Hand Surgery and Rehabilitation 38 (2019) 358–363

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Elsevier Masson France
EM|consulte
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Original article

The state of microsurgical practice in French forward surgical facilities from 2003 to 2015

Pratique de la microchirurgie dans les formations chirurgicales de l'avant françaises de 2003 à 2015

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ARTICLE INFO

Article history:
Received 9 June 2019
Received in revised form 30 August 2019
Accepted 17 September 2019
Available online 21 September 2019

Keywords:
Hand injury
Microsurgery
Military
Nerve repair
Replantation

ABSTRACT

Microsurgery is an unusual procedure in the theatres of military operations. We sought to analyze the state of microsurgical practices in the French medical treatment facilities (MTFs) deployed around the world in the 21st century. A retrospective study was conducted among all patients who were operated on in French forward surgical facilities between 2003 and 2015. Those who underwent microsurgical procedures for nerve injury, vascular injury, or extremity reconstruction were included. Only early vascular results were assessed. Among the 2589 patients operated on for an extremity injury during the study period, 56 (2.1%) were included, with the group composed of 29 patients with isolated nerve injuries, 28 patients with nerve and arterial injuries, and two patients with isolated arterial injuries, mostly at the hand level. Nerve procedures predominantly consisted of direct suturing, although autografting and nerve transfers were also performed. Thirteen microvascular repairs were carried out, including nine cases of proximal or digital revascularization; revascularization was successful in six of the nine cases. These procedures were completed by orthopedic surgeons trained in microsurgery, mostly under loupes magnification. Routine nerve repair in the field seems to be specific to French MTFs. Salvage of amputated or devascularized fingers in the combat zone had never been reported before. Such emphasizes the need to train deployed orthopedic surgeons to perform microsurgical procedures and to equip all MTFs with basic microsurgical sets and magnification means.

Mots clés :
Lésions de la main
Militaire
Microchirurgie
Réparation nerveuse
Replantation

RÉSUMÉ

La microchirurgie est une pratique inhabituelle sur les théâtres d'opérations militaires. Notre objectif était d'analyser la pratique microchirurgicale dans les formations sanitaires françaises déployées dans le monde depuis les années 2000. Une étude rétrospective a été menée chez les patients opérés dans les structures chirurgicales de l'avant entre 2003 et 2015. Ont été inclus ceux traités par microchirurgie pour des lésions nerveuses, des lésions vasculaires, ou des gestes de reconstruction. Seuls les résultats vasculaires précoces ont été évalués. Parmi les 2589 patients opérés pour un traumatisme des membres durant la période étudiée, 56 (2,1 %) ont été inclus. Ils totalisaient 29 lésions nerveuses isolées, 28 lésions nerveuses et artérielles combinées et deux lésions artérielles isolées. Les gestes nerveux étaient essentiellement des sutures directes, mais des autogreffes et transferts nerveux ont aussi été effectués. Treize réparations microvasculaires ont été effectuées dont neuf revascularisations proximales ou digitales. Six des neuf revascularisations ont été réussies. Ces gestes ont été effectués par des chirurgiens

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https://doi.org/10.1016/j.hansur.2019.09.003
2468-1229/

orthopédistes formés à la microchirurgie, le plus souvent sous loupes grossissantes. La pratique courante de réparations nerveuses à l'avant semble être une spécificité française. La réalisation de revascularisations digitales dans les zones de combat n'avait jamais été rapportée auparavant. Cela plaide pour une formation à la microchirurgie des chirurgiens orthopédistes militaires projetables et pour un équipement microchirurgical minimal dans les formations sanitaires de l'avant.

1. Introduction

Microsurgical practice in the combat theatre has been seldom reported on in modern armed conflicts [1–6]. Battlefield medical support is indeed dedicated providing lifesaving, limb-saving and sight-preserving care. Once stabilized, military patients are evacuated out of the combat zone to receive more advanced treatment in appropriate medical facilities and trauma centers [5–7]. However, reconstructive procedures are often performed in the field for local nationals in countries where infrastructures are destroyed, as part of the medical support to the population [8,9]. Microsurgical procedures are difficult to achieve in this setting considering the need for specialized equipment and staff that tend to only be available in specialized centers located far from the combat area [5]. Despite these limitations, several studies to date have reported on the use of microsurgical procedures for free-flap transfer, nerve repair or digital revascularization in military forward surgical facilities [1–3,6–9].

Only two known articles describe soft-tissue coverage using free-flap transfers within a combat or austere environment [1,2]. During the Balkans war, Tajsic and Husum [1] were the first to show that skilled surgical teams can perform advanced reconstruction surgery with limited resources. Klem et al. [2] reported a series of 31 free flaps for extremities or face/neck complex tissue defects in United States combat support hospitals (CSHs) deployed in Iraq and Afghanistan. These procedures were performed by military plastic surgeons, hand surgeons or head and neck surgeons working closely with orthopedic surgeons. In similar circumstances, Franke et al. [4] reported six cases of free fibular transfers to treat bone loss in Afghanistan.

In our experience free flaps are not used for extremity reconstruction in such a setting, mostly because of the lack of plastic surgeons in French CSHs, but also because they require lengthy operative times that may jeopardize the operational activity of the facility if a mass casualty situation occurs [10]. However, we found that microsurgical procedures were routinely performed for nerve repair, particularly at the hand level [7]. Despite an incidence of 8.1% for peripheral nerve injuries among combat casualties, few studies mention nerve repair completion in forward surgical facilities [3,7,9,11]. In addition, we recently reported two original cases of digital replantation in French soldiers managed by forward surgical teams (FSTs). These procedures were completed by orthopedic surgeons trained to perform microsurgery during their residency [6].

The present study aimed to analyze the microsurgical practice of French military orthopedic surgeons during their deployment in various theatres of operations in the 21st century, and to outline the consequences in terms of initial or continuous education.

2. Patients and methods

We conducted a retrospective study among all patients operated on in French forward surgical facilities between 2003 and 2015 using the database OPEX© (Service de Santé des Armées). This study was approved by the Department of Surgery of the French Health Military Service. Patients who underwent a microsurgical procedure on the field for nerve injury, vascular injury or extremity reconstruction were included. Patients who did not require microsurgical repair or for whom the procedure was performed after repatriation were excluded.

The following preoperative parameters were studied: patient demographics (e.g., age, gender, origin), theatres of operations, injury mechanism, location and type, together with associated lesions. Operative parameters included the time from trauma to surgery, the type of microsurgical repair (i.e., nerve or vascular), and suture materials and optical magnification means used. Outcomes of nerve repair were not evaluated because long-term follow-up was impossible to achieve in the case of most patients. Conversely, early results of vascular repair were assessed before patient transfer or repatriation.

Data were collected and treated with Excel software (Microsoft Corp., Redmond, WA, USA) to calculate means and standard deviations. A Student's *t*-test was used for normal, continuous quantitative variables. Qualitative variables were compared using Fisher's exact test. *P*-values of less than 0.05 were considered significant.

3. Results

During the period of study, 2589 patients were operated on for extremity trauma in the various combat theatres in which the French Army was involved. Among them, 287 (11%) presented with hand injuries and 56 (2.1%) were included after they received a microsurgical procedure on the field. Their mean age was 32 ± 11 years, including five children under 16 years of age. The male to female ratio was 5. The distribution among French soldiers, foreign soldiers and local civilians was homogenous in this cohort (Table 1). Most patients were managed in the Kabul International Airport (KaIA) CSH–Afghanistan and by the Epervier FST deployed in Chad since 1986 (Table 2). Injury mechanisms are detailed in Fig. 1. Gunshot wounds were predominant among ballistic injuries and being cut by a sharp object was the main mechanism of noncombat-related injuries. In comparison with patients overall, the proportion of ballistic trauma was significantly higher in this cohort ($P < 0.01$).

As three patients presented with two injuries requiring microsurgery, an overall of 59 injuries were analyzed. There were 29 isolated nerve injuries, 28 nerve and arterial injuries, and two isolated arterial injuries. Except for five sciatic nerve lesions, all nerve injuries involved the upper extremities. Thirty-three (56%) injuries were located at the hand level (Fig. 2). Nine arterial injuries were associated with distal ischemia, including two brachial artery injuries, one simultaneous radial and ulnar arteries injury, and six digital devascularizations or amputations. These lesions were combined with 19 flexor tendon lacerations, nine muscle injuries, and 21 fractures including 14 metacarpal or phalangeal fractures. Associated injuries were blast-related with multiple superficial or penetrative wounds (11 cases) and closed fractures (two cases).

Patients were treated by orthopedic hand surgeons in 34 cases and by orthopedic surgeons who were not hand surgeons in 22 cases. A vascular surgeon was present in three cases with

Table 1
Patients demographics.

	Operated patients ($n = 2589$)	Operated patients with hand injury ($n = 287$)	Study patients ($n = 56$)
Gender, *n* (%)			
Males	2237 (86.4)	262 (91.3)	47 (83.9)
Females	352 (13.6)	25 (8.7)	9 (16.1)
Children < 16 yo, *n* (%)	452 (17.5)	40 (14)	5 (9)
Status, *n* (%)			
French soldiers	452 (17.5)	109 (38)	15 (26.8)
Foreign soldiers	362 (14)	27 (9.4)	13 (23.2)
Local civilians	1556 (60)	127 (44.2)	17 (30.4)
Others	219 (8.5)	24 (8.4)	11 (19.6)
Mechanism, *n* (%)			
Ballistic trauma	647 (25)	73 (25.4)	24 (42.8)
Other trauma	1942 (75)	214 (74.6)	35 (57.2)

Table 2
Distribution of patients among forward surgical facilities.

Theatre of operations/Facility	Number of patients
Afghanistan/CSH	31
Central African Republic/FST	1
Chad/FST	11
Charles-de-Gaulle carrier/FST	1
Ivory Cost/FST	5
Jordan/FST	1
Kosovo/FST	4
Mali/FST	2
Total	56

CSH: combat support hospital; FST: forward surgical team.

arterial injury. Thirty-nine injuries were treated within 24 hours as emergencies, 11 nerve sutures were performed in the sub-acute period (within three weeks) and nine nerve reconstructions were performed in the chronic period. The mean delay to surgery was 18 ± 44 days in the whole cohort. This delay was significantly shorter for hand injuries (3 days vs. 38 days; $P = 0.009$). Nerve procedures consisted of seven neurolysis, 38 direct sutures, seven autografts, four nerve transfers for brachial plexus injuries or flap reinnervation, and one vein wrapping for painful neuroma. Fibrin glue was used in 15 cases, only at the KaIA CSH. Arterial injuries were managed by electrocautery or ligation in 17 cases, by end-to-end anastomosis in 11 cases, and by venous grafting in two cases of small-diameter brachial artery missile injury. No vein repair was performed in cases of digital replantation, mostly because of technical issues. Procedures were carried out under magnification loupes in 38 cases and under operating microscope in 18 cases treated at the KaIA CSH.

Revascularization procedures were successful in six of nine cases, including two digital revascularizations and one distal replantation. Two arterial repairs failed immediately or in the following hours after a distal thumb replantation and a ring finger revascularization (Table 3). Vascular results could not be evaluated in a foreign military patient who was immediately repatriated. Twenty-four patients were evacuated to their home country (22 military members, one refugee, and one contractor), whereas 32 (six military members, 16 local civilians, and 10 contractors/expats) were followed in the field facility or in local hospitals. A clinical case is provided in Fig. 3.

4. Discussion

To our knowledge, apart from the paper by Klem et al. [2] about free-flap coverage, this study is the first to evaluate the microsurgical practice in forward surgical facilities. It deals primarily with the management of nerve injuries, mostly at the hand level, but also reports a unique series of digital revascularizations performed in austere conditions.

It is well known that hand injuries are common in theaters of military operations. They are responsible for numerous aeromedical evacuations and of a large proportion of patients being placed on restricted duty [7,13–15]. In this cohort, hand trauma patients represented 11% of all patients operated on for extremity traumas. This is consistent with the results of Penn-Barwell et al. [14] who found that casualties with isolated hand injuries represented 6.5% of all British casualties evacuated from Iraq and Afghanistan. As we found in our previous study, noncombat-related injuries are predominant (57%) [7]. Miller et al. [15] already showed that these injuries are a significant problem in the combat zone. However, the proportion of combat-related injuries (43%) is far superior to the 9% reported by Penn-Barwell et al. [14]. This may be explained by a

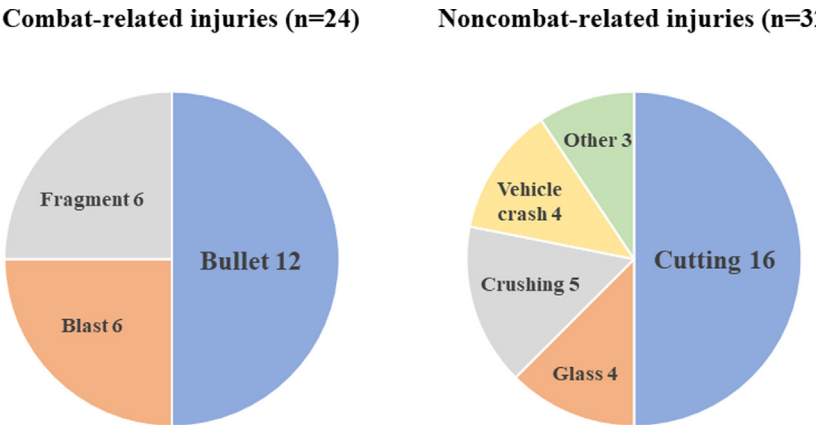

Fig. 1. Injury mechanism.

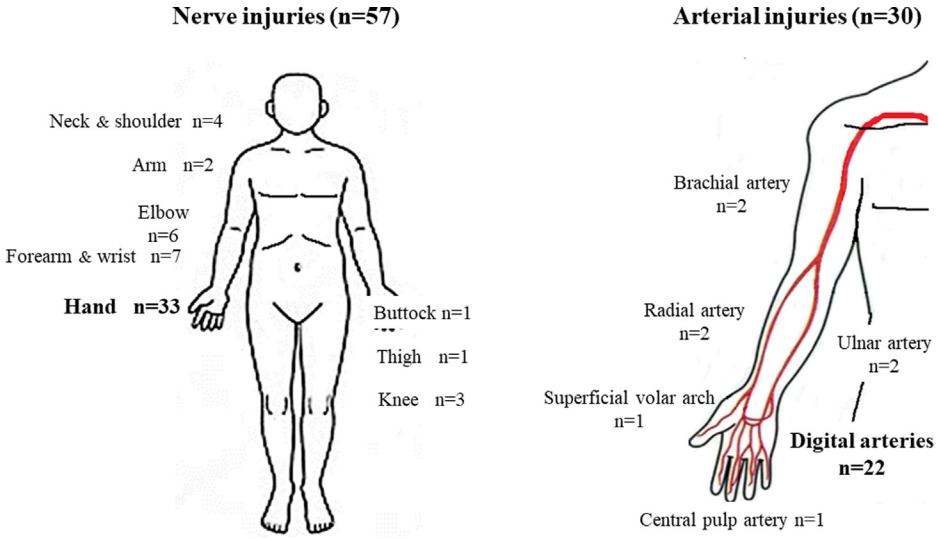

Fig. 2. Distribution of nerve and arterial injuries.

Table 3
Management of patients with digital amputation or devascularization.

Case	Mechanism	Injury	Vascular repair (artery/vein)	Vascular result	Revision surgery
1	Crushing	Medius distal phalanx amputation	1/0	Success	–
2	Crushing	Thumb distal phalanx amputation	1/0	Failure	Local flap
3	Crushing	Thumb proximal phalanx open fracture	1/0	NA	NA
4	Blast	Thumb MCP open fracture	1/0	Success	MCP arthrodesis
5	Avulsion	Urbaniak 1 ring finger [12]	1[a]/0	Failure	Amputation
6	Bullet	Index proximal phalanx open fracture	1/0	Success	–

MCP: metacarpophalangeal; NA: not available.
[a] Direct cross-suture.

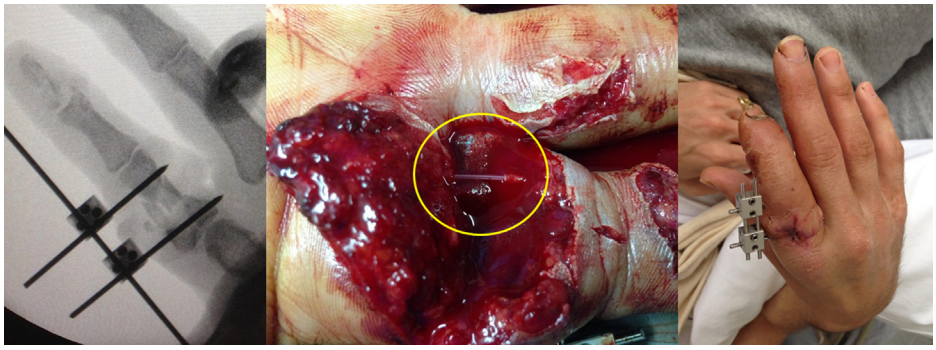

Fig. 3. Isolated gunshot wound of the index finger with distal ischemia: external fixation (a and c) and volar ulnar artery repair over an intravenous catheter under magnification loupes (b).

selection bias, as the most severe hand injuries were probably included in this cohort.

The routine practice of nerve repair in the combat zone is the first specificity of this series. Our experience is different from the one of Penn-Barwell et al. [14] who recommended delaying tendon and nerve repair until patient repatriation for a better function outcome. The deployment of orthopedic surgeons trained in microsurgery (even if they were not hand surgeons) explains why primary nerve repair was performed among military patients or civilian expats. In some cases, this permitted the avoidance of evacuation and the maintenance of patients suffering from hand trauma at their workstation when intensive physiotherapy was not required (e.g., in cases of isolated digital nerve injury). Many local nationals also beneficiated from primary or secondary nerve repair as part of the medical support provided to the population [8]. Although various studies have been published about reconstructive surgery in forward surgical units, we did not find another series reporting on nerve repair [2–4,10]. Naturally, we cannot make any recommendation, as nerve repair results were not evaluated in this heterogeneous series. In addition, we must point out that in peripheral nerve surgery the results obtained with loupes are usually inferior to those obtained using microscope [16–18].

Despite a limited number of cases, our series of digital revascularization and replantation cases achieved in deployed military settings is unique. Work-related injuries due to crushing were predominant, in accordance with the findings of Miller et al. [15]. This mechanism can lead to partial or complete amputations, which are fortunately rare in military practice. According to Brininger et al. [19] such injuries represent less than 0.2% of all

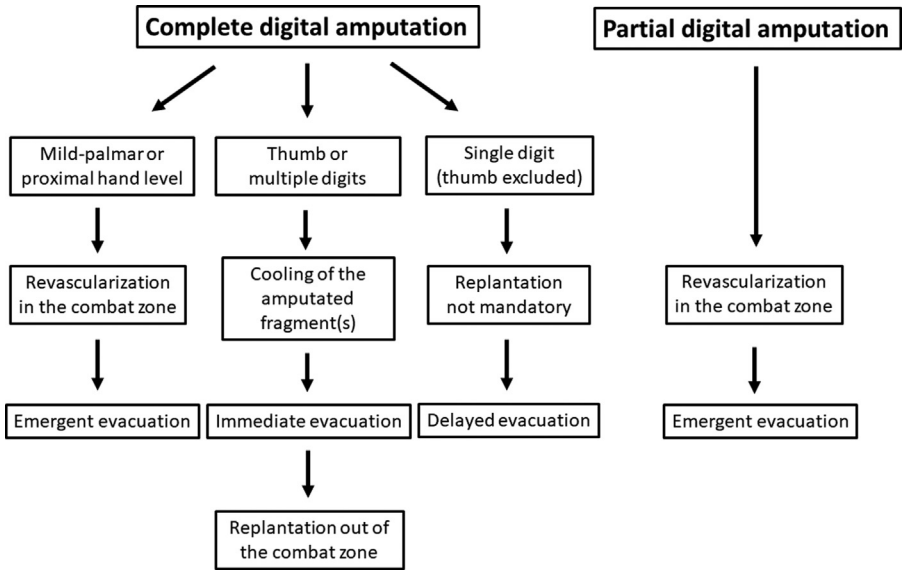

Fig. 4. Algorithm for management of digital or hand amputations in French forward surgical facilities [6].

upper-extremity injuries sustained by the United States military during both peacetime and wartime. Usually, the salvage of ischemic digital injuries is impossible in the combat zone where specialized surgeons and equipment are often not available. This limitation of battlefield medical support may provoke medico-legal matters related to the notion of "loss of chance" [6]. However, this series suggests that digital revascularization can be performed (or at least attempted) by deployed orthopedic surgeons trained to perform microsurgery with magnification loupes. These procedures are obviously dedicated to isolated hand injuries and rarely intended to combat trauma, considering their severity with potential associated injuries or a massive casualty situation [20]. Based on this experience, we have already proposed an algorithm for the management of noncombat-related digital amputations in the combat zone (Fig. 4) [6]. Despite a substantial risk of failure in this setting, we believe that hand or digital revascularization should be attempted when the situation does not allow for evacuation of the patient to specialized units in an appropriate time.

Completion of such microsurgical procedures by FSTs requires deployed orthopedic surgeons trained in microsurgery. This was possible here because most French military orthopedic surgeons complete a microsurgical degree during their residency, including those who do not intend to specialize in hand surgery. All of them routinely treat patients with hand trauma in military hospitals. Only patients with complex hand injuries, including mangled extremities or digital amputation requiring replantation, are referred to civilian specialized hand surgery units [6]. In fact, most procedures were performed by orthopedic surgeons who were also hand surgeons and who had a regular practice of microsurgery in France. This explains why complex nerve reconstructions such as nerve autografting and nerve transfers were carried out in local patients.

The availability of appropriate microsurgical equipment is another concern in battlefield medical treatment facilities (MTFs) [2]. In FSTs (role 2 MTFs), all procedures were performed under magnification loupes. Operating microscopes and fibrin glue were only available in the KaIA CSH (a role 3 MTF) where ophthalmologists and neurosurgeons were deployed. It must also be noted that surgeons often brought their personal magnification loupes and microsurgical sets, as this equipment is not included in the FST endowment. However, as there was no dedicated equipment, major vascular surgery instruments and 7/0 or 6/0 sutures were used in many cases of arterial and nerve repair. We agree with Klem et al. [2] that knowledge of microvascular anatomy, meticulous tissue handling, and good surgical judgment are probably more important than sophisticated instrumentation in achieving successful outcomes.

The limitations of this study mainly include its retrospective nature and the selection bias related to the special surgical activity in French FSTs with a recurrent presence of hand surgeons. These facilities widely contribute to medical support of the population in selected African countries, where they can be deployed for decades. They manage numerous civilian patients who cannot afford the cost of care in local hospitals with daily performance of emergency and reconstructive surgeries, including for hand trauma [7,15]. If nerve suture and autografting can be performed by any orthopedic surgeon trained in microsurgery, we acknowledge that the proper achievement of digital replantation is much more challenging and unpredictable in this setting. Finally, the absence of any evaluation of the functional outcomes of nerve repair is also questionable.

Conclusion

This study reveals the nature of regular microsurgical practice in French MTFs, which mostly relates to managing hand injuries. These procedures were performed by orthopedic surgeons trained in completing microsurgery with limited equipment. Future directions may include microsurgery simulation programs as part of continuous medical education and the provision of magnification loupes and basic microsurgical sets in FSTs.

Disclaimers

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the French Army Health Medical Service.

Disclosure of interest

The authors declare that they have no competing interest.

Acknowledgments

The authors thank all the surgeons who took part in the treatment of the patients.

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