there was no significant difference in postpacking fluid loss between any group, implying that if a novice responder can access the site of hemorrhage, then an effective but radical prehospital intervention might be provided.

Thus, theoretically otherwise unsurvivable casualties with no other treatment options might be offered such as a lifesaving intervention (LSI), considering that the most recent review of Canadian Forces deaths in Afghanistan automatically deemed all cases of torso exsanguination "nonpreventable."[25] The Trauma Hemostasis and Oxygenation Research (THOR) Network has defined an LSI as a medical procedure that if not performed conveys a high probability of morbidity or death,[11,26] with the terms far-forward and austere denoting environments in which professional health care providers do not normally operate.[11] Delayed evacuations refer to situations in which evacuation times exceed 60 minutes and prolonged for more than 6 hours from point of wounding until arrival at a medical treatment facility capable of providing damage-control surgery.[11] The current reality is that the wounded warriors of the future will increasingly be seriously injured in far-forward locations, facing prolonged or nonevacuations, being cared for by motivated but nonsurgically trained providers, yet requiring LSIs (most commonly for hemorrhage control) if they have a hope of survival.

Gerhardt et al.[26] recently reviewed data from a forward operating base supporting urban combat. They found that while LSIs were required in most casualties requiring evacuation, the scope of practice required for performing these LSIs before medical treatment facility arrival were beyond that of conventional forces combat medics, and thus, few LSIs were performed by them near the point of injury. They thus speculated that emergency telemedical direction might enable the potential deployment of advanced LSIs, thus providing a more efficient RDCR to those most in need.[26] Telemedicine is simply the provision of medical care at a distance using communication technologies. Remote telementoring is a form of telemedicine that involves a more experienced mentor providing guidance at a distance to a less experienced mentee who may be performing any number of required tasks.[15,23,27,28] Mentoring may be best achieved in a "just in time" fashion where an appropriate mentor is available to facilitate problem solving in response to immediate needs.[27] With ongoing improvements in technology and especially connectivity, it is likely that austere medical situations in the future will have access to remote medical direction. We used a conceptually (but not necessarily technically) simple model of hepatic packing. It is likely that other remote damage-control surgical techniques may also be telementorable, and further efforts will continue to evaluate these requirements. Any amount of prepreformance briefing would be highly desirable and augmentative to the flexibility in the scope telementoring provides.

Great strides have been made through the introduction of RDCR techniques and philosophies in recent years,[11] with major advances in resuscitative techniques that a far-forward damage-control laparotomy might not be unthinkable. Chaudery et al.[29] recently reviewed the current technologies potentially available in the prehospital setting to enable abdominal hemorrhage control in catastrophic hemorrhage, noting that most studies were preclinical in vivo trials. Of the potential techniques, specifically intra-abdominal foam injection[30–32] and resuscitative endovascular aortic balloon occlusion,[33,34] were considered as attractive candidates.[29] Chaudery et al. notably did not consider prehospital open surgical interventions as a potential option despite noting that "manual force is one of the most effective means of controlling bleeding." However, as early as 1983, NASA think-tanks identified the ability to perform laparotomy as the minimum desirable surgical capability to save lives before transfer to earth, arguably one of the most dramatic prehospital settings.[35,36]

In the present study, there was no difference in fluid loss between nonmentored MedTechs and surgeons; however, there was greater fluid loss in those being mentored. This was likely related to the technical settings of the Cut Suit, which has a versatile fluid loss capability. Thus, the selection of a 12 psi (82.74 kPa) hemorrhage rate, while accurately replicating conditions of exsanguination, was conducted at supraphysiologic pressures, greatly exaggerating any effect of delay, even appropriate delay, on fluid loss parameters in any group. We thus speculate that the mentored group had greater fluid loss because of the brief but inherent nature of a two-way communication between the mentor and the mentee. So while this delay likely explains increased fluid loss, the increased confidence that the mentored MedTechs reported was notable. Preliminary data still being fully analyzed noted that the while the RTM MedTechs demonstrated stress levels similar to those of the surgeons, the UTM MedTechs had significantly higher stress levels as indexed by the low frequency–to–high frequency ratio of heart rate variability (Jocelyn Keillor, personal communication, February 1, 2014). Therefore, one of the greatest benefits of the telepresence of an experienced and presumably emotionally distanced expert may be to bring reassurance and confidence to a far-forward responder, who will often unfortunately be extremely emotionally close to the victim.

The information technologies used were simple "off-the-shelf" software with two-way audio and one-way video display as this was a proof-of-concept study. The Skype proprietary "closed source" software is protected by multiple systems to address security and privacy.[37] All information is sent over secured socket layer that uses 256-bit Advanced Encryption Standard (AES) for all the information, leaving a transmitting computer that can only be decrypted by the Skype server. Nonetheless, greater encryption will typically be required for special operations. It is only logical that ever greater information and encryption capabilities will continue to expand in the future. The same can be expected of the degree of communication richness between the mentor and the mentee. The mentored MedTechs could only hear the remote mentor. There are rapidly evolving technologies in which the mentor may in the future by able to telestrate[38] on displayed images such as anatomy demonstration on a heads-up video display[39] worn by the MedTech for instance.

## Limitations of the Study

There are limitations to this study. We were not able to measure iatrogenic injuries as a result of improper laparotomy techniques. Therefore, this may have biased the study against telementored medics. More "simulated blood loss" was observed in the telementored group, as these medics took longer to open the abdomen and pack the solid organs. While the Cut Suit currently will demonstrate gross inadvertent bowel injuries and advances in the materials and construction of the model is constantly progressing, mammalian tissues are still perceived to be more susceptible to inadvertent injury. Thus, future complementary studies may be considered in animal models, where the outcome of interest is not only time to task completion and successful solid organ packing but also iatrogenic injuries to the bowel or other visceral structures.

In conclusion, perihepatic packing of an exsanguinating liver hemorrhage simulation was readily performed by military MedTechs after a focused briefing without obvious performance differences compared with trained surgeons. While real-time RTM did not improve study outcomes, it significantly increased nonsurgeon procedural confidence, which may increase the feasibility of the concept in actual operational application.

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