Case Report

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Successful Fluoroscopy-Free Extremity Endovascular Revascularization in an Austere Environment

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Background: The use of endovascular techniques in military trauma has increased over time. We present a case of stent-graft placement in a far-forward medical treatment facility (MTF).
Methods: A 27-year-old male sustained a blast injury to his upper extremities. He was admitted to a Role 2 MTF 7 hours post-injury. On presentation, he was hemodynamically stable, with multiple closed fractures of both hands, a partial amputation of the right forearm, and the absence of right upper-extremity pulses. Plain radiographs revealed two metallic fragments overlying the right humerus head.
The patient underwent a completion below-elbow amputation and right brachial artery exploration. Following the insertion of an arterial sheath, a multipurpose 5-Fr catheter was used to obtain a single-shot angiogram, which demonstrated a traumatic sub-total occlusion of the axillary artery.
Using a combination of gentle catheter-wire manipulation and serial radiography, the lesion was traversed and access to normal subclavian artery obtained. A Fluency® Stent-Graft (6 × 100 mm) was then deployed, followed by a completion angiogram, which demonstrated the restoration of extremity perfusion.
Results: The patient was evacuated to the next echelon of care on day 5 with good perfusion of the extremity. Computed tomography angiography on day 30 demonstrated thrombotic occlusion of the stent-graft; however, the extremity was viable and further revascularization was not clinically indicated. He was discharged on day 78 following conversion to internal osteosynthesis.
Conclusion: Endovascular revascularization of extremity trauma is possible in an austere environment, although techniques need to be refined to support a reduced logistical footprint.

Keywords: *Arterial Trauma; Military Trauma; Stent-Graft; Endovascular; Vascular Trauma; Endovascular Trauma Management*

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INTRODUCTION

Combat casualty care has dramatically improved over the last decades. Alongside the military medical revolution, a paradigm shift in war surgery is taking place [1–4]. One of the most important achievements of modern military surgery lies in the implementation of endovascular techniques that have been primarily applied by civilian surgeons. Having been shown to be effective in trauma care, endovascular capabilities in a combat zone

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have significantly improved over time, and many advanced endovascular procedures are now being performed by military surgeons on the frontline.

Resuscitative endovascular balloon occlusion of the aorta (REBOA), embolization, and stent or stent-graft implantation are among the most effective endovascular procedures for trauma care. REBOA is now being effectively used in far-forward medical treatment facilities (MTFs) and even at Role I by Special Operations Surgical Teams and in prehospital settings [5–8]. More sophisticated techniques—embolization and stenting—have been widely used in Combat Support Hospitals during the recent conflicts in Iraq and Afghanistan [9–12]. However, advanced endovascular procedures typically require fluoroscopy imaging and a wide spectrum of endovascular devices: wires, catheters, coils, stents, etc.; hence, there is still no opportunity to push forward these life-saving interventions to Role 1 and Role 2 MTFs where only basic open-damage control surgery can currently be provided.

Herewith, we present a case of successful fluoroscopy-free upper-extremity endovascular revascularization using very limited endovascular equipment and poor X-ray imaging at a Role 2 MTF.

Figure 1 Simultaneous surgery is undertaken to the patient at a Role 2 medical treatment facility. External fixation of the left upper arm and debridement and vascular surgery on the right upper arm are performed.

CASE DESCRIPTION

A 27-year-old male sustained a blast injury to his upper extremities while holding the handrail of a track and was injured by small fragments during an explosion. Due to the patient's remote location, he was admitted to a Role 2 MTF 7 hours post-injury with splints applied over both his hands in tactical field care. On presentation, he was hemodynamically stable, with a Glasgow Coma Scale score of 13, and with multiple closed fractures of both hands, a partial amputation of the right forearm, and the absence of right upper-extremity pulses. Plain extremity radiographs confirmed multiple hand fractures, and two metallic fragments were observed on top of the right humerus head; however, no obvious entry wounds were ascertained. Primary laboratory testing revealed a hemoglobin level of 7.8 g/dl, platelets of 143×10^9/l, a pH of 7.39 and base excess of –2 mmol/l.

The patient was taken into the operation room, intubated and—along with resuscitation with three units of red packed blood cells and three units of fresh frozen plasma—underwent simultaneous surgery on both hands (severe bilateral triple fractures) (Figure 1). On the right arm, completion below-the-elbow debridement-amputation and a right brachial artery exploration were performed, revealing a diminished pulse (Figure 2*a*). An attempt to advance a Fogarty catheter in a proximal direction failed as the catheter met resistance at a distance of 40 cm. Following the insertion of an arterial 6-Fr sheath, a standard J-tip guidewire failed to pass through the zone of resistance at the subclavian-axillary level (Figure 2*b*). A multipurpose 5-Fr catheter was advanced over the wire to obtain a single-shot angiogram, which demonstrated traumatic sub-total occlusion of the axillary artery at the level of two metallic fragments (Figure 3*a*,*b*). Additional patient examination revealed two small holes (2–3 mm in diameter) in the right part of neck zone II under the patient's beard.

To restore arterial patency, the sheath was upsized to the only 11-Fr sheath available. Using a combination of gentle catheter-wire manipulation and serial radiography (a portable X-ray machine), the lesion was traversed and access to the normal subclavian artery (a middle portion) obtained (Figure 3*c*). A Fluency® Stent-Graft (6 × 100 mm) was then deployed, followed by a completion angiogram, which demonstrated the restoration of extremity perfusion (Figure 3*d*). No post-dilatation was performed. During the whole 80-min endovascular procedure, more than 50 radiographs were taken in total and 80 cc of contrast media was injected. At the end of the operation, the sheath was removed followed by lateral arterial suture (Prolene 6/0). The bilateral upper extremities fractures were then immobilized with external fixators. The endovascular procedure was performed by a military trauma surgeon trained in vascular and endovascular surgery who had completed several Endovascular Trauma Management workshops and who had personal, albeit limited, expertise in stent-grafting.

The patient was not treated with either anticoagulation or antiplatelet therapy, as there was an ongoing risk of traumatic brain injury. On post-injury day 1, the amputated extremity was found pale and pulseless (at the elbow) with collateral flow on Doppler examination. The patient was transported to the nearest hospital for computed tomography (CT) scanning of the head and CT angiography of the right upper extremity. CT revealed in-stent thrombotic occlusion but no significant brain injury. The first necessitated additional

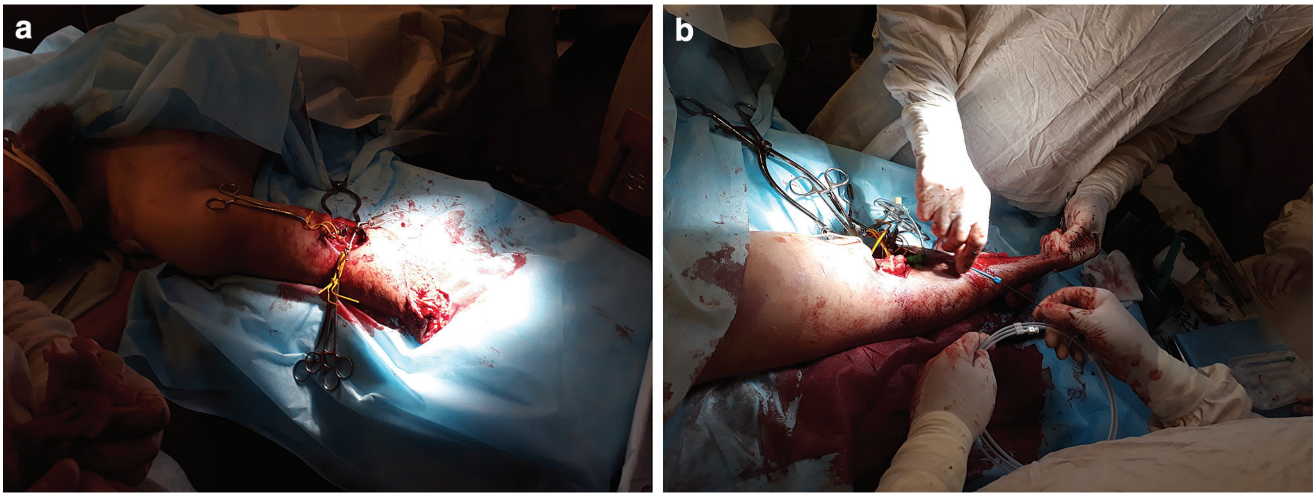

Figure 2 A below-elbow amputation and exploration of the right brachial bifurcation. (**a**) A diminished pulse is noted upon examination, which necessitates urgent surgery. (**b**) The brachial artery is cannulated with a 6-Fr sheath and a wire is advanced to perform retrograde angiography.

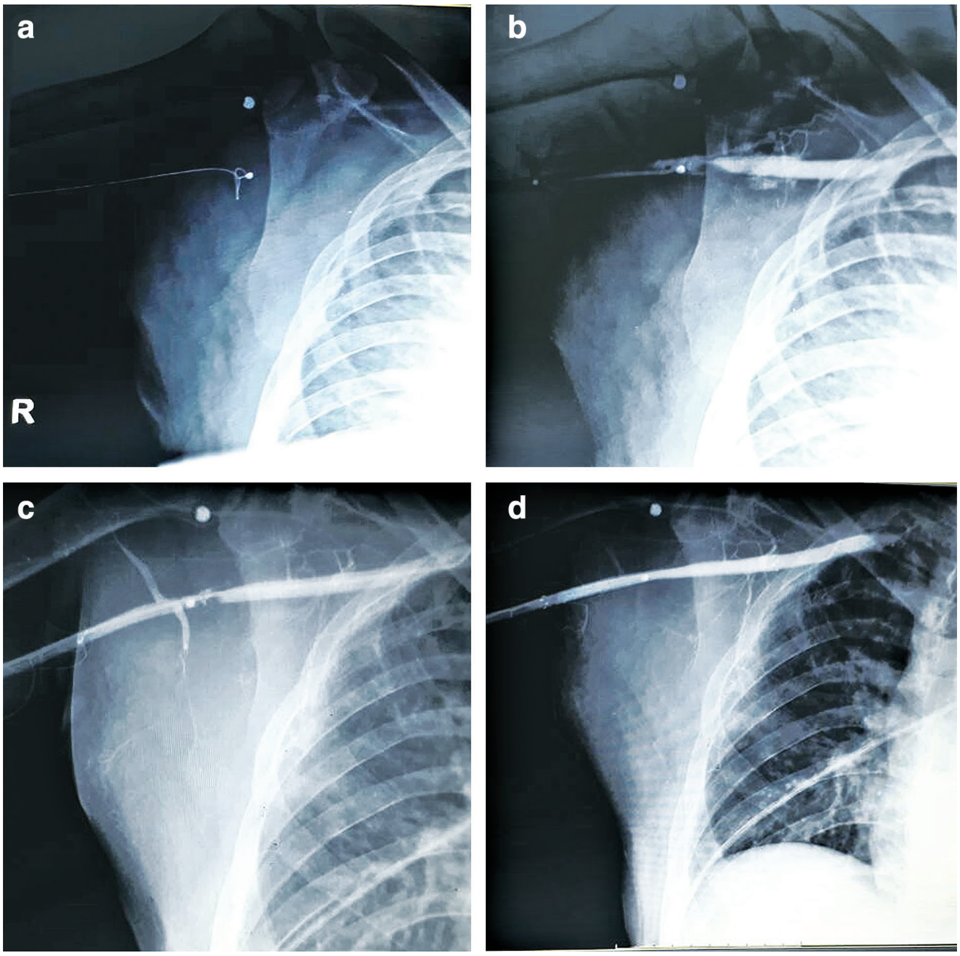

Figure 3 Fluoroscopy-free angiography and stent-graft implantation (a series of plain radiographs). (**a**) A guidewire meets resistance at the level of the axillary artery injury (two small metallic fragments are seen). (**b**) Retrograde angiography is performed to visualize the injury pattern. (**c**) An arterial lesion is traversed by a catheter, and angiography demonstrates sub-total occlusion of the axillary artery. (**d**) A completion angiogram demonstrating blood flow after stent-graft implantation.

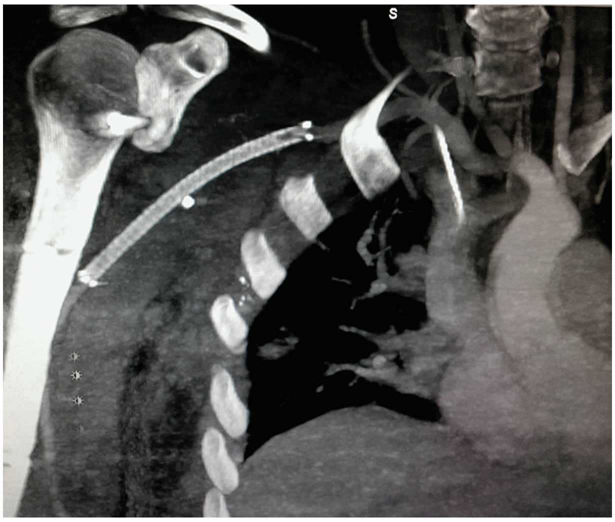

Figure 4 Day 3 CT-angiography demonstrates patency of the stent-graft and a metallic fragment lying over the vessel wall.

elbow-sparing surgical debridement of the right lower arm and re-exploration of the brachial artery bifurcation. A Fogarty catheter thrombectomy allowed extremity perfusion to reoccur, and low-molecular weight heparin (daily 10,000 IU of dalteparin), and dual anti-platelet therapy (daily 75 mg of clopidogrel and 100 mg of aspirin) were administered intra- and post-operatively. Regular Doppler examinations and day 3 CT angiography confirmed stent-graft patency and good right upper-extremity perfusion (Figure 4). On post-operative day 5, the patient was evacuated to the next echelon of care with good perfusion of the extremity. His clinical course was uneventful, the amputation stump healed completely, and no additional interventions were required. CT angiography on day 30 demonstrated thrombotic occlusion of the stent-graft; however, the extremity was viable and further revascularization was not clinically indicated. No anticoagulation was administered afterwards. The patient was discharged on day 78 following conversion to internal osteosynthesis. Two years post-injury, the patient wears a cosmetic terminal prosthesis but experiences neither phantom limb nor residual limb pain in its use.

DISCUSSION

This is the first case report to demonstrate the possibility of implementation of a sophisticated endovascular procedure—stent-graft implantation—in a far-forward (Role 2) medical facility. The Role 2 MTF is typically deployed in tents aimed to provide basic resuscitative and damage control surgery [13,14]. Surgery is usually performed by a forward surgical team consisting of a few surgeons and nurses, but not including either a vascular surgeon or an interventional radiologist [13]. At this level of care, no mobile fluoroscopy unit (C-arm) is available and only limited equipment and diagnostic tools, such as portable X-ray and ultrasound machines, are used.

A portable X-ray device was the only tool available to localize the zone of arterial injury. A single-shot angiography permitted the understanding of the mechanism and the type of arterial injury, as a pulseless arm in blunt trauma is usually caused by either concomitant bone fracture or (neuro)vascular traction injury. In this case, a careful secondary survey in addition to angiography ruled out both these potential injuries and revealed that the injury mechanism was penetrating rather than blunt, and also that two small fragments had caused the axillary arterial wall injury and concomitant occlusive thrombosis.

Recognized limb-threatening ischemia requires urgent intervention to restore perfusion and to avoid major amputation. It can be performed in one of the following ways: open surgery, endovascular stent-grafting (permanent or temporary), or as a hybrid procedure. An open approach to vascular injuries is regarded as the gold standard in civilian and military trauma care. A review of PROOVIT Registry data has demonstrated that penetrating wounds are predominantly treated with open surgery [15]; however, this results in additional trauma and blood loss. On the other hand, covered stent deployment is now a feasible alternative for patients with an axillo-subclavian injury as it leads to shorter procedure time and less blood loss, and is less technically challenging [16–19]. Stent-graft implantation, however, necessitates dual anti-platelet therapy that may theoretically worsen traumatic brain injury, which we had no possibility of excluding upon admission. In addition, endovascular devices of different sizes and lengths are required for the precise healing of an arterial lesion and adequate blood flow restoration. In our case, only two 100-mm long stent-grafts were available at the time of surgery. Our 6-mm stent seemed to fit the lesion since it covered the axillary artery and crossed to the first portion of the brachial artery, which was 4–5 mm in diameter; however, it turned out to be inadequate even for short-term patency, and reluctant inappropriate sizing was likely to be a reason for early in-stent thrombotic occlusion. Apparently, in our setting, if limb ischemia had progressively deteriorated, then open surgery would have been the method of choice to restore perfusion by either replacement or bypass of the implanted stent-graft.

Temporary stent-graft placement, as part of an "endovascular damage control" strategy, is regarded as an alternative option. Rohlffs and co-authors reported a case in which a through-and-through wire technique followed by three stent-graft deployments were successfully used as a temporary bridging tool for a completely transected axillary artery [20]. The stent-graft, implanted in our patient for temporary limb perfusion, could also be used as a "temporary endovascular shunt." Thus, by reaching Role 5 MTF, the patient could undergo the next stage of surgery—either open reconstruction or the endovascular correction of a possible stenosis according to CT or standard transfemoral angiography.

The latest option for healing such a lesion is to establish endovascular proximal control for open vascular repair—a method described as early as in the 1990s [21]. Gilani and co-authors [19] proposed temporary balloon occlusion of the subclavian artery to allow through-and-through recanalization of a lesion via the brachial artery followed by stent deployment. Hörer and Reva described another hybrid technique (endovascular and open) to control bleeding with minimal blood loss, where a balloon catheter was temporarily placed from below or from above (crossing the aortic bifurcation) to control iatrogenic inguinal or retro-peritoneal bleeding [22]. Proximal control of the right subclavian artery followed by open repair could have been an option in our case to avoid the necessity of prolonged anti-platelet therapy; however, subclavian artery catheterization requires fluoroscopy imaging, which was unavailable.

In the given austere setting, where diagnostic and treatment options are limited, personnel and the surgical/endovascular inventory play important roles. According to the Joint Trauma System Clinical Practice Guideline, the following broad spectrum trauma-specific endovascular armamentarium is recommended for in-theater capability in the treatment of wartime vascular injuries: wires, sheaths, catheters, angioplasty and occlusion balloons, bare-metal and covered self-expandable stents of different sizes, inferior vena cava filters, embolization materials, snares, dilators, and other accessories [23]. It is, however, also applicable in a Role 3 MTF, where advanced surgical techniques can be used by a team of professionals in a stable setting. At our Role 2 MTF, there were only a few sheaths, wires, catheters, balloons and coils, and a pair of stent-grafts available during deployment. This limited endovascular inventory was mostly used for angiography and REBOA. While the latter is now a prehospital damage control option and included in Advanced Resuscitative Care [24], "direct" stent implantation can become a Role 1 or even pre-hospital intervention—as part of a "temporary endovascular shunting" strategy—in the near future.

Since the role of endovascular surgery in wartime injuries is increasing over time, personnel have to be ready to confront the new frontiers. This kind of advanced endovascular intervention, as well as the previously described REBOA cases [25], were performed by military vascular surgeons with personal experience in interventional radiology. While vascular cases are the most challenging during deployment, basic and specific endovascular training is required for military surgeons, austere surgical teams, and medics.

CONCLUSION

Our case has demonstrated the feasibility of an advanced intervention—endovascular revascularization of extremity trauma—in a far-forward Role 2 MTF with limited equipment and imaging capabilities, although techniques need to be refined to support a reduced logistical footprint. Successful fluoroscopy-free axillary artery stenting was effective in restoring the perfusion of a severely injured limb. Further evaluation of endovascular surgery in a theater of war, and the role of basic and advanced interventions on the frontline is certainly needed.

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