

Initial Experience of US Marine Corps Forward Resuscitative Surgical System During Operation Iraqi Freedom

Lowell W. Chambers, MD; Peter Rhee, MD, MPH; Bruce C. Baker, MD; John Perciballi, MD; Miguel Cubano, MD; Michael Compeggie, MD; Michael Nace, RN, CEN, ACNP-CS; Harold R. Bohman, MD

Hypothesis: Modern US Marine Corps (USMC) combat tactics are dynamic and nonlinear. While effective strategically, this can prolong the time it takes to transport the wounded to surgical capability, potentially worsening outcomes. To offset this, the USMC developed the Forward Resuscitative Surgical System (FRSS). By operating in close proximity to active combat units, these small, rapidly mobile trauma surgical teams can decrease the interval between wounding and arrival at surgical intervention with resultant improvement in outcomes.

Design: Case series.

Setting: Echelon 2 surgical units during the invasion phase of Operation Iraqi Freedom.

Patients: Ninety combat casualties, consisting of 30 USMC and 60 Iraqi patients, were treated in the FRSS between March 21 and April 22, 2003.

Interventions: Tactical surgical intervention consisting of selectively applied damage control or definitive trauma surgical procedures.

Main Outcome Measures: Time to surgical intervention and outcome following treatment in the FRSS.

Results: Ninety combat casualties with 170 injuries required 149 procedures by 6 FRSS teams. The USMC patients were received within a median of 1 hour of wounding with the critically injured being received within a median of 30 minutes. Fifty-three USMC personnel were killed in action and 3 died of wounds for a killed in action rate of 13.5% and a died of wounds rate of 0.8% during the invasion phase of Operation Iraqi Freedom. All Marines treated in the FRSS survived.

Conclusion: The use of the FRSS in close proximity to the point of engagement during the initial, dynamic combat phase of Operation Iraqi Freedom prevented delays in surgical intervention of USMC combat casualties with resultant beneficial effects on patient outcomes.

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Author Affiliations:

Departments of Surgery, First Medical Battalion/Naval Hospital Camp Pendleton, Camp Pendleton, Calif (Drs Chambers, Baker, and Bohman); Naval Trauma Training Center, Los Angeles, Calif (Dr Rhee); Naval Hospital Pensacola, Pensacola, Fla (Dr Perciballi); Naval Hospital Jacksonville, Jacksonville, Fla (Dr Cubano); Naval Hospital Camp Lejeune, Camp Lejeune, NC (Dr Compeggie); and US Marine Corps Command and Staff College, Quantico, Va (Mr Nace).

CURRENT US MARINE CORPS (USMC) doctrine involves frequent use of expeditionary maneuver warfare. Tactically, this means combat units are moving rapidly, often bypassing less significant opposing forces to engage key targets. This policy results in combatants often traveling hundreds of miles away from the supporting units that contain traditional surgical teams. Such dynamic and nonlinear warfare poses obvious logistical difficulties to US Navy medical personnel who provide support to USMC combatants. To prevent these tactics from leading to severe delays in critically injured Marines reaching surgical intervention, the USMC and US Navy developed the Forward Resuscitative Surgery System (FRSS). These small,

mobile trauma surgical teams are designed to provide tactical surgical intervention of combat casualties in the forward area. This report documents the initial use of the FRSS during the first phase of Operation Iraqi Freedom (OIF).

METHODS

DATA COLLECTION

Data concerning admission and care in the FRSS were maintained prospectively. Patients with airway or respiratory compromise, Glasgow Coma Scale score of 8 or lower, or hemorrhagic shock of class 3 or higher were classified as critical. Interval between injury and arrival was of particular concern and was determined based on the time of wounding recorded on information tags attached to most patients, or when this wasn't available, by ask-

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ing the patient or accompanying patients. Times less than 4 hours were rounded off in 15-minute intervals, while those longer were rounded off to the nearest hour. Accuracy of calculated intervals for USMC patients was confirmed by retrospective review of databases that contained the times the evacuation missions were requested.

Follow-up data on USMC patients were obtained by review of records from higher-echelon medical facilities where the patients received subsequent care. Follow-up on Iraqi patients was unsuccessful in most cases because of the language barrier and the lack of consistent patient identifiers between different levels of care. The killed in action (KIA) and died of wounds (DOW) rates were calculated using official US Navy and Marine Corps casualty databases. Killed in action was defined as those who died before reaching a treatment facility containing a physician, and DOW was defined as those who died after reaching a treatment facility. Following the recommendation of Bzik and Bellamy,¹ only patients with injuries severe enough to warrant admission at least overnight in echelon 3 medical facilities were counted as wounded in action.

FRSS METHODS

The FRSS is an 8-person team, composed of 2 surgeons, an anesthesiologist, a critical care nurse, 2 surgical technicians, an independent duty corpsman or physician's assistant, and a basic corpsman. The system can be set up within 1 hour by an experienced team and is equipped to perform up to 18 major surgical procedures over 48 hours without relief or resupply. Four preoperative and/or postoperative patients and 1 intraoperative patient can be cared for simultaneously. When relocation is necessary, the system can be taken down and repackaged within 1 hour for transport with a CH-53 "Sea Stallion" helicopter on 2 US Air Force 463-L pallets or in 1 high-back, high-mobility multipurpose vehicle and 1 high-mobility, multipurpose vehicle ambulance with trailers.

The team normally uses 2 BASE-X (Bea Maurer, Inc, Fairfield, Va) shelter tents that can be joined and are part of the equipment block, or it can work out of a shelter of opportunity. When set up, the system provides 2 preoperative and 2 postoperative stations in 1 tent and 1 operating theater in the other tent. The equipment block contains 133 items weighing 1858 lb (836.1 kg), and each block of consumables consists of 201 items weighing 942 lb (423.9 kg). The entire system, including shelters, generators, fuel, and water, weighs 6700 lb (3015 kg), takes up 400 cu ft³, and costs \$347 000. Power is provided by two 3-kW generators, while medical-grade oxygen is self-generated using 2 portable 10-L/min oxygen generators. Propaq monitors (Welch Allyn, Beaverton, Ore), portable suction units, and fluid warming/rapid infusion systems are available at each bed. Univent ventilators (Impact Instrumentation, Inc, West Caldwell, NJ) are stationed in the operating room and at the 2 primary postoperative beds. Three major thoracic/abdominal sets, 1 rudimentary craniotomy set, and 3 extremity sets of surgical instruments are available. After initial use, surgical instruments are cleaned with Klenzyme (STERIS Corp, Mentor, Ohio) and disinfected with Cidex (Johnson and Johnson, New Brunswick, NJ). General anesthesia is provided using a draw-over vaporizer and portable ventilator. Up to 80 U of type O blood are maintained in 2 small refrigerators that can run off either the generators or transport vehicles. A SonoSite portable ultrasound unit (SonoSite Inc, Bothell, Wash) and basic laboratories are available for diagnostic use. Resupply blocks of consumable items are forwarded via supply chains or carried along with the teams when extra vehicles are available and more sustained casualty receiving is anticipated.

Each FRSS team is colocated with a shock trauma platoon (STP) to assist with triage and initial resuscitation. The STPs are 25-personnel teams (composed of emergency department physicians, physician's assistants, nurses, corpsman, and Marines) that function as forward emergency departments. The STP also greatly increases holding capability, acting as a rudimentary surgical ward for patients who are stable postoperatively.

During the invasion phase of OIF, casualties were initially treated by Navy corpsmen attached to each Marine combat unit. Most patients had intravenous access, antibiotics, and analgesics administered during or before transport. Hypovolemic resuscitation for hemorrhagic shock (with administration of isotonic fluid only when patients developed mental status changes or lost their radial pulse) was established as doctrine but appeared to be variably practiced in the field. Tourniquets were used for control of extremity hemorrhage until patients were out of the line of fire and less restrictive means could be attempted. QuikClot (Z-MEDICA, Newington, Conn), a new hemostatic dressing, was available for use with external hemorrhage uncontrolled by all other means.

Almost all patients were transported by rotary wing air casualty evacuation from point of wounding or forward collection points to the STP where they were rapidly triaged. In accordance with the Geneva Convention, the political status of casualties was not a factor during medical triage with enemy combatants and civilians receiving the same prioritization and care as US Marines. Care of Iraqi patients was complicated by lack of available translators, limiting communication to gestures and short Arabic phrases in most instances.

Only casualties requiring immediate care for life- or limb-threatening injuries were initially taken into the FRSS. All other patients were treated in the STP while medical evacuation (MEDEVAC) (from 1 medical treatment facility to another) was arranged to a higher level of care.

The extent of surgical procedures performed in the FRSS varied depending on the physiologic status of the patient, number of casualties, resources available, and tactical situation. Persistently unstable patients, those requiring surgery while multiple other casualties were being received, and those being treated during hazardous tactical situations underwent damage-control procedures. Casualties who stabilized with initial control of hemorrhage underwent definitive procedures when resources were available and conditions appropriate. This selective use of damage control or definitive surgery in the field was referred to as "tactical surgical intervention" and thought of as a fourth level to the stages of tactical combat casualty care as described by Butler et al.² This differs from damage-control procedures done in major medical centers solely on the basis of physiologic exhaustion.³ In circumstances of limited resources or tactical danger, patients who have sustained severe enough injuries to require damage-control approaches for physiologic instability alone would need to be triaged as expectant or delayed to increase the salvage of greater numbers of less severely injured patients.

Once all immediate patients had been attended to, more stable patients requiring surgical intervention were treated in the FRSS when resources were available and expedient MEDEVAC was not available. For example, patients with open fractures were treated with debridement, pulsed lavage, and splinting. External fixation was used when there was concurrent vascular procedures or if fractures were extremely unstable.

Postoperatively, critical patients were cared for in the FRSS postoperative area while expedient MEDEVAC was arranged. More stable patients were transferred back to the STP where they were cared for while awaiting MEDEVAC.

Because many casualties were in critical condition postoperatively, a system of providing intensive care during subse-

RESULTS

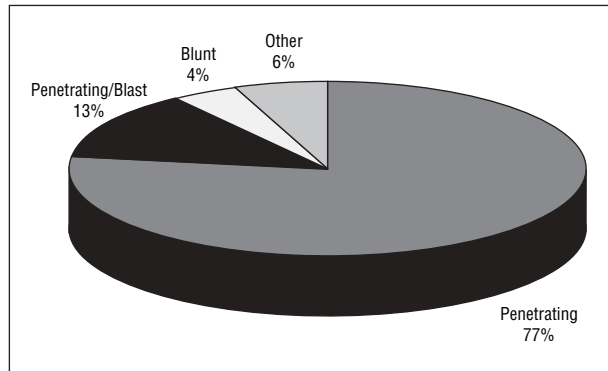


Figure 1. Mechanism of injury, all patients.

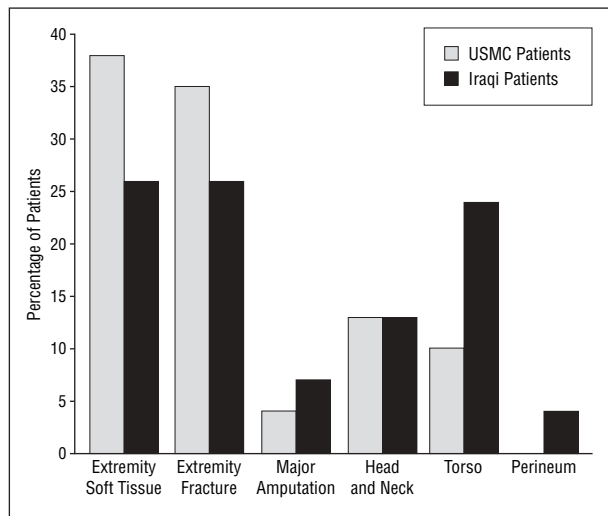


Figure 2. Location of injuries as percentage of total. USMC indicates US Marine Corps.

Table 1. Procedures Performed

Procedure	USMC	Iraqi Nationals	Total
Craniectomy	0	1	1
Airway control	1	5	6
Neck exploration	1	3	4
Thoracotomy	1	1	2
Damage-control celiotomy	3	1	4
Definitive celiotomy	2	12	14
Major amputation	2	12	14
Digit amputation	7	12	19
Extremity vascular	2	2	4
Fasciotomy	5	10	15
External fixation	0	6	6
Debridement, irrigation, and splinting	6	20	26
Debridement, irrigation, and dressing	6	28	34
Total	36	113	149

Abbreviation: USMC, US Marine Corps.

quent transport was essential. The FRSS used specially trained "en route care" nurses who helped assist in the care of severely injured patients from the point of FRSS admission. They then continued critical care during subsequent transport to higher echelons of care.

Between March 21 and April 22, 2003, 338 combat casualties (203 USMC, 135 Iraqi) were cared for by 6 FRSS/STP teams. Ninety patients (30 USMC, 60 Iraqi) with 170 injuries (48 USMC, 122 Iraqi) were treated in the FRSS.

The vast majority of injuries were penetrating (Figure 1). Thirteen percent of patients had both penetrating injuries and evidence of blast injury in the form of perforated tympanic membranes. There were no casualties with pulmonary or hollow, viscous blast injuries. Extremity injury was the most common injury, occurring in 64% (109/170) of the casualties (77% USMC [72/122], 59% Iraqi [29/60]). It was also the most severe injury or the only injury in 49% (44/90) of the casualties (50% USMC [15/30], 48% Iraqi [29/60]). Reflective of the large number of isolated extremity injuries, the average Injury Severity Score was 8 with a range of 1 to 41 for USMC patients and 11 with a range of 1 to 35 for Iraqi patients. Iraqi patients had a greater number of torso injuries relative to USMC patients (Figure 2).

The time of wounding was known in all USMC patients and the median interval from wounding to arrival at the FRSS for Marines was 1 hour with a range of 15 minutes to 40 hours. Time of wounding was known in 35 of the Iraqi patients, and the median time from wounding to arrival of these patients was 2 hours with a range of 30 minutes to 5 days.

A total of 149 procedures (36 USMC, 113 Iraqi) were performed by the 6 FRSS teams (Table 1). There were 21 patients deemed critical (Table 2). The mean Injury Severity Scores and median times from wounding to arrival at the FRSS were as follows: all patients, ISS of 21 or higher, time of 60 minutes; USMC patients, ISS of 22 or higher, time of 30 minutes (range, 15-120 minutes); and Iraqi patients, ISS of 20 or higher, time of 60 minutes (range, 30-720 minutes). It was collectively agreed by the treating FRSS surgeons that 8 of these patients (indicated with an asterisk in Table 2) would have died had the FRSS not been in theater and thus the time to surgical care prolonged.

Twenty-five patients from the STP or FRSS required en route care, and the physiologic needs for care during transport are shown in Figure 3. These transport missions averaged 2.5 hours and ranged from 40 minutes to 8.5 hours. No significant complications occurred during transport of these critical patients, with all arriving at the next level of care in stable or improved condition.

No USMC casualties treated in the FRSS died, but 7 USMC patients developed 10 complications as summarized in Table 3. Complete follow-up information was unavailable on Iraqi patients, but there were 3 confirmed deaths in Iraqi patients who were treated in the FRSS. Two Iraqi children died of traumatic brain injury, and 1 Iraqi soldier died of multisystem organ dysfunction after a damage-control vascular procedure. These are patients 13, 16, and 19 as listed in Table 2.

Throughout the theater, 393 Marines sustained significant injuries while engaging enemy forces during the invasion phase of OIF. Fifty-three were KIA and 3 DOW for a KIA rate of 13.5% and a DOW rate of 0.8%.

Table 2. Critical Patient Summary

Casualty No./ Description	Critical Criteria	Mechanism	Injury	Treatment
1/USMC	Airway compromise	Fragment to face	Open mandible fracture; airway loss	Airway control; pressure dressing
2*/USMC	Class 4 shock	Fragment to right flank	Grade 3 colon laceration; grade 2 liver laceration; IVC laceration; extensive soft tissue loss to back and retroperitoneum	Damage-control celiotomy
3/USMC	Class 4 shock	Fragment to lower extremity	Traumatic below-knee amputation	Completion amputation
4*/USMC	Class 4 shock	Gunshot wound to left thoracoabdomen	Grade 3 spleen laceration; 2 gastric lacerations; diaphragm laceration; left renal contusion; left pulmonary contusion; T-10 spinal cord transection; paravertebral hemorrhage	Damage-control celiotomy and thoracotomy
5*/USMC	Class 4 shock	Gunshot wound to right abdomen	IVC laceration, grade 2 laceration of 3rd portion of duodenum; multiple grade 2 small-intestine lacerations; paravertebral hematoma; L1 spinal cord transection	Definitive celiotomy
6/Iraqi child	Class 3 shock	Fragment/blast	Bilateral open tibia/fibula fracture; grade 1 small-intestine laceration; retinal detachment; urethral laceration; zone 2 neck laceration	DIS with vascular ligation; definitive celiotomy; suprapubic catheter; eye patch; limited neck exploration
7*/Iraqi child	Class 4 shock	Fragment/blast	Left lower extremity traumatic amputation; right upper extremity traumatic amputation; right foot open fracture	Completion lower extremity amputation; completion right upper amputation; external fixation right ankle
8/Iraqi child	Class 3 shock	Gunshot wound to left thoracoabdomen	Hemothorax; diaphragm laceration; gastric laceration; grade 2 spleen laceration	Tube thoracostomy; definitive celiotomy
9/Iraqi	Airway compromise	Gunshot wound to posterior neck	Paravertebral hematoma	Airway control; wound packing
10/Iraqi	Class 4 shock	Fragment to lower extremity and abdomen	Right femur fracture with SFA laceration; abdominal wall laceration	DIS and hemorrhage control; local exploration
11/Female Iraqi	GCS<8; airway compromise	Fragment/blast	Closed head injury; fetal demise; diffuse soft-tissue injuries	Airway control; wound dressings
12*/Iraqi	Class 4 shock	Fragment/blast	Grade 3 colon laceration; grade 2 small intestine laceration; 2 gastric lacerations; grade 2 liver laceration; right radius and ulna open fracture with bone loss and radial artery laceration; right open femur fracture	Definitive celiotomy; radial artery ligation; 2 DIS
13/Iraqi child	GCS<8; class 4 shock; airway compromise	Fragment/blast	Closed head injury with no localization; traumatic right above-knee amputation; mangled left lower extremity	Airway control; completion amputations
14*/Iraqi	Class 4 shock	Gunshot wound to left thoracoabdomen	Hemopneumothorax; grade 3 spleen laceration; diaphragm laceration	Tube thoracostomy; definitive celiotomy
15/Iraqi	GCS<8; class 3 shock	Blunt (motor vehicle crash)	Closed head injury; scalp and facial lacerations; closed right femur fracture; blunt abdominal injury with grade 3 liver laceration; rib fracture/hemopneumothorax	Airway control; DID and closure lacerations; femur splinting; definitive celiotomy; tube thoracostomy
16/Iraqi	Class 4 shock	Fragment to lower extremities	Right thigh laceration; SFA laceration with ischemia; SFV transection; open right femur fracture with bone loss; left thigh extensive soft-tissue loss	Damage-control vascular procedure; DID left thigh
17/Iraqi child	GCS<8; airway compromise	Fragment/blast	Open skull fracture with cerebral penetration	Airway control
18/Iraqi	Class 4 shock	Fragment to upper extremity	Open radial fracture, radial artery laceration	DIS; ligation radial artery
19/Iraqi child	GCS<8; airway compromise; class 4 shock	Fragment/blast	Open depressed skull fracture; epidural hematoma; left forearm traumatic amputation; bilateral soft-tissue wounds with compartment syndrome	Craniectomy; completion amputation; fasciotomies
20*/Iraqi	Class 4 shock	Gunshot wound to abdomen	Grade 3 renal laceration; adrenal artery laceration; grade 3 spleen laceration; proximal splenic vein laceration; pulmonary contusion	Resuscitative thoracotomy; damage-control celiotomy
21*/Iraqi	Class 4 shock	Gunshot wound to abdomen	Grade 2 colon laceration; multiple grade 2 small-intestine lacerations	Damage-control celiotomy

Abbreviations: DID, debridement, irrigation, and dressing; DIS, debridement, irrigation, and splinting; GCS, Glasgow Coma Scale score; IVC, inferior vena cava; SFA, superficial femoral artery; SFV, superficial femoral vein; USMC, US Marine Corps.

*Salvage patients.

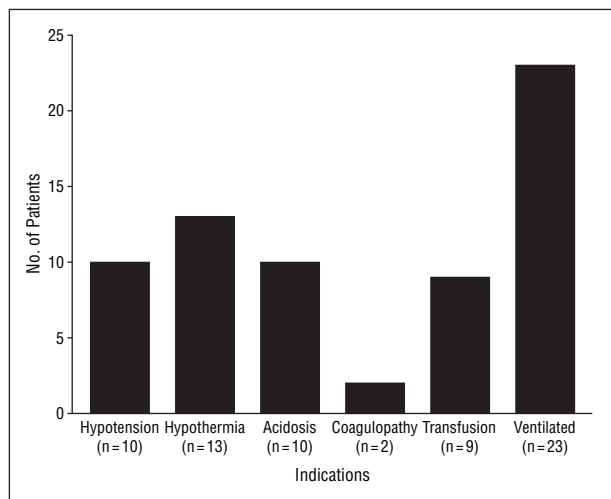


Figure 3. Incidence of indications for en route care.

Three FRSS teams drew enemy fire on 5 occasions, and 2 colocated teams had their tents showered with fragmentation when a nearby ammunition storage area exploded; however, no FRSS members were injured.

COMMENT

Advances in surgery, anesthesia, blood transfusion, and antibiotics have reduced the DOW rate from 8% during World War I to 3% during the Vietnam War.⁴⁻⁶ The KIA rate of approximately 20% has, however, remained virtually unchanged during the last 150 years. This discouraging fact stems from combat injuries having somewhat of an all-or-none nature with the majority of patients either sustaining rapidly fatal injuries or surviving with relatively minor, less life-threatening injuries.^{6,7}

Analysis of large numbers of casualties from the Vietnam War by Bellamy⁷ and the Israeli experience from Lebanon by Gofrit⁸ indicates 65% to 80% of those KIA die almost immediately from penetrating head injury or exsanguination. Suspended animation or other radical advances in trauma care may ultimately permit salvage of some of these “immediate KIAs.”^{9,10} Currently, however, the only feasible action available to this class of casualties is decreasing the incidence through preventive means such as improvements in body armor.

A significant subset (20%-35%) of KIA patients die within minutes of wounding from uncontrolled hemorrhage.^{7,8,11} Some of these “early KIAs” may be salvageable if more expedient access to surgical intervention can be provided. Several authors’ experiences support this. The British surgical team providing care during the Oman counterinsurgency operation of 1973 received the majority of the 80 critically injured patients they treated within 30 minutes and obtained an enviably low KIA rate of 8.8% while maintaining a DOW rate of 2.7%.⁴ Mobile surgical teams supporting Croatian special forces teams more recently demonstrated decreased mortality by working within 1 to 2 km of active combat operations with resultant average times between wounding and surgical intervention of 20 to 35 minutes.¹² Such short intervals are difficult to attain, how-

ever, and experience from other recent combat operations, such as the Falkland Islands campaign and Desert Storm, with larger and slower-moving, traditional surgical teams demonstrated a trend toward prolonged transport times and increased mortality.¹³⁻¹⁵

As warfare continues to become more rapid and non-linear, this could prolong transport times, which would result in increased numbers of potentially salvageable casualties being lost. The USMC and US Navy thus developed the FRSS. The development of the FRSS was not necessarily to improve outcome but to at least keep it similar to previous wars, because modern-day warfare can result in the front lines changing by hundreds of miles daily. The larger and more robust medical treatment facilities used before the development of the FRSS were deemed not mobile enough to keep up with the rapidly moving, asymmetric, and nonlinear battlefield. By placing small, mobile trauma surgical teams such as the FRSS far forward in the battlefield, the idea was to minimize the time between wounding and surgical intervention, preventing delays in care and the resultant increases in morbidity and mortality.

There are potential disadvantages to placing small surgical teams with relatively limited assets far forward. This includes potentially increasing the risk of losing critical surgical resources including personnel to enemy fire. However, large, relatively static medical support units in the perceived “rear” may actually find themselves to be more attractive targets for terrorist and insurgent attacks, whereas the small, mobile units such as the FRSS are in close proximity to aggressive Marine combat units where they can be provided protection and are relatively smaller targets.

Dispersing surgical assets throughout the theater could also lessen resources in other medical facilities, hampering their ability to deliver optimal care.¹⁶ Balancing this are the advantages of receiving casualties more expeditiously and the flexibility afforded by smaller units that can colocate and work as 1 large unit or function independently. The more forward location of FRSS teams during OIF allowed them to receive casualties a median of 4 hours sooner than the more traditionally located surgical company that received the majority of casualties during the early invasion phase of OIF.¹⁷ Though a number of patients died during transport to the surgical company during this time, only 1 died after arrival, making the company’s DOW rate 2%.¹⁷ The surgical company’s performance during OIF does not appear to have been adversely affected by the placement of several surgeons into FRSS teams.

Because the FRSS has limited resources for intraoperative and postoperative care in addition to the more austere forward setting, it could potentially result in worse outcomes for the casualties. However, meticulous planning, intensive training, careful equipment selection, and good evacuation capability may be able to minimize these issues. One striking illustration of the ability of well-trained teams to overcome the adversity of austere circumstances and surroundings from OIF was the salvage of a patient who was in septic shock 12 hours after sustaining a grade 2 colon laceration and multiple small-bowel lacerations from an abdominal gunshot wound (patient 21 in Table 2). During his tenuous postoperative

Table 3. Complications

Initial Injury	FRSS Intervention	Complications
Abdominal gunshot wound	Damage-control celiotomy	Pancreatitis
Abdominal gunshot wound (casualty 5 in Table 2)	Definitive celiotomy	Fascial dehiscence; spinoperitoneal fistula
Thoracoabdominal gunshot wound (casualty 4 in Table 2)	Damage-control celiotomy and thoracotomy	Pneumonia; pseudomeningocele; burn at QuikClot (Z-MEDICA, Newington, Conn) site
Open scapula fracture	Washout	Wound infection
Abdominal gunshot wound	Definitive celiotomy with primary closure of grade 2 colon laceration	Colonic leak
Neck fragmentation wound	Limited neck exploration	Wound infection
Comminuted mandible fracture with loss of airway (casualty 1 in Table 2)	Airway control	Infection of mandibular plate at echelon 5 facility

Abbreviation: FRSS, Forward Resuscitative Surgical System.

course, winds greater than 60 miles per hour during a sandstorm blew down the FRSS tents, destroying his ventilator. The patient's airway was rapidly resecured and resuscitation continued while the tent was being repaired. Once the extreme winds abated and MEDEVAC was possible, the patient was transferred in improving condition. Careful patient selection and proper application of tactical surgical intervention is, however, essential to prevent the very real possibility of worsening outcomes. Performing operations that should wait until the next level of care or attempting definitive surgery when damage control is more appropriate are pitfalls that must be avoided.

The development of the FRSS has also raised concern about the feasibility of transporting critically ill patients after performance of far-forward surgical intervention.^{3,16} Previously, MEDEVAC from a treatment facility to another required stable patients, and no means were available for transporting highly unstable patients. However, in response to this new need, the en route care transportation team was developed and established. The personnel from the en route care team were used in the FRSS until needed for transport, which aided in the care received at the FRSS. They were also highly successful and effective in providing critical care during MEDEVAC to the next level of care. These nurses faced the unenviable task of transporting critically ill, unstable patients via rotary wing, fixed wing, and ground transport over several hundred miles of desert. The absence of significant en route complications and arrival of all patients in stable or improved conditions at the next level of care demonstrates an ability to provide effective ongoing critical care despite austere circumstances.

The KIA and DOW rates of 13.5% and 0.8%, respectively, are lower than previous experiences, providing optimism that the FRSS works and is effective. The short experience and relatively low number of casualties prevent definitive conclusions until more experience with the system has been gathered. Nonetheless, the fact the FRSS had no USMC casualties die following surgery must be noted. Additionally noteworthy is the survival of at least 8 critically injured casualties who would not, in the judgment of the surgeons who treated them, have survived longer transport times to surgical therapy.

The development of currently used ceramic-plated body armor also played a significant role in preventing lethal injuries. Its effectiveness is demonstrated by the decreased incidence of torso injuries seen in Marines who wore it (10%) compared with Iraqis who did not (24%). Of the 5 Marine torso injuries we observed, 4 penetrated through relative soft spots between the ceramic plates while 1 occurred in a Marine while his flak jacket was off. No penetration through the plates was observed. This is similar to the experience of Mabry et al¹⁸ during the Battle of the Black Sea in Somalia. The body armor in these cases, while not preventing injury completely, diminished the severity of injury to the point these patients were salvageable with expedient surgical intervention. Future refinements of body armor, such as hardening the flank "soft spots" while retaining the flexibility necessary for mobility, should further diminish both the overall incidence and severity of penetrating torso trauma.

Consistent with previous recent experiences,^{19,20} the majority of Marine injuries involved the extremities (77%). Anticipating this, orthopedic surgeons were selected for positions in 3 of the FRSS teams. This was found to be extremely helpful in managing the multiple severe extremity injuries encountered. Of the 23 Marines who underwent debridement and irrigation of open fractures, amputation sites, or large soft-tissue wounds, 2 developed wound infections. This infection rate of 9% compares favorably with the 20% to 40% rates of infection seen during the Vietnam War and the 1973 Arab-Israeli conflict.²¹

The 3 patients who died merit some discussion. Two of these were multiply injured patients with traumatic brain injuries (Glasgow Coma Scale score <8) who would have been triaged as expectant had resources been more limited. Since resources were available, an attempt was made to salvage the casualties, but they did not survive. The third death was in an Iraqi soldier who sustained a large fragment wound to his right thigh resulting in a comminuted open femur fracture with superficial femoral artery and vein lacerations. The patient was hypotensive on arrival with a cold pulseless foot. Gross contamination of the wound was present, as he appeared to have been lying in the dirt for some time. He underwent a dam-

age-control vascular procedure with ligation of the superficial femoral vein, shunting of the superficial femoral artery, irrigation and debridement of the soft tissue, external fixation, and distal fasciotomies that resulted in restoration of blood flow to his foot. He remained cold, acidotic, and hypothermic during the procedure but gradually stabilized postoperatively and during MEDEVAC. While awaiting further MEDEVAC via fixed wing from the surgical company, the shunt clotted and the patient redeveloped limb-threatening ischemia. The patient's lower extremity was consequently cadaveric on finally reaching a Navy fleet hospital hours later. He underwent a high above-knee amputation but subsequently developed multisystem organ dysfunction and died.

There are some lessons learned from the FRSS experience during the invasion phase of OIF that will benefit future missions. The FRSS did not have pediatric equipment or supplies. Of the 21 critical casualties, 6 were Iraqi children. The FRSS has been amended to contain pediatric supplies as a result of this experience. The lack of translators complicated caring for Iraqi patients. Greater numbers of translators and more emphasis on learning rudimentary medical phrases in the dialect of the region in which future conflicts are conducted would be helpful in overcoming such difficulties.

A significant interval for training and preparation was available between deployment for OIF and the actual onset of hostilities. Future conflicts are unlikely to allow for such last-minute preparations, and it is essential that a full complement of fully trained teams be consistently available for rapid deployment and action. The Navy is currently assembling greater numbers of FRSS teams to accomplish this end. Complicating the training of these teams is the minimal trauma care provided by most military hospitals during peacetime. To offset this severe limitation in trauma exposure, the FRSS teams are being trained at the Navy Trauma Training Center, which is located in the Los Angeles County Medical Center in California. The FRSS members attend the training center every 1 to 2 years during which the entire team undergoes an intense 29 days of hands-on inner-city trauma care and tactical combat casualty care instruction.

In summary, the FRSS is a relatively new concept that overcame many logistical difficulties and successfully supported the modern, dynamic, nonlinear war strategies of the USMC during the invasion phase of OIF. The use of the FRSS allowed rapid access to surgical care from the point of wounding. The outcome for those treated at the FRSS was better than in previous conflicts, but the number of casualties treated was relatively small. The newly developed en route care system allowed the critically ill postoperative casualties to be transported to higher-level facilities and was vital to its

success. Continued improvements and refinements of the combat casualty care system are mandatory to support our Marines and sailors who find themselves in harm's way.

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Correspondence: Harold Bohman, MD, Department of Surgery, Naval Hospital, Box 555191, Camp Pendleton, CA 92055-5191 (hrbohman@cpen.med.navy.mil).

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