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Severe Trauma Patients Requiring Undelayable Combined Cranial and Extra-Cranial Surgery: A Proof-of-Concept Monocentric Study

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ABSTRACT

Introduction:

To date, there is no evidence concerning the emergency surgical management of severe trauma patients (STP) with severe traumatic brain injury (STBI) presenting a life-threatening intracranial hematoma and a concomitant extra-cranial non-compressible active bleeding. Current guidelines recommend stopping the extra-cranial bleeding first. Nevertheless, the long-term outcome of STP with STBI mainly depends from intracranial lesions. Thus, we propose a combined damage-control surgical strategy aiming to reduce the time spent with intracranial hypertension and to hasten the admission in the intensive care unit. The main objective of the study is to evaluate the benefits of combined cranial and extra-cranial surgery of STP on the long-term outcome.

Materials and Methods:

We retrospectively searched through the database of STBI of a level 1 trauma center facility (Sainte-Anne Military Teaching Hospital, Toulon, France) from 2007 until 2021 looking for patients who benefited from combined cranial and extra-cranial surgery in an acute setting.

Results:

The research yielded 8 patients. The mean age was 35 years old (±14) and the male to female sex ratio was 1.7/1. The trauma mechanism was a fall in 50% of the cases and a traffic accident in 50% of the cases. The median Glasgow coma scale score was 8 (IQR 4) before intubation. The median Injury Severity Score was 41 (IQR 16). Seven patients (88%) presented hypovolemic shock upon admission. Six patients (75%) benefited from damage-control laparotomy among, whom 4 (67%) underwent hemostatic splenectomy. One patient benefited from drainage of tension pneumothorax, and one patient benefited from external fixator of multiple limb fractures. Seven patients (88%) benefited from decompressive craniectomy for acute subdural hematoma (5 patients) or major brain contusion (2 patients). One patient (12%) benefited from craniotomy for epidural hematoma. Three patients presented intraoperative profound hypovolemic shock. Six patients (75%) presented a favorable neurologic outcome with minor complications from extra-cranial surgeries and 2 patients died (25%).

Conclusion:

Performing combined life-saving cranial and extra-cranial surgery is feasible and safe as long as the trauma teams are trained according to the principles of damage control. It may be beneficial for the neurologic prognostic of STP with STBI requiring cranial and extra-cranial surgery.

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INTRODUCTION

There are clear guidelines concerning the initial management of severe trauma patients (STP) with concomitant severe traumatic brain injury (STBI).[1] It addresses the issue of young patients around 40 years old, predominantly male, who sustained high-velocity traffic accident with an Injury Severity Score (ISS) ≥16 and an Abbreviated Injury Scale (AIS) ≥3 in 2 different anatomic regions, including the head.[2] Thanks to the emergence of the concept of damage control 30 years ago,[3] these patients now benefit from a 3-step emergency management, including "abbreviated" damage-control surgery, then resuscitation in the intensive care unit, and planned definitive surgery a few days later.[4] This strategy led to a reduction of the preventable mortality during the first 6 to 24 hours. After initial resuscitation in the emergency room, a full-body computed tomography (FB-CT) scan allows proceeding with damage-control surgery in decreasing order of seriousness,[5] with life-threatening non-compressible extra-cranial bleeding coming first.[1] Intraoperative neuro-resuscitation is guided by the invasive monitoring of intracranial pressure (ICP).[6,7]

On the other hand, STBI stands among the leading causes of early mortality and long-term disability worldwide.[8] The emergency management of patients suffering from STBI is guided by clear recommendations and include a basic

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neurologic examination (Glasgow coma scale [GCS], pupils, and focal symptoms) and prompt brain CT scan.[7,9] Current guidelines support the urgent evacuation of life-threatening epidural hematoma (EDH) or acute subdural hematoma (ASH) within 4 hours following trauma in order to achieve the best neurological outcome.[10,11]

Yet, there are no guidelines concerning the emergency surgical management of STP presenting a life-threatening intracranial hematoma and a concomitant life-threatening noncompressible extra-cranial bleeding. It is recommended that the extra-cranial bleeding should be stopped first and that intracranial hemorrhage should be evacuated right afterward.[1] Going beyond the principle of reducing the preventable mortality of STP, we address the issue of the preventable neurological morbidity. Combining the cranial and the extra-cranial surgery would allow to reduce the time spent with intracranial hypertension (ICH) and to hasten the admission in the intensive care unit.

MATERIALS AND METHODS

Source Population

We retrospectively screened the database of the operating theatre as well as the registry of STBI patients of the intensive care unit looking for all the patients who sustained head trauma and who were operated on in an emergency setting with a cranial surgery at our level 1 trauma center (Sainte-Anne Military Teaching Hospital, Toulon, France) between 2007 and 2021. Every patient who benefited from undelayable combined cranial and extra-cranial surgery were included.

Inclusion and Exclusion Criteria

Undelayable cranial emergencies included EDH or ASH meeting commonly accepted surgical criteria, massive brain contusion causing intracranial hypertension, and life-threatening depressed skull fracture (DSF). Diffuse traumatic brain injury requiring decompressive craniectomy (DC) despite maximal neuro-resuscitation measures and chronic subdural hematoma were excluded. The "undelayable" character of the surgery was defined as a procedure carried out immediately after the admission of the patient, as soon as the FB-CT scan was completed. The surgeries were defined as "combined" when the incision of the next procedure was made before the completion of the previous procedure.

Undelayable extra-cranial emergencies included noncompressible thoracic, abdominal, or pelvic hemorrhage and multiple long bones or open fractures at risk of exsanguination, contamination or fat embolism. Ophtalmologic, maxillo-facial, and oto-rhino-laryngologic emergencies were excluded.

Data Extraction

The patients' files were screened looking for the following information: age and sex; mechanism of the trauma; GCS; pupil examination; emergency imaging modality; brain CT scan findings; ISS and AIS; hypovolemic shock; coagulation parameters; transfusion requirements within the first 24 hours; combined surgery carried out; eventual interventional radiology procedure; second look surgeries; delay of eventual cranioplasty; and outcome according to the Glasgow Outcome Scale (GOS, ranging from 1 to 5 with 1 being "death" and 5 being "good recovery").

Primary and Secondary Endpoints of the Study

The main objective of the study was to evaluate the benefits of combined cranial and extra-cranial surgery of STP on the long-term outcome. The secondary endpoint of the study was to evaluate the safety of combining two heavy emergency surgical procedures from a resuscitation viewpoint.

Statistics

Categorical variables were presented as numbers and percentages. Regarding quantitative variables, discrete variables were presented as median and interquartile range (IQR) and continuous variables were presented as mean $\pm$ standard deviation (SD).

RESULTS

Database Research (Fig. 1)

The screening of the database of the operating theatre and of the registry of the intensive care unit looking for patients operated on for undelayable traumatic intracranial lesions between 2007 and 2021 yielded 310 results. Eleven patients benefited from combined cranial and extra-cranial procedures, among whom 3 ophthalmologic or maxillo-facial surgeries were excluded. Hence, 8 patients were finally retained.

Epidemiology, Clinical Presentation and Brain CT Scan Findings (Table I and Supplementary Table S1)

The mean age was 35 years old ($\pm$14) and the male to female sex ratio was 1.7/1. The trauma mechanism was a fall from a height in half of the cases and a traffic accident mainly as pedestrian for the other half. The median GCS was 8 (IQR 4.25) before intubation. The pupil examination was reported in 6 cases (75%); it was normal in 5 cases, and there was 1 case of unilateral mydriasis. Focal symptoms were reported in 1 case (12%) with hemiplegia.

The median ISS was 41 (IQR 16.25). The median AIS were 5 for the head (IQR 0.25), 4 for the thorax (IQR 1), 4 for the abdomen (IQR 1.75), 1 for the pelvis (2.25), 1 for the spine (IQR 2), and 0 for extremity/orthopedics (IQR 0.5). Seven patients (88%) presented hypovolemic shock upon admission, among whom 2 patients (25%) still presented hemodynamic instability despite initial resuscitation.

Most patients were operated on for extra-axial hematomas. Five patients (63%) were operated on for an ASH (number 2, 4, 5, 6, and 8). It was associated with brain contusions in 4 cases and with traumatic subarachnoid hemorrhage in 3 cases. In one case, it was associated with a DSF

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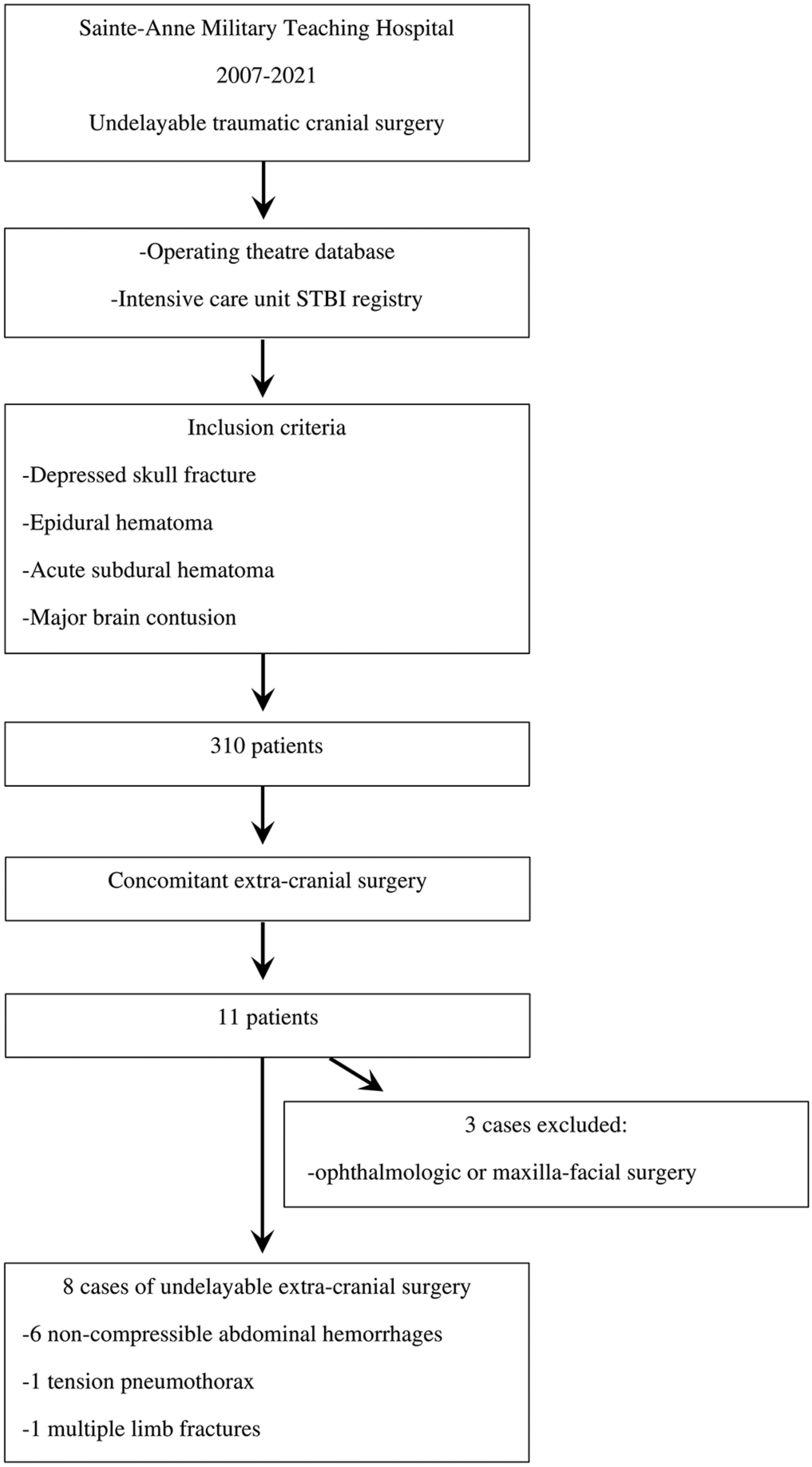

FIGURE 1. Patient flowchart. STBI (severe traumatic brain injury).

and an EDH. Two patients (25%) were operated on for an EDH (number 1 and 7). In one case, it was associated with a cranio-cerebral wound (CCW) and a major brain contusion, and in the other case, it was caused by a skull fracture. Last, patient 3 (12%) presented a DSF with an underlying major cerebral contusion.

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TABLE I. Patient Characteristics

Patient	Age sex	Mechanism	Prehospital/ admission GCS	Pupils	Focal sign	ISS	Head AIS	Other AIS	Grade/shock/ SBP (mmHg)
1	♂ 34	8 m fall	7/sedated	N	Left HP	50	5	T3, A4, E2	HDI/Yes/60
2	♀ 54	3 m fall	14/13 then sedated	N	–	22	5	T5, P3, S2	No
3	♂ 31	6 m fall	9/sedated	–	–	48	5	T4, A3, S2	HDS/Yes/-
4	♀ 55	12 m fall	11/sedated	–	–	34	4	T4, A4, P3, S2	HDS/Yes/90
5	♂ 16	Traffic (pedestrian)	4/3	N	–	27	4	T4, A4, P2	HDS/Yes/-
6	♀ 37	Traffic (pedestrian)	7/sedated	Left My	–	41	5	T3, E3, P2	HDS/Yes/80
7	♂ 21	Traffic (motorcycle)	3/sedated	N	–	41	5	A4	HDS/Yes/100
8	♂ 30	Traffic (pedestrian)	14/10	N	–	66	5	T4, A5, S3	HDI/Yes/60

Abbreviations: A, abdomen; AIS, abbreviated injury scale; E, extremity/orthopedics, GCS, Glasgow coma scale; HDI, hemodynamic instability after initial resuscitation; HDS, hemodynamic stability after initial resuscitation; HP, hemiplegia; ISS, injury severity score; My, mydriasis; N, normal; P, pelvis; S, spine; SBP, systolic blood pressure; T, thorax.

Combined Surgery (Table II)

All the patients benefited from FB-CT scan before surgical management. Six patients (number 1, 3–5, 7, and 8) (75%) underwent emergency laparotomy for noncompressible abdominal hemorrhage. Among them, 4 patients (50%) benefited from hemostatic splenectomy and 2 patients (25%) from abdominal packing. One patient (12.5%) benefited from external fixators for multiple limb fractures. One patient (12.5%) benefited from drainage of a tension pneumothorax. Seven patients (87.5%) benefited from decompressive craniectomy and 1 patient (12.5%) from craniotomy.

Below are concisely presented the trauma mechanism, clinical presentation, CT findings, and emergency surgical management for each patient:

1) Patient 8 was a 34-year-old man who sustained an 8-m fall. He presented with a GCS of 10 and deep hemorrhagic shock and underwent placement of a Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA). FB-CT scan showed left-sided epidural and subdural hematomas associated with diffuse traumatic brain injuries (contusions and petechiae) and diffuse abdominal effusion with American Association for the Surgery of Trauma (AAST) grade V spleen injury. He underwent damage-control laparotomy with hemostatic splenectomy and perihepatic packing combined with DC and suffered from intraoperative deep hypotension. Because of intracranial hypertension despite the DC, an external ventricular drain (EVD) was added at day 2, but the patient died soon afterward.
2) Patient 4 was a 55-year-old woman who sustained a 12-m fall. Upon admission, she presented with a GCS of 11, hemorrhagic shock, and a left leg wound. FB-CT scan showed a right ASH, abdominal effusion with an AAST grade V spleen injury, and a left femoral shaft fracture. She underwent hemostatic splenectomy along with DC and suffered from intraoperative deep hypotension. She also benefited from quick leg debridement. She benefited from femoral immobilization until definitive femoral shaft fixation at day 4.
3) Patient 5 was a 16-year-old boy who was struck by a car and presented with a GCS of 3 and hemorrhagic shock upon admission. FB-CT scan showed a left ASH with a brain contusion and abdominal effusion with an AAST grade V spleen injury. He underwent hemostatic splenectomy combined with the placement of an intracranial pressure monitor (ICPM), which was immediately converted into DC because of major intracranial hypertension. He also benefited from external fixator (EF) on the left leg immediately afterwards.
4) Patient 7 was a 21 year-old man who sustained a motorcycle accident and presented with a GCS of 3 and hemorrhagic shock. FB-CT scan showed a right frontal EDH associated with abdominal effusion from an AAST grade V spleen injury. He underwent hemostatic splenectomy combined with a craniotomy for evacuation of the EDH.
5) Patient 1 was a 34-year-old man who sustained an 8-m fall and presented with a GCS of 7 before intubation. Upon admission, he presented a CCW and profound hemorrhagic shock. FB-CT scan showed an EDH and a major temporal contusion underneath the CCW and moderate abdominal effusion. He was taken to the operating room for damage-control cranial surgery, but deep hypotension motivated to repeat the FAST scan that showed increased abdominal effusion. Thus, he underwent damage-control laparotomy with perihepatic and preperitoneal packing, combined with DC and placement of an EVD. Because of repeated hypotension, abdominal CT scan was performed and showed active bleeding from the right hepatic artery, which was embolized.
6) Patient 3 was a 31-year-old man who sustained a 6-m fall and presented with a GCS of 9 before intubation. Upon admission, he suffered from hemorrhagic shock. FB-CT showed a frontal DSF with a major brain contusion underneath, moderate abdominal effusion, and a femoral shaft fracture and a radius fracture. He was taken to the operating room for damage-control cranial

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TABLE II. Combined Surgery and Outcome

		Combined damage-control surgery										
Patient	Preoperative imaging	Extra-cranial procedure	Cranial procedure	Intraoperative hypovolemic shock	Other damage-control surgery	Interventional radiology	Second look extra-cranial surgery (timing)	Delayed planned extra-cranial surgery (timing)	ICPM	Tracheotomy	Cranioplasty	GOS (last follow-up)
1	FB-CT + FAST scan	LP packing	DC, EVD	–	–	right hepatic artery emboliza-tion	LP (48 h)	–	EVD	Yes	4 months	4 (6 months)
2	FB-CT	tPNO drainage	ICPM then DC	–	–	–	–	–	ICPM	Yes	3 months	5 (10 years)
3	FB-CT + FAST scan	LP packing	DC	–	–	–	LP (48 h)	DF femur, radius (48 h)	ICPM	Yes	–	1 (1 year)
4	FB-CT	LP splenec-tomy	DC	Yes	Leg debride-ment	–	–	DF femur (96 h)	ICPM	–	4 months with VPS	5 (6 years)
5	FB-CT	LP splenec-tomy	ICPM then DC	–	EF Left leg	–	–	–	ICPM	–	2 months	5 (4 years)
6	FB-CT	EF right femur, right tibia and left wrist, debride-ment left leg	ICPM then DC	Yes	–	–	–	DF right femur, right tibia, left tibia, left wrist (120 h)	ICPM		LTFU	5 (6 months)
7	FB-CT + FAST scan	LP splenec-tomy	Cr	–	–	–	–	–	–	–	–	5 (6 months)
8	FB-CT	REBOA, LP splenec-tomy packing	DC	Yes	EVD (48 h)	–	LP (48 h)	–	ICPM	Yes	–	1

Abbreviations: DF, definitive fracture fixation; EF, external fixator; EVD, external ventricular drain; FAST, focused assessment with sonography for trauma; FB-CT, full-body computed tomography scan; GOS, Glasgow outcome scale; ICPM, intracranial pressure monitor; LP, laparotomy; LTFU, lost to follow-up; REBOA, resuscitative endovascular balloon occlusion of the aorta; tPNO, tension pneumothorax; VPS, ventriculo-peritoneal shunt.

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surgery, but deep hypotension motivated to repeat the FAST scan, which showed increased abdominal effusion. Thus, a laparotomy with perihepatic and preperitoneal packing was performed along with DC. The 2 fractures were immobilized until definitive osteosynthesis at day 2. Abdominal de-packing was also performed at day 2. The patient passed away from bedsore complications a few weeks afterward.

7) Patient 2 was a 54-year-old woman who sustained a 3-m fall. Upon admission, she was hemodynamically stable and presented a GCS of 13. Because of rapid neurologic worsening, she benefited from urgent FB-CT scan, which showed a left ASH with a brain contusion, associated with a tension pneumothorax. She was taken to the operating room where she underwent placement of a chest tube along with an ICPM, which was immediately converted to DC because of major intracranial hypertension.
8) Patient 6 was a 37-year-old woman who was struck by a car and presented with a GCS of 7 before intubation. There was a hemorrhagic shock upon admission. FB-CT showed a complex skull fracture with a right ASH and a brain contusion underneath combined with multiple limb fractures. She underwent the placement of 3 different EF by 2 senior orthopedic surgeons along with an ICPM by the neurosurgeon, which was immediately converted to DC because of major intracranial hypertension. She suffered from intraoperative deep hypotension. She benefited from definitive fracture fixation at day 4.

Coagulation Parameters, Massive Transfusion Protocol, and Intraoperative Hypovolemic Shock (Supplementary Table S2)

Six patients (number 1, 3–6, 8; 75%) presented a coagulopathy upon admission. The mean hemoglobin level was 9.7 g/dL (±2.6), the median prothrombin time 55% (IQR 15), and the mean fibrinogen level 1.6 g/L (±0.6). Seven patients (88%) benefited from a massive transfusion protocol with a median number of 7 (IQR 3) units of packed red blood cells, 5.5 units (IQR 4.5) of fresh frozen plasma, and 1 unit (IQR 1) of platelet concentrate.

Three patients (number 4, 6, and 8) (38%) suffered from intraoperative hypovolemic shock. They presented preoperative coagulopathy with a mean hemoglobin level of 8 g/dL (±0.9) and a median prothrombin time of 48% (IQR 22). Aside from DC, one of them underwent REBOA followed by hemostatic splenectomy, the second underwent hemostatic splenectomy, and the third one benefited from EF for multiple limb fractures.

Second Look Extra-cranial Surgery and Delayed Planned Extra-cranial Procedures

The 3 patients (number 1, 3, and 8) who benefited from abdominal packing underwent a second look laparotomy for abdominal de-packing 48 hours afterward.

Patient 6 benefited from emergency placement of multiple external fixators in order to limit exsanguination from long bones fracture. Definitive fixation was performed a few days later according to the principles of damage control. Patient 5 underwent the placement of an EF for a left tibial fracture directly after the combined surgery. This fixator was left in place until bone consolidation. Patient 4 only benefited from leg debridement in the acute setting and benefited from femoral shaft fixation a few days later.

Neurological Outcome (Table II)

Half of the patients ($n = 4$) underwent a tracheotomy. Among the 7 patients who benefited from DC, 4 benefited from early cranioplasty after a mean delay of 3.3 (±1) months, 2 died, and 1 was transferred to another facility and lost to follow-up. In this series, 6 patients survived (75%) with a median GOS of 5 (IQR 1.75) after a mean follow-up of 3.6 (±3.9) years. Five patients presented a GOS of 5 and 1 patient a GOS of 4 (4 being "moderate disability," which is considered a good neurological outcome).

Outcome regarding Extra-cranial Injuries

All the patients who underwent hemostatic splenectomy benefited from a 2-year-long antibiotic prophylaxis with penicillin V (phenoxymethylpenicillin) and proper vaccination against encapsulated bacteria (*Neisseria meningitidis*, *Haemophilus influenzae b,* and *Streptococcus pneumoniae*).

Patient 4 presented a small bowel occlusion by flange 1 year after the splenectomy, which required a 2-time procedure. Her femoral fracture healed properly, and she was pain free 2 years afterward. Patient 5 benefited from the removal of EF 9 months after the trauma and did well since then.

DISCUSSION

Context

Great progress has been made in patient triage,[12] prehospital emergency care,[13] and initial resuscitation over the past 30 years. Thus, the profile of STP has evolved toward more severely injured and somewhat older patients, with greater ISS and higher in-hospital mortality.[14] In the same way, the reduction of the preventable early mortality caused by exsanguination thanks to the implementation of massive transfusion protocols has opened the door to a new type of STP with concomitant STBI and noncompressible extra-cranial hemorrhage.[15,16] Current recommendations have focused on the reduction of the preventable mortality during the first 6–24 hours with timely correction of coagulopathy, urgent intervention aiming to stop any life-threatening bleeding, and then neuro-resuscitation guided by invasive ICP monitoring. Nevertheless, the prognosis of STP with concomitant STBI mainly depends on the seriousness of intracranial lesions, independently from extra-cranial injuries.[17–20] Thus, driven by the assertion stating that "time is brain,"[21] we think that

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there is room for improvement in combining any intervention aiming to stop an extra-cranial bleeding and the cranial surgery for the evacuation of an intracranial hematoma.

Resuscitation Objectives

The initial emergency care of STP with concomitant STBI is a race against time. The trauma leader objectives are to maintain a proper cerebral perfusion pressure and to limit exsanguination as much as possible in the same time. Neuro-resuscitation guidelines recommend to maintain the SBP >110 mm Hg even if it may sustain extra-cranial bleeding,[22] the $SpO_2 \geq 96$, the $PaCO_2$ between 30 and 35 mmHg, the body temperature between 35 and 37°C and blood sugar level between 8 and 10 mmol/L in order to limit the occurrence of secondary brain insults.[23] Coagulation objectives are to maintain the platelet count >100 G/L and the fibrinogen level >1.5–2 g/L,[24] the hemoglobin level above 70 g/L in patients with no cardiovascular or oncologic comorbidities, and the prothrombin time above 70%.

Feasibility, Safety and Results of Combined Cranial, and Extra-cranial Surgery

There is growing evidence supporting the systematic use of FB-CT scan in the acute management of severe trauma patients in order to "diagnose first what kills first".[5,25] Previous studies identified a 25% reduction in the mortality rate of severe trauma patients managed with a FB-CT.[26] In our institution, all severe trauma patients benefit from a FB-CT, apart from those suffering obvious and catastrophic traumatic lesions that require immediate surgical management. Thus, all the patients included in this study benefited from FB-CT regardless of their hemodynamic status upon admission.

The priority is to stop the bleeding using an "abbreviated" damage-control thoracotomy or laparotomy.[27,28] STP suffer from a trauma-induced coagulopathy[29] but also from a brain-induced coagulopathy with fibrinolysis and increased consumption of coagulation factors.[30] Coagulopathy, along with the lethal triad in a shocked patient, sustain the ongoing bleeding. This vicious hemorrhagic circle is the rationale for damage-control procedures designed to "prioritize short-term physiological recovery over anatomical reconstruction."[31] As a fact, 6 patients (75%) in this series presented a coagulopathy, and 7 patients (88%) were massively transfused. Three patients (38%) suffered from intraoperative profound hypovolemic shock, but no early death was reported.

In such context, the concomitant evacuation of intracranial hematoma should be performed according to the principles of damage-control neurosurgery introduced 20 years ago.[32] DC represents the fast, safe, and reproducible technique in order to immediately alleviate ICH with evacuation of any extra-axial or intra-axial hematoma.[33,34] It also provides long-term control of ICP by allowing the brain to freely expand under the skin. In this series, 7 patients (88%) benefited from DC, and only one patient benefited from craniotomy for an isolated EDH. However, the extended skin incision of DC may cause important blood loss. The timing of cranial incision must be a joint decision between the trauma leader and the operating neurosurgeon, considering the absolute necessity of stopping the extra-cranial bleeding first but also the hemorrhagic risk of the neurosurgical procedure itself.

Combined cranial and extra-cranial damage-control surgery is particularly demanding for the surgeons and the trauma leader. At least one surgical team must work outside of its usual operating room, and the operating senior surgeons must have proper access to their operative field, although damage-control thoracotomy, laparotomy, or orthopedic EF are usually performed in supine position, which is perfectly suited for DC. In the same way, STP with STBI undergoing early extra-cranial procedures suffers higher blood loss, which is amplified in the case of concomitant DC.[35,36] Hence, the resuscitation team should anticipate the need of intraoperative massive transfusion protocol.

Damage-control procedures imply that a "second look" or a "delayed planned" surgery must be performed after the optimization of the patient in the intensive care unit. Hence, thoracic or visceral surgeries usually require de-packing within 48 hours. Damage-control neurosurgery is also a 2-time procedure and early cranioplasty within 3 months must be discussed between the neurosurgeon and the rehabilitation physician in order to optimize cerebral metabolism and neurological outcome.[37] In this series, cranioplasty was performed within a mean delay of 3.3 months after DC.

The 25% mortality rate in this series was comparable to that of larger original series concerning STP.[17–20,35,36] Besides, all the survivors presented a favorable long-term neurologic outcome. They did not suffer from unreasonable morbidity related to the extra-cranial damage-control procedures performed.

Limitations of the Study

This was a retrospective monocentric study without control group, with no possibility to evaluate the superiority of combined surgery compared with sequential surgery. The small patient sample limited the power of this study. Nevertheless, prospective randomized trials will be very difficult to conduct on such a rare trauma situation and in an utmost emergency context.

The coordination of 2 surgical teams in an extreme emergency setting may be very difficult to achieve for the trauma leader. In this study, it was made possible in part thanks to the reasonable size of our level 1 trauma center facility. Also, military surgeons are trained to perform damage-control surgery but also to operate in degraded conditions and low-resource environments (Fig. 2).[38]

Last, damage-control procedures, such as hemostatic splenectomy, may seem aggressive because of the possible future complications encountered, such as overwhelming postsplenectomy infection. This could be avoided with

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FIGURE 2. Example of patient 7. (A) Brain CT scan in axial view shows a right frontal epidural hematoma (white arrow). (B) CT scan of the abdomen in coronal view displays a splenic rupture (white arrow) with a peri-splenic hematoma (white arrowheads). (C, miniature) Active bleeding from a branch of the splenic artery (white arrow). (D) Intraoperative photograph of combined cranial and extra-cranial surgery where the visceral team (on the right) performs (E, miniature) hemostatic splenectomy. (F) The neurosurgical team (on the right) performs a craniotomy for the evacuation of the epidural hematoma.

combined procedures being carried out in a hybrid operating room where an active bleeding from the branches of the splenic artery could benefit from selective endovascular embolization in order to preserve the organ.[39]

CONCLUSION

Recent advances in prehospital emergency care and resuscitation have led to hospital admission of severely injured patients, presenting an intracranial hematoma and a concomitant noncompressible extra-cranial bleeding. To date, there is no guidelines concerning the emergency surgical management of such patients in the literature, which encourages the "implementation of a simultaneous multisystem surgery including radiologic interventional procedures" with no supporting evidence. It is currently recommended to stop the extra-cranial bleeding first and to perform neurosurgical evacuation of the hematoma right afterward. We present the first original patient series aiming to reduce the time spent with intracranial hypertension in order to optimize the preventable neurologic morbidity and to hasten the admission in the intensive care unit in order to optimize resuscitation. For this purpose, the hemostatic extra-cranial procedure was engaged, and the damage-control cranial surgery was begun as soon as extra-cranial hemostasis was achieved. The mortality rate was 25% and the long-term neurologic outcome of the survivors was systematically favorable. Considering our results, we encourage trauma teams to consider performing combined cranial and extra-cranial surgery in STP with concomitant STBI whenever they deem it necessary. The next step will be to perform combined procedures in hybrid operating rooms with selective embolization of the noncompressible extra-cranial bleeding.

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SUPPLEMENTARY MATERIAL

Supplementary material is available at Military Medicine online.

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CONFLICT OF INTEREST STATEMENT

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or nonfinancial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

ETHICAL APPROVAL

This study was approved by the National Committee of the French College of Neurosurgeons on November 4, 2021, under the referenced number IRB00011687.

This study was conducted in accordance with ethical standards as stated in the Declaration of Helsinki of 1964 and its further amendment of 2013.

DATA AVAILABILITY

All the relevant data are included in the manuscript. There are no data deposit for this work.

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