The first MNSUs were created by Hugh Cairns during World War II. Their aim was to provide specific treatment for head injuries (total removal of bone fragments under direct vision, wound closure, and air evacuation) close to the fighting with sufficient mobility to be redeployed “where the need was greatest.” The units initially included 1 neurosurgeon, 1 neurologist, and 1 “anaesthetist,” and paramedical staff trained for neurosurgical casualties, and were provided with sufficient equipment to be able to perform at least 200 operations without replacements. They were serviced by field ambulances attached to a hospital or casualty clearing station located further from the battlefield. Such units were subsequently developed and used by the Canadian Army during World War II and later on by the Eighth US Army during the 2nd year of the Korean War. In their paper, Meirowsky and Barnett emphasized the advantages of such units: mobility, the earliest possible neurosurgical management, and economy (because of reduced morbidity). Enhanced mobility imposed a number of constraints, including portable surgical kits restricted to a variety of instruments necessary to perform craniotomies and/or craniectomies. That is why, according to Metrowski and colleagues, only experienced neurosurgeons could be deployed in MNSUs, not only because of their specific knowledge of intracranial injuries, but also because of their surgical know-how.

After this period, the management of wartime neurosurgical casualties changed for several reasons:

1. Logistics. During the Vietnam War, evacuation of patients greatly improved with the development of air ambulances: the UH-1D (Huey) was able to transport 6–9 patients at a time within 30–35 minutes following injury. Patients were evacuated to facilities such as evacuation hospitals where a neurosurgeon was present on the surgical staff.

2. Techniques. The evolution of surgical instruments (surgical microscope), neuroradiological tools (CT), and resuscitation facilities improved the management of neurosurgical casualties. Many of the advances were associated with an increase in the size, weight, and complexity of equipment, however, and were not suitable for use in mobile structures such as Level 2 medical field units.

3. Indications. Treatment of penetrating head injuries evolved with the widespread acceptance of more conservative surgical treatment proposed by some authors. With these developments, neurosurgical capability became fixed in Level 3 facilities. The neurosurgeon lost his mobility and capacity to operate close to the front line, paradoxically because of the improvements in his practice. This situation became controversial because some

The authors present the French concept of a mobile neurosurgical unit (MNSU) as used to provide specific support to remote military medicosurgical units deployed in Africa, South America, Central Europe, and Afghanistan. From 2001 to 2009, 15 missions were performed, for 16 patients. All but 3 of these missions (those in Kosovo, French Guyana, and Afghanistan) concerned Africa. Eleven patients were French soldiers, 3 were civilians, and 2 were Djiboutian soldiers. The conditions that MNSUs were requested for included craniocerebral wounds (2 cases), closed head trauma (7 cases), spinal trauma (5 cases), and spontaneous intracranial hemorrhage (2 cases). In 5 of the 16 cases, neurosurgical treatment was provided on site. All French soldiers and 2 civilians were evacuated to France. The MNSU can be deployed for timely treatment when some delay in neurosurgical management is acceptable.

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KEY WORDS • mobile team • French neurosurgery • war surgery

Abbreviations used in this paper: medevac = medical evacuation; MNSU = mobile neurosurgical unit.

advocated the presence of a neurosurgeon in Level 2 facilities to shorten the time between injury and surgery.\textsuperscript{13}

The current deployment of French medical surgical units outside France involves peace-keeping missions and health care for military personnel. Supporting medical units include Level 2 or Level 2–3 medicsurgical groups in which surgical suites do not allow optimal neurosurgical practice. These conditions are improving with telemedicine, development of telesurgical tools, and the recent deployment of radiological facilities (mobile CT units) in Africa, Central Europe, and Afghanistan. General surgeons are supposed to be trained for neurosurgical emergencies, but in practice, the time devoted to specific education is relatively short.\textsuperscript{14,15}

This can be partially explained by the fact that there is no mandatory course in neurosurgery during the education of military general surgeons in France. Specific workshops are held only occasionally, although a significant effort was recently begun in 2007 to implement regular specialized neurosurgical training for general and orthopedic surgeons. The management of the main spinal, head and neck, and neurosurgical emergencies is presented, in order to improve the versatility of these practitioners before their deployment in Level 2 and 3 units.

The establishment of a permanent telephone and Internet link in a single rear structure in Paris, Val-de-Grâce Military Hospital, has greatly improved the quality of communication between neurosurgeons and French remote medicsurgical teams. Remote consultations are generally initiated by telephone, and, when possible, data are transmitted by Internet. The on-call neurosurgeon may contact the radiologist when images are transmitted (no radiologist is deployed outside France because there are very few radiologists in the French Army). Nevertheless image and information transfer systems are still not always available in every location where they might be needed. In 2000, difficulties in sending a neurosurgeon into Sarajevo to operate on a patient with an open cranio-cerebral wound before his transfer to France led us to propose the creation of a mobile team including neurosurgical and resuscitation staff.

### The Modern French MNSU

A complete MNSU consists of 1 active duty military neurosurgeon, 1 general medical nurse, and 1 operating room nurse trained in managing neurosurgical casualties. One anesthesiologist and 1 nurse anesthetist may be added to this unit on demand. Specific surgical equipment is permanently available in our neurosurgical department. It includes cranial and spinal emergency sets, spinal cervicodorsal and lumbosacral osteosynthesis sets, and an intracranial pressure monitoring kit.

The medical units that might have need of an MNSU are remote French military airborne surgical units (Level 2 medical support) and medicsurgical groups (Level 2–3 medical support) based in Africa, Central Europe, and Afghanistan.

An MNSU may be requested to take care of civilian or military patients with neurosurgical emergencies. The neurosurgical consultation is initiated by telephone, generally with the presence of the anesthesiologist, and the images may be transmitted using the telemedicine system to the neurosurgical Department of Val-de-Grâce Hospital. The decision to send an MNSU or a single neurosurgeon must be approved by the office of the Surgeon General.

When requested, MNSUs may be carried by light military aircraft based in Villacoublay (approximately 6 miles away from Percy Military Trauma Centre Hospital, Clamart). These aircraft are also used for nonmedical missions and are not permanently equipped for medical transport. These aircraft are able to receive and transport one severely wounded patient with resuscitation equipment (Fig. 1). Regular flights may also be used for patient transport when the case is not an emergency, and regular military or civilian flights may be used when a single neurosurgeon is required.

### Summary of Recent Missions

From January 2001 to November 2009, 15 missions were performed (Table 2). They can be summarized as follows:

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**TABLE 1: Theoretical classification of the NATO levels of medical support**

<table>
<thead>
<tr>
<th>Level</th>
<th>Role &amp; Main Characteristics</th>
<th>Staffing</th>
<th>Force Size†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>primary health care &amp; immediate life-saving procedures; integrated into the fighting unit (France); no surgical or patient holding capability</td>
<td>1–2 doctors (France: 1); 6–2 paramedics (France: 1 nurse)</td>
<td>ranges from a combat company (France: 150 personnel) to a battalion (500–600 personnel)</td>
</tr>
<tr>
<td>2</td>
<td>increased medical capability &amp; limited inpatient bed space (4–20 beds); basic field lab &amp; x-ray equipment, blood bank; high mobility (theoretical); examples: Forward Surgical Team, Mobile Field Surgical Team (US), Airborne Surgical Unit (France)</td>
<td>surgical staff (1–3 general/visceral surgeons, orthopedist, anesthesiologist, OR nurse, nurse anesthetic): 20–40 personnel</td>
<td>brigade (&gt;1000 personnel)</td>
</tr>
<tr>
<td>3</td>
<td>emergency &amp; definitive medical &amp; surgical management, intensive care; high-level lab &amp; radiological capabilities (including CT), no mobility</td>
<td>15–20 doctors; multidisciplinary staff (including ENT surgeon, ophthalmologist, neurosurgeon, urologist); 80–200+ personnel</td>
<td>&gt;5000 personnel</td>
</tr>
</tbody>
</table>

* Theoretical classification based on information from Department of Defense, 2004, and Seet, 1999. Each service and nation have different types of unit at each level. Abbreviation: ENT = ear, nose, and throat. † Size of the force to be supported by the level specified.
### TABLE 2: Summary of the MNSU activity between 2001 and 2009*

<table>
<thead>
<tr>
<th>Mission Code</th>
<th>Date</th>
<th>Pt Age (yrs), Sex</th>
<th>Combat Status</th>
<th>Available Data†</th>
<th>Internet Facilities</th>
<th>Departure</th>
<th>Surgery on Site</th>
<th>Evacuation to France</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Chad)</td>
<td>Jan 2001</td>
<td>40, F civilian</td>
<td>traffic accident 6 days previously, incompl UE deficit, C4–5 dislocation</td>
<td>yes</td>
<td>delayed, reg military flight</td>
<td>yes</td>
<td>no</td>
<td>favorable, neurol improve-ment</td>
<td></td>
</tr>
<tr>
<td>2 (Cameroon)</td>
<td>Jan 2003</td>
<td>37, M Fr soldier</td>
<td>severe head trauma, coma, acute SDH?</td>
<td>no</td>
<td>emerg, w/ medevac team</td>
<td>no</td>
<td>yes</td>
<td>death 2 days after arrival in France</td>
<td></td>
</tr>
<tr>
<td>3 (Chad)</td>
<td>Feb 2004</td>
<td>8, M civilian</td>
<td>traffic accident, severe head trauma, coma</td>
<td>no</td>
<td>emerg, w/ medevac team</td>
<td>no</td>
<td>yes</td>
<td>death 21 days after arrival in France</td>
<td></td>
</tr>
<tr>
<td>4 (Djibouti)</td>
<td>May 2004</td>
<td>34, M Djib soldier</td>
<td>traffic accident, quadriplegia, C5–6 dislocation</td>
<td>yes</td>
<td>delayed, reg civilian flight</td>
<td>yes</td>
<td>no</td>
<td>death 13 months after trauma</td>
<td></td>
</tr>
<tr>
<td>5 (Djibouti)</td>
<td>Nov 2004</td>
<td>44, M Fr soldier</td>
<td>open craniocerebral wound, neurol deterioration</td>
<td>yes</td>
<td>emerg, w/ medevac team</td>
<td>yes</td>
<td>yes</td>
<td>favorable, neurol recovery, cranioplasty 1yr post injury</td>
<td></td>
</tr>
<tr>
<td>6 (Djibouti)</td>
<td>Feb 2006</td>
<td>21, M Fr soldier</td>
<td>ICH, posterior fossa AVM, hydrocephalus?, GCS 14</td>
<td>no</td>
<td>emerg, w/ medevac team</td>
<td>no</td>
<td>yes</td>
<td>favorable, AVM embolization</td>
<td></td>
</tr>
<tr>
<td>7 (Djibouti)</td>
<td>Jan 2008</td>
<td>25, M Fr soldier</td>
<td>traffic accident, severe head trauma, intracranial contusions, GCS 14, secondary agitation &amp; sedation</td>
<td>no</td>
<td>emerg, w/ medevac team</td>
<td>no</td>
<td>yes</td>
<td>favorable, conservative management</td>
<td></td>
</tr>
<tr>
<td>8 (Djibouti)</td>
<td>Oct 2008</td>
<td>44, M Fr soldier</td>
<td>craniofacial trauma, GCS 12, lt hema- paresis, rt intraparenchymal frontotemporal contusions</td>
<td>yes</td>
<td>emerg, w/ medevac team</td>
<td>yes</td>
<td>yes</td>
<td>favorable, neuropsych sequelae</td>
<td></td>
</tr>
<tr>
<td>9 (Gabon)</td>
<td>Nov 2008</td>
<td>40, M Fr soldier</td>
<td>cervical trauma (parachuting injury), UE paresthesiae, C4–5 instability?</td>
<td>no</td>
<td>emerg, w/ medevac team</td>
<td>no</td>
<td>yes</td>
<td>favorable, conservative treatment</td>
<td></td>
</tr>
<tr>
<td>10 (Gabon)</td>
<td>Jan 2009</td>
<td>22, M Fr soldier</td>
<td>severe closed head trauma, bifrontal intraparenchymal contusions, vault fracture, GCS 14</td>
<td>yes</td>
<td>emerg, w/ medevac team</td>
<td>no</td>
<td>yes</td>
<td>favorable, mild neuropsych sequelae</td>
<td></td>
</tr>
<tr>
<td>11 (Kosovo)</td>
<td>May 2009</td>
<td>52, M Fr soldier</td>
<td>ICH, posterior fossa AVM, hydrocephalus GCS 7</td>
<td>no</td>
<td>emerg, w/ medevac team</td>
<td>yes</td>
<td>yes</td>
<td>favorable, AVM embolization</td>
<td></td>
</tr>
<tr>
<td>12 (Fr Guyana)</td>
<td>Aug 2009</td>
<td>23, M Fr soldier</td>
<td>penetrating craniocerebral knife injury, GCS 13</td>
<td>yes</td>
<td>emerg, w/ medevac team</td>
<td>yes</td>
<td>yes</td>
<td>favorable</td>
<td></td>
</tr>
<tr>
<td>13 (Djibouti)</td>
<td>Oct 2009</td>
<td>25, M Djib soldier</td>
<td>traffic accident, quadriplegia, C6–7 dislocation</td>
<td>yes</td>
<td>delayed reg civilian flight</td>
<td>yes</td>
<td>no</td>
<td>stable</td>
<td></td>
</tr>
<tr>
<td>14 (Djibouti)</td>
<td>Oct 2009</td>
<td>5 mos, M Fr civilian</td>
<td>severe closed head injury, epidural hematoma, GCS 5</td>
<td>yes</td>
<td>emerg, w/ civilian ped medevac team</td>
<td>yes</td>
<td>yes</td>
<td>favorable, neuropsych sequelae</td>
<td></td>
</tr>
<tr>
<td>15 (Afghanist-</td>
<td>Nov 2009</td>
<td>31, M Fr soldier</td>
<td>traffic accident, severe closed head injury, GCS 5, acute SDH</td>
<td>yes</td>
<td>emerg, w/ medevac team</td>
<td>yes</td>
<td>yes</td>
<td>severe neuropsych sequelae</td>
<td></td>
</tr>
<tr>
<td>16 (Djibouti)</td>
<td>Oct 2009</td>
<td>30, M Fr soldier</td>
<td>traffic accident, spinal trauma, incompl UE deficit, C-7 pars articularis fracture</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
<td>favorable, cervical anterior arthrodesis</td>
<td></td>
</tr>
</tbody>
</table>

* AVM = arteriovenous malformation; Djib = Djiboutian; Djibouti = Republic of Djibouti; emerg = emergency; ICH = intracerebral hemorrhage; incompl = incomplete; Fr = French; GCS = Glasgow Coma Scale; neurol = neurological; neuropsych = neuropsychological; ped = pediatric; Pt = Patient; reg = regular; SDH = subdural hematoma; UE = upper extremity.
† Data available before MSNU was sent.
1. “Immediate emergency” cases in which data were transmitted by telephone and Internet, there was an indication for surgery, and an MNSU was sent with a medevac team: 5 cases (2 open craniocerebral wounds, 3 severe closed head injuries); Missions 5, 8, 12, 14, and 15 (Figs. 2 and 3).

2. “Immediate emergency” cases in which data were transmitted only by telephone and/or there was failure of communication by Internet, an MNSU was sent with a medevac team, and the indication for surgery was discussed on site: 7 cases (2 spontaneous intracerebral hemorrhages, 3 cases of closed head trauma, 2 spinal trauma cases); Missions 2, 3, 6, 7, 9, 10, and 11 (Fig. 4). It was determined that surgery was not required in 5 of these 7 cases. In the remaining case, placement of an external ventricular drain was required for treatment of intraventricular hemorrhage.

3. “Delayed emergency” cases in which data were transmitted by telephone and Internet, there was an indication for surgery, and a neurosurgeon was sent with appropriate surgical equipment: 4 cases (closed spinal trauma); Missions 1, 4, 5, and 13. Transport was accomplished by regular military or civilian flight.

The time from MNSU activation to takeoff was less than 3 hours for each “immediate emergency” case. Time to operation in-country depended on the time of flight to destination (8 hours for Mission 15, Afghanistan).

**Discussion**

Neurosurgery represents a small part of the activity of Level 2 and 3 French medicosurgical units deployed outside France. During the civil war in N’Djamena in 1980, the French Military Airborne Advance Surgical Unit received 1484 wounded patients and performed 518 surgical procedures; 27 patients presented with opened craniocerebral wounds, with 14 of these being treated surgically. Two other patients presented with paraplegia (due to war-related vertebromedullary wounds) and died; these patients constituted 1.95% of the casualties, and the procedures related to their care represented 2.7% of the surgical procedures performed. A more recent publication reported that neurosurgical procedures during a United Nations peace-keeping mission in Rwanda represented 2% of the overall interventions. Eleven of these 17 procedures were considered emergencies and 6 were considered elective, including repair of scalp or cranial defects or meningocele and surgical treatment of osteomyelitis or chronic subdural hematoma. These data confirm that the presence of neurosurgeons on site is unnecessary, despite the conclusions of a 2000 report. Many publications emphasize the necessity of serious training in neurosurgery for deployed general surgeons—training that includes management of neurotrauma, infections of the CNS, and indeed congenital pathologies for the pediatric civilian population. This training can be supported and updated by specialized military illustrated manuals or other publications.

Nevertheless, this training is often limited to the treatment of some chronic subdural hematomas, open cranial wounds, and/or a few acute extradural hematomas, in conditions in which complete neurosurgical facilities are available. The situation is different in remote areas. Telemedicine and telesurgical assistance (limited to surgical coaching by telephone or message in most cases) certainly reduce the stress of isolated and generally young surgeons. This mode of support obviously depends on the availability of adequate computer systems, the quality and reliability of which continue to improve. Two examples of cases in which teleassistance was used are illustrated in Figs. 5 and 6. In both of these cases,
The French mobile neurosurgical unit

The technology allowed appropriate management without deployment of an MNSU. The patient in the first example was a 40-year-old French soldier who was admitted to the French Level 2 medicosurgical unit in Kabul in status epilepticus, which was considered at the time to be due to “posttraumatic contusion.” An emergency CT scan performed on site showed a possible cerebral contusion (Fig. 5). There was no radiologist available in Kabul, and the pictures were transmitted to the neurosurgical department at Val-de-Grâce, where the on-call neurosurgeon requested a radiological diagnosis. No diagnosis could be established at this stage, and the patient, who did not require an MNSU, was evacuated to France for further studies (MR imaging) and specific management. The MR images led to a tentative diagnosis of intraaxial right frontal tumor. The final diagnosis after surgery was cerebral ganglioglioma.

The patient in the second example was a 2-year-old boy with severe head trauma resulting from a fall. The child had a Glasgow Coma Scale score of 13, and an emergency CT scan revealed a very large extradural hematoma of the cranial vault. A consultation was conducted via the Internet and telephone (Fig. 6). The on-call neurosurgeon at Val-de-Grâce (R.D.) established the diagnosis of subdural hematoma, and a 3D CT reconstruction was created so that a schematic guide could be prepared for the use of the surgeons on site. Using Microsoft PowerPoint, the neurosurgeon marked the sites for the skin incision, bilateral craniotomies, and dural tack-up sutures for bleeding control and hemostasis directly onto the 3D...
CT reconstruction. This guidance permitted the general surgeon and the orthopedic surgeon in Djibouti to successfully perform the surgery. Thanks to the telephone link, the general surgeon was able to report their progress and concerns during and after the surgery. The postoperative course showed dramatic improvement, and the child was rapidly discharged home. The surgeons in Djibouti reported that the indications for the tack-up sutures were of great utility when significant bleeding occurred from the midline as the hematoma was progressively removed.

This was the first such use of this technology by this team and was possible because 3D CT reconstructions were performed and transmitted via Internet. The schematic seemed to be the best way for the neurosurgical consultant in France to explain the surgical procedure to non–neurosurgeons in Djibouti (better than verbal description by telephone). Again, the MNSU was finally not required for this child.

We think MNSUs represent an interesting supplementary tool for remote units for situations in which a delay in neurosurgical management is acceptable. Certainly, there are cases in which the sending of a neurosurgeon turns out to be unnecessary, as we could say with respect to some of the cases in our series, and sometimes the lack of precise and accurate information can result in an MNSU being requested unnecessarily. In our system, evacuation of the severely wounded is a high priority. Including a neurosurgeon in the evacuation team does not pose logistical challenges other than the need to find sufficient space on the airplane, and can be beneficial for the patient, even when no surgery is needed in the final analysis.

Conclusions

Neurosurgical emergencies represent a small part of the activity of remote French Level 2 and 3 medicosurgical units. Training of general surgeons is the basis for the management of these cases, and such training is optimally supplemented with teleassistance. The MNSU is a relatively low-cost tool for providing additional support for these remote units in some cases.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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References
1. Amirjamshidi A, Abbassioun K, Rahmat H: Minimal debridement or simple wound closure as the only surgical treatment in war victims with low-velocity penetrating head injuries. Indications and management protocol based upon more than 8 years follow-up of 99 cases from Iran-Iraq conflict. Surg Neurol 60:105–111, 2003
11. Perrin J: [One year of war neurosurgery in the French expedi-

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