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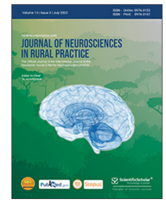

Review Article

Severe trauma patients requiring undelayable combined cranial and extracranial surgery: A scoping review of an emerging concept

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ABSTRACT

Objectives: Although patients suffering from severe traumatic brain injury (sTBI) and severe trauma patients (STP) have been extensively studied separately, there is scarce evidence concerning STP with concomitant sTBI. In particular, there are no guidelines regarding the emergency surgical management of patients presenting a concomitant life-threatening intracranial hematoma (ICH) and a life-threatening non-compressible extra-cranial hemorrhage (NCEH).

Materials and Methods: A scoping review was conducted on Medline database from inception to September 2021.

Results: The review yielded 138 articles among which 10 were retained in the quantitative analysis for a total of 2086 patients. Seven hundrer and eighty-seven patients presented concomitant sTBI and extra-cranial severe injuries. The mean age was 38.2 years-old and the male to female sex ratio was 2.8/1. Regarding the patients with concomitant cranial and extra-cranial injuries, the mean ISS was 32.1, and the mean AIS per organ were 4.0 for the head, 3.3 for the thorax, 2.9 for the abdomen and 2.7 for extremity. This review highlighted the following concepts: emergency peripheric osteosynthesis can be safely performed in patients with concomitant sTBI (grade C). Invasive intracranial pressure monitoring is mandatory during extra-cranial surgery in patients with sTBI (grade C). The outcome of STP with concomitant sTBI mainly depends on the seriousness of sTBI, independently from the presence of extra-cranial injuries (grade C). After exclusion of early-hospital mortality, the impact of extra-cranial injuries on mortality in patients with concomitant sTBI is uncertain (grade C). There are no recommendations regarding the combined surgical management of patients with concomitant ICH and NCEH (grade D).

Conclusion: This review revealed the lack of evidence for the emergency surgical management of patients with concomitant ICH and NCEH. Hence, we introduce the concept of combined cranial and extra-cranial surgery. This damage-control surgical strategy aims to reduce the time spent with intracranial hypertension and to hasten the admission in the intensive care unit. Further studies are required to validate this concept in clinical practice.

Keywords: Severe trauma patient, Traumatic brain injury, Intracranial hematoma, Non-compressible hemorrhage, Combined surgery, Damage control

INTRODUCTION

There is a flourishing medical literature regarding the management of severe trauma patients (STP) with concomitant severe traumatic brain injury (sTBI). It addresses the issue of young patients around 40 years old, predominantly male (3/1),[1] who generally sustained high-velocity traffic accident with an Injury Severity Score (ISS) ≥16[2] and an Abbreviated Injury Scale (AIS) of ≥3 in two different anatomic regions including the head.[3] These patients present a four-staged mortality curve caused by massive exsanguination on the trauma scene, then continuous bleeding sustained by trauma-induced coagulopathy or sTBI within the first 6–24 h and finally multiorgan failure or sTBI thereafter.[4] Thanks to the emergence of the concept of "damage control" 30 years ago,[5] a three step "damage control resuscitation" has now become the standard of care for these patients which led to a reduction of preventable deaths within the first 6–24 h.[6,7] On arrival in the emergency room, the resuscitation maneuvers should be a choreography orchestrated just like a Formula-1 pit stop,[8,9] then the patients should undergo full-body computed tomography (CT) scan.[10-12] The current guidelines recommend intervention for life-threatening bleeding in the first instance followed by emergency cranial surgery for relieving intracranial hypertension (ICH) if

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necessary.[13,14] Any surgical procedure carried out at this stage should comply with damage control principles. The second stage of care consists of a few days of optimization in the intensive care unit to maintain adequate systolic blood pressure (SBP), cerebral perfusion pressure, and coagulation parameters.[13]

On the other hand, TBI stands among the leading causes of disability worldwide[15] with an incidence of approximately 262/100,000 people.[16] Recent progress in road prevention has led to a change in the epidemiology of TBI,[16] with a diminution of young patients sustaining traffic accidents and an augmentation of old patients suffering serious falls.[17] The emergency care of isolated TBI includes a basic neurologic examination with the Glasgow Coma Scale (GCS) score, the pupils and motor focalization signs,[18-20] and prompt brain CT scan.[21] Then, the current guidelines support urgent evacuation of life-threatening epidural hematoma (EDH) or acute subdural hematoma (ASH) within 4 h following trauma to achieve the best neurological outcome.[22-24]

Although STP and sTBI patients have been extensively studied separately, there is only scarce evidence concerning STP presenting a concomitant life-threatening intracranial hematoma (ICH) and a life-threatening extracranial bleeding. To date, it is recommended that extracranial damage control procedure for non-compressible bleeding should be performed first and that the neurosurgical emergency should be dealt with right afterward.[13] Going beyond the concept of preventable mortality in STP with sTBI, we address the unsolved issue of the preventable neurologic morbidity by reducing the time spent with intracranial hypertension.[13,25,26] Hence, this review aims to synthetize current knowledge on the emergency surgical management of STP suffering from undelayable concomitant cranial and extracranial lesions.

MATERIALS AND METHODS

Database and bibliographic research

We conducted a scoping literature review focused on STP requiring both a cranial and an extracranial procedure, using two different sources.

First, Medline database (ncbi.nlm.nih.gov/pubmed/) was screened from inception until September 2021. We used the advanced research mode with the following associations of terms in the title: (Brain injury OR Head trauma OR Epidural OR Acute subdural OR Subdural OR Cranial OR Neurosurgery OR Cranial surgery) AND (Polytrauma OR Femur OR Pelvis OR Pelvis OR orthopedic OR visceral OR abdominal OR abdomen OR spleen OR endovascular OR thorax).

Second, we searched potentially eligible works directly in the reference list of relevant articles.

Inclusion and exclusion criteria

All the English language patient original series or case reports reporting cranial procedures and extracranial procedures carried out during the first 24 h following trauma were included in the study, regardless of the objectives of the study or the length of the follow-up. Given the paucity of the literature on the subject, the original patient series concerning STP with a cranial procedure without extracranial procedure during the first 24 h following trauma was also retained. Review articles, abstracts, expert opinions, and editorials relevant to the subject were included in the discussion.

The exclusion criteria were articles written in foreign language, articles not found on the internet despite being indexed in Medline, STP series with no cranial procedure carried out, pediatric series, and articles not directly relevant to the subject.

Data extraction

All the articles included in the quantitative analysis were screened in a systematic manner and the following information were extracted: Author and year of publication; study type, inclusion criteria and study goal; age and sex of the patients; cause of polytrauma; mean ISS, head AIS, and peripheric AIS; GCS; pupil examination; presence of an open fracture; hemorrhagic shock; tracheal intubation and tracheotomy; intracranial pressure (ICP) monitoring; neurosurgical procedures; peripheral procedures performed early (≤24 h) or late (>24 h); whether the cranial and peripheric procedure was performed concomitantly; secondary brain insults; Glasgow Outcome Scale (GOS); and mortality. This work was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[27]

Primary and secondary endpoints

The first aim of this work was to synthetize current knowledge concerning STP requiring undelayable concomitant cranial and extracranial surgery. The other objective of this study was to evaluate the feasibility of combining an extracranial procedure for non-compressible hemorrhage and a cranial procedure for hematoma evacuation, to reduce the time spent with intracranial hypertension.

Statistical analysis and level of evidence

Given the heterogeneity of the articles included in this review, the original statistical analyses were retained if they were deemed relevant. No further statistical analysis was carried out. A two-sided $P \leq 0.5$ was considered to indicate statistical significance.

The level of evidence of each statement was reported using the Levels of Evidence of Oxford Centre for Evidence-Based Medicine and also according to the Grading of

Recommendations, Assessment, Development, and Evaluation methodology.[28,29]

RESULTS

Database and bibliographic research

The Medline search yielded 138 articles after removal of duplicates. One hundred and twenty-two articles met one of the exclusion criteria after reading the abstract. After reading the text entirely, the remaining 16 articles were also excluded from the study [Figure 1].

The bibliographic research yielded 44 articles. Nineteen articles met the exclusion criteria after reading the abstract. After reading the text entirely, 13 articles also met the exclusion criteria. Hence, 12 articles were finally retrained in the qualitative analysis and 10 articles in the quantitative analysis.[30-39] Seven articles were published before 2002, and the remaining three articles were published since 2018.

The articles included displayed an important heterogeneity regarding both the study goal and the inclusion criteria. Five articles (42%%) were focused on the optimal timing of extracranial surgery in the context of sTBI,[30-32,34,35] 4 articles (33%) dealt with neurological outcome in sTBI patients depending on the presence of extracranial injury,[33,36-38] and 1 article (8%) was focused on defining clinical and biological characteristics associated with neurological outcome in STP with sTBI.[39] The last 2 articles (17%) included in the qualitative analysis were an expert opinion and a recommendation article.[13,26]

Epidemiology

A total of 2086 patients were included, among which 787 patients (38%) suffered from severe trauma associated with sTBI. The mean age was 38.2 years old; it was 31.8 years old in the articles published before 2002 and 50.2 years old in the articles published since 2018. The male-to-female sex ratio was 2.8/1. The main reported causes of polytrauma were traffic accident in 52% of the cases, fall from height in 13% of the cases, and assault in 9% of the cases.

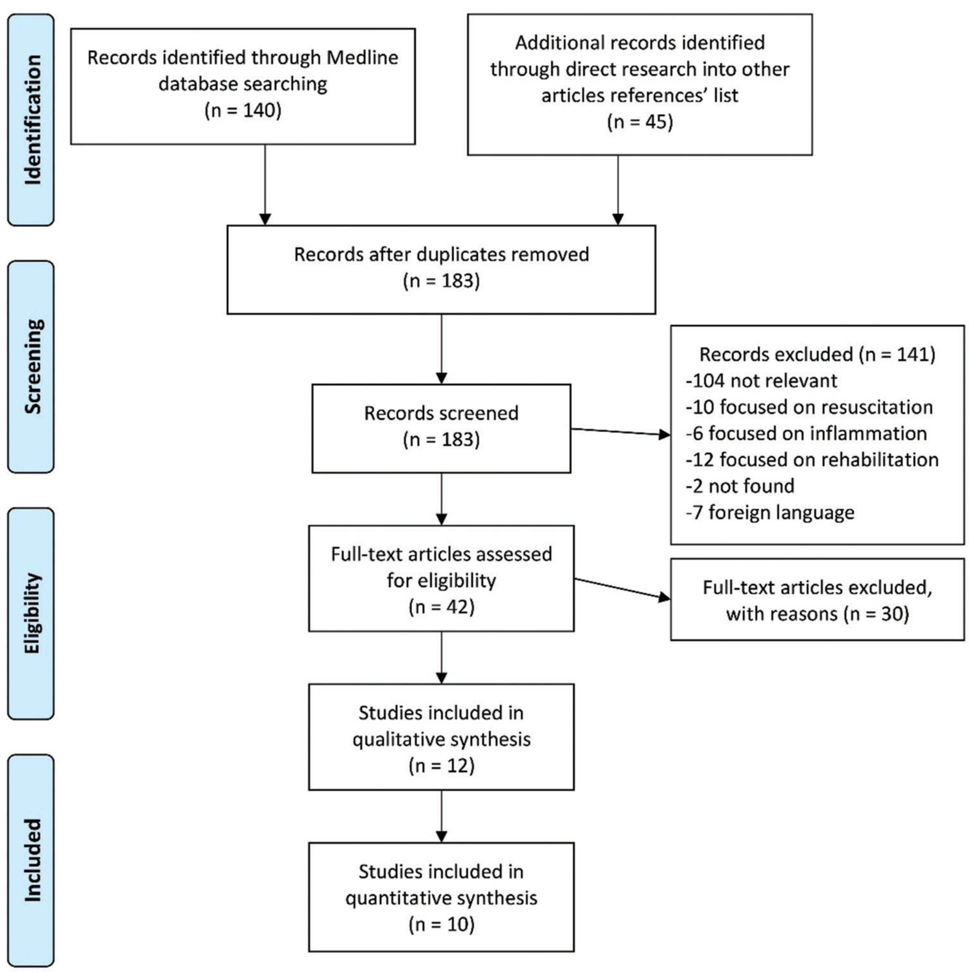

Figure 1: Preferred reporting items for systematic reviews and meta-analyses flowchart.

Clinical presentation

Considering only STP with concomitant sTBI, the mean ISS was 32.1. The mean head AIS was 4.0, and the mean peripheric AIS was 3.3 for the thorax, 2.9 for the abdomen, and 2.7 for extremity/orthopedics. The mean GCS score was 9.6 out of 15. About 23% of these patients presented with hemodynamic shock compared with 4% of the patients with TBI only. It is noteworthy that two authors reported a significantly higher rate of shock among STP with TBI and extracranial injuries compared with patients with isolated TBI ($P < 0.001$)[37] and among patients with an unfavorable outcome ($P < 0.001$).[39] In the three studies which mentioned it, the coagulation parameters were significantly altered with a diminution of the platelet count, a rise of the prothrombin time, and a rise of D-dimers and fibrin degradation products [Tables 1 and 2].[37-39]

TBI patterns

Considering only STP with concomitant sTBI, there were 12% (n = 195) of skull fractures reported. There were 2% (n = 27) of depressed fractures which were operated on. There were 10% (n = 161) of EDH, 13% (n = 212) of ASH, and 3% (n = 56) of unspecified extra-axial lesions. There were 12% (n = 202) of traumatic subarachnoid hemorrhage, 17% (n = 281) of brain contusion, and finally 2% (n = 36) of diffuse axonal injury reported [Supplementary Table 1].

Surgical management

Considering only STP with concomitant sTBI (n = 1587), 20% (n = 316) underwent a cranial procedure. It was a craniotomy in 90% of the cases (n = 284), and in 10% of the cases (n = 32), the procedure was not specified between craniotomy and craniectomy. In 1.6% of the cases (n = 27), the cranial and the extracranial surgeries were performed <24 h after the trauma. Among these 27 cases, 3 patients (0.2%) underwent a combined cranial and abdominal procedure [Table 3].

In the articles focused on the timing of peripheric osteosynthesis in the context of concomitant TBI, the mean extremity/orthopedic AIS was significantly higher ($P \leq 0.01$) and there was a significantly higher rate of open fractures ($P \leq 0.02$) in early peripheric osteosynthesis (EPO) groups compared with delayed peripheric osteosynthesis (DPO) groups.[34,35] 3/4 articles were in favor of EPO within the first 24 h following trauma. In two of them, no difference in the outcome between EPO and DPO groups was found (P=0.23 and P = not significant).[34,35] However, the patients who underwent EPO presented higher need of blood transfusion ($P = 0.01$)[34,35] and fluid resuscitation ($P = 0.01$)[34] compared with DPO groups. Three articles reported early thoracotomy and laparotomy within the first 24 h following trauma, although no subgroup analysis was carried out.[32,35,36]

Perioperative management

Six articles mentioned the use of invasive ICP monitoring devices.[32-36,38] About 14% (n = 295) of the patients benefited from invasive ICP monitoring, among which there were 53% (n = 157) of intraparenchymal monitors, 20% (n = 58) of external ventricular drains (EVD), and 27% (n = 80) of unspecified devices. No difference in the occurrence of episodes of ICH was observed between the groups of EPO and the groups of DPO.[34,35] On the same way, no difference was observed between the groups of isolated sTBI and the groups of STP with sTBI.[33,36] Thus, 4/4 articles were in favor of invasive ICP monitoring during peripheric procedures.[34-36]

Four articles reported the secondary brain insults that occurred perioperatively or during the intensive care unit stay. Regarding hypotension (generally defined as a SBP ≤90 mmHg or a mean arterial pressure ≤ 65 mmHg) and hypoxia, two articles reported a comparable occurrence rate between polytrauma patients with TBI undergoing EPO or DPO (P = not significant),[34,35] and one article reported in-hospital comparable rates between TBI patients without or with peripheric injuries ($P = 0.959$ and $P = 0.333$).[36]

Complications

Complications were only mentioned in six articles. Neurological complications were not only reporteds in one article which mentioned infection of ICP monitor, meningitis, and encephalitis but also post-operative seizures after peripheric osteosynthesis whether they were in the EPO or the DPO group [Supplementary Table 2].[34]

Concerning extracranial complications, the series exhibited high rates of nosocomial infection (30 up to 34%) and septic shock (up to 14%) in polytraumatized patients with sTBI but also deep venous thrombosis and pulmonary embolism (4 up to 10%). The important number of other rarely reported complications, such as fat embolism, acute respiratory distress syndrome, acute pancreatitis, acute cholecystitis, acute renal failure, stress ulcer or gastrointestinal bleeding, and decubitus ulcer, reflects the seriousness of STP with sTBI in this review.

Outcome

In this review, considering only STP with concomitant sTBI, 67% of the patients presented a favorable outcome defined as a GOS ≥4 (4 being considered "moderate severe disability"). The mortality rate for these patients was 18% [Table 4]. 3/3 articles showed that sTBI predicted neurological outcome independently from the presence of extracranial lesions ($P < 0.05$), and one article showed no difference in the outcome between patients without and with extracranial injuries ($P = 0.301$) [Table 4].[33,36-39]

Table 1: Patient characteristics.

Author year	Study type	Inclusion criteria and study goal	Total patients/ patients with TBI and peripheral injury (percentage)	Main studied parameters/ groups	Mean age	Sex ratio ♂/♀	Cause of polytrauma	Mean ISS	Mean head AIS	Mean extremity AIS
1888 Martens and Ectors	Retrospective monocentric	Neurological outcome in TBI patients depending on timing of peripheric surgery	73/73 (100%)	-Timing of osteosynthesis -Hypoxia	33	3/1	-	40	-	-
1990 Kotwica *et al.*	Retrospective monocentric	Timing of peripheric osteosynthesis in TBI patients with pelvis/ lower limbs fracture	100/100 (100%)	EPO (≤24 h) (n=51) DPO (>24 h) (n=49)	44	-	75% traffic 20% fall	-	-	-
1993 Wisner *et al.*	Retrospective monocentric	Timing of cranial or abdominal surgery in trauma patients with TBI	800/-	-Timing of craniotomy -Timing of abdominal surgery	29.9	-	59% traffic 16% fall 15% assault	-	-	-
1996 Heinzelmann *et al.*	Retrospective monocentric	Neurological outcome in patients with EDH depending on peripheric injuries and hospital complications	139/57 (41%)	† (*n*=82) *(*n*=57)	39 38	2.7/1	-	24.7 36.5	4.9 5	- T 2.9 A 3.3 E 2.5
1998 Kalb *et al.*	Retrospective monocentric	Secondary brain injuries and neurological outcome depending on timing of peripheric osteosynthesis in polytrauma patients (ISS≥16) with TBI (head AIS≥2) and surgical orthopedic fracture (AIS≥2)	123/123 (100%)	EPO (≤24 h) (*n*=84) DPO (>24 h) (*n*=39)	32 32	2.1/1 2.6/1	100% blunt 100% blunt	33 31	4 3.9	E 2.9 (*P*=0.01) E 2.6
1998 Velmahos *et al.*	Retrospective monocentric	Mortality and neurological outcome depending on timing of peripheric osteosynthesis in trauma patients with	47/47 (100%)	EPO (≤24 h) (*n*=22) DPO (>24h) (*n*=25)	34 30	3.7/1	87% traffic 11% fall 2% assault	25 23	3.8 3.4	E 2.9 (*P*=0.0002) E 2.4

(Contd...)

Table 1: *(Continued).*

Author year	Study type	Inclusion criteria and study goal	Total patients/ patients with TBI and peripheral injury (percentage)	Main studied parameters/ groups	Mean age	Sex ratio ♂/♀	Cause of polytrauma	Mean ISS	Mean head AIS	Mean extremity AIS
		TBI (GCS≤8 and head AIS ≥) and surgical long bone fracture								
2001 Sarrafzadeh *et al.*	Prospective monocentric	Neurological outcome in TBI patients (aged 6–75, GCS≤8) without or with peripheric injuries (ISS≥30)	80/44 (55%)	†(*n*=36)	36	4.1/1	25% traffic (pedestrian) 28% fall	25	4.9	-
				*(*n*=44)	28	5.3/1	72% traffic	39.5 (*P*<0.0005)	4.8	
2018 Watanabe *et al.*	Retrospective monocentric	Neurological outcome in TBI patients (head AIS≥3) without or with peripheric injuries (peripheric AIS≥3)	485/142 (29.3%)	† (*n*=343)	50.9	2.3/1	25.7% traffic 1.2% fall 2.9% assault	17	4.0	-
				*(*n*=142)	52.1	2.2/1	24.6% traffic 2.8% fall 0.7% assault	34 (p<0.001)	4.0	T 3.4 A 2.8 E 2.7
2019 Crawford *et al.*	Retrospective monocentric	Neurological worsening and in-hospital mortality in TBI patients (head AIS≥3) without or with chest trauma (chest AIS≥1)	57/19 (33%)	†(*n*=38) TBI with chest trauma (*n*=19)	44.1 33.3	2.8/1 9/1	71.9% blunt 3.5% penetrating	20 33 (*P*=0.02)	-	-
2021 Liu *et al.*	Retrospective monocentric	Clinical and biological characteristics for prediction of prognosis in polytrauma patients (ISS≥16, peripheric AIS≥2) with TBI (Head AIS≥3)	182/182 (100%)	Favorable outcome group (GOS 4–5) (n=134)	48.4	2.8/1	61.9% traffic 26.9% fall 3% assault	25.1	3.5	-
				Unfavorable outcome group (GOS 1–3) (*n*=48)	56 (*P*<0.01)	3/1	72.9% traffic 26.9% fall 2.1% assault	29.2 (*P*<0.01)	4.0 (*P*<0.001)	-

A: Abdomen, AIS: Abbreviated injury scale, DPO: Delayed peripheric osteosynthesis group, E: Extremity/orthopedic, EDH: Epidural hematoma, EPO: Early peripheric osteosynthesis group, GCS: Glasgow Coma Scale, ISS: Injury Severity Score, T: Thorax, TBI: Traumatic brain injury, †patients with isolated severe TBI, *patients with concomitant severe TBI and extracranial injuries

Table 2: Clinical presentation.

Author year	Inclusion criteria and study goal	Main studied parameters/ groups	GCS on admission	Pupil examination	Open peripheric fracture	Hemorrhagic shock	Tracheal intubation/ tracheotomy	Immediate neurological worsening
1888 Martens and Ectors	Neurological outcome in TBI patients depending on timing of peripheric surgery	- Timing of peripheric osteosynthesis - Hypoxia	6 (mean)	-	-	25% (*n*=18)	-	5 (6.8%) after early osteosynthesis
1990 Kotwica *et al.*	Timing of peripheric osteosynthesis in TBI patients with pelvis/lower limbs fracture	EPO (*n*=51) DPO (n=49)	10–15: 48% 7–9: 27% 3–6: 25% 49% 29% 22%	-	-	18 (35%) 12 (24%)	-	-
1993 Wisner *et al.*	Timing of cranial or abdominal surgery in trauma patients with TBI	Total (*n*=800) Craniotomy group (*n*=52) Therapeutic laparotomy group (*n*=40)	-	-	- - -	-	196 (24.5%) on the field/-	-
1996 Heinzelmann *et al.*	Neurological outcome in patients with EDH depending on peripheric injuries and hospital complications	†(*n*=82) *(*n*=57)	10.6 (mean) 10.4 (mean)	-	-	-	-	– 6 (7.3%) ICP>15–18 (22%) ICP>15 from other complications – 10 (17.5%) ICP>15–6 (10.5%) ICP>15 from other complications
1998 Kalb *et al.*	Secondary brain injuries and neurological outcome depending on timing of peripheric osteosynthesis in polytrauma patients (ISS≥16) with TBI (head AIS≥2) and surgical orthopedic fracture (AIS≥2)	EPO (*n*=84) DPO (*n*=39)	9.7 (mean) 9.9 (mean)	-	47 (56%) (*P*=0.01) 5 (13%)	24 (28.6%) 13 (33.3%)	-/23 (27.4%) -/10 (25.6%)	-
1998 Velmahos *et al.*	Mortality and neurological outcome depending on timing of peripheric osteosynthesis in trauma patients with TBI (GCS≤8 and head AIS ≥) and surgical long bone fracture	EPO (*n*=22) DPO (*n*=25)	5.8 (mean) 5.7 (mean)	-	16 (72.7%) (*P*=0.02) 9 (36%)	3 (13.6%) 5 (20%)	-	– 20 (42%) ↓ GCS≥3 – 13 (28%) ↑ ICP>20–2 (4%) ↓ neurologic examination

(Contd...)

Table 2: *(Continued).*

Author year	Inclusion criteria and study goal	Main studied parameters/groups	GCS on admission	Pupil examination	Open peripheric fracture	Hemorrhagic shock	Tracheal intubation/tracheotomy	Immediate neurological worsening
2001 Sarrafzadeh *et al.*	Neurological outcome in TBI patients (aged 6–75, GCS≤8) without or with peripheric injuries (ISS≥30)	Peripheric injuries group (n=39)	13.1 (mean)	0	-	4 (10.3%)	-	-
		†(*n*=36) *(*n*=44)	5.2 (mean) 5.6 (mean)	8 (22.2%) 16 (36.4%)		1 (2.8%) 7 (15.9%)	36 (100%) 44 (100%)	
2018 Watanabe *et al.*	Neurological outcome in TBI patients (head AIS≥3) without or with peripheric injuries (peripheric AIS≥3)	†(*n*=343) *(*n*=142)	12 (mean) 11 (mean)	-	-	13 (3.8%) 19 (13.4%) (*P*<0.001)	-	-
2019 Crawford *et al.*	Neurological worsening and in-hospital mortality in TBI patients (head AIS≥3) without or with chest trauma (chest AIS≥1)	†(*n*=38)	Motor 3/6 (mean)	-	-	-	46 (80.7%) among which 22 (38.6%) on the field/-	15 (39.5%)
		TBI with chest trauma (*n*=19)	Motor 3/6 (mean)					8 (42.1%)
2021 Liu *et al.*	Clinical and biological characteristics for prediction of prognosis in polytrauma patients (ISS≥16, peripheric AIS≥2) with TBI (head AIS≥3)	Favorable outcome group (GOS 4–5) (*n*=134)	12.9 (mean)	- Unilateral mydriasis 6 (4.5%) - bilateral mydriasis 1 (0.7%)	-	20 (14.9%) Heart rate>100	25 (18.7%)/21 (15.7%)	-
		Unfavorable outcome group (GOS 1–3) (*n*=48)	8.4 (mean) (*P*<0.001)	- Unilateral mydriasis 7 (14.6%) - Bilateral mydriasis 6 (12.5%) (*P*<0.001)	-	20 (41.7%) Heart rate>100 (*P*<0.001)	35 (72.9%)/34 (70.8%)	

AIS: Abbreviated injury scale, DPO: Delayed peripheric osteosynthesis group, EPO: Early peripheric osteosynthesis group, GCS: Glasgow Coma Scale, GOS: Glasgow Outcome Scale, ICP: Intracranial pressure, ISS: Injury Severity Score, TBI: Traumatic brain injury, ↑Rise, augmentation, ↓Diminution, †patients with isolated severe TBI, *patients with concomitant severe TBI and extracranial injuries

Table 3: Combined surgical procedures performed.

Author year	Inclusion criteria and study goal	Main studied parameters/groups	ICP monitoring/ external ventricular drain	Neurosurgical Procedures	Other early surgical procedures ≤24 h	Other delayed surgical procedures >24 h	Secondary brain insults: Hypotension/ hypoxia/IHT	Concomitant procedures
1888 Martens and Ectors	Neurological outcome in TBI patients depending on timing of peripheric surgery	- Timing of osteosynthesis - Hypoxia	-	3 EDH (4%)	33: 18 LAP/TY, 13 internal fixations and two hemostatic procedures	9 PO	30 (41.1%)/26 (35.6%)/-	-
1990 Kotwica *et al.*	Timing of peripheric osteosynthesis in TBI patients with pelvis/ lower limbs fracture	EPO (*n*=51)	-	8 ASH (16%)	27 tibia, 17 femur, and seven pelvis	-	-	≤24 h: 8 CO and early osteosyntheses
		DPO (*n*=49)		8 ASH (16%)	-	36 tibia, 10 femur, and three pelvis		
1993 Wisner *et al.*	Timing of cranial or abdominal surgery in trauma patients with TBI	- Timing of craniotomy - Timing of abdominal surgery	48 ICPM (6%)	52 CO (6.5%): 8 EDH, 14 ASH, 20 contusions, 20 depressed skull fractures	103 LAP (40 therapeutic) 102 PO 84 other procedures	-	-	3 CO and therapeutic abdominal surgeries
1996 Heinzelmann *et al.*	Neurological outcome in patients with EDH depending on peripheric injuries and hospital complications	†(*n*=82) *(*n*=57)	8 ICPM (6%) solely	119 EDH (86%)	-	-	-/-/24 (29.3%) -/-/16 (28.1%)	-
1998 Kalb *et al.*	Secondary brain injuries and neurological outcome depending on timing of peripheric osteosynthesis in polytrauma patients (ISS≥16) with TBI (head AIS≥2) and surgical orthopedic fracture (AIS≥2)	EPO (*n*=84)	58 ICPM (69%) (p=0.03)	14 CO	37 patients other procedures: 12 LAP, eight vascular, eight Mx-OPH, six fasciotomies, and three TRC	62 patients: 95 fracture debridement, 35 PO, 20 TRC, 14 Mx-OPH, 12 plastic, four LAP, three CO, three SPI, and two fasciotomies	Lowest SBP 95/11 (13.1%) SaO_2<90%/12 (20.7%)	≤24 h: 14 CO and peripheric osteosyntheses
		DPO (*n*=39)	14 ICPM (36%)	6 CO	Six LAP, four fasciotomies, and one Mx-OPH	39 PO 24 patients other procedures: 35 fracture debridements, 10 TRC, nine Mx-OPH, seven SPI, three LAP, and two CO	Lowest SBP 99/5 (12.8%) SaO_2<90%/5 (35.7%)	-

(Contd...)

Table 3: *(Continued).*

Author year	Inclusion criteria and study goal	Main studied parameters/groups	ICP monitoring/ external ventricular drain	Neurosurgical Procedures	Other early surgical procedures ≤24 h	Other delayed surgical procedures >24 h	Secondary brain insults: Hypotension/ hypoxia/IHT	Concomitant procedures
1998 Velmahos *et al.*	Mortality and neurological outcome depending on timing of peripheric osteosynthesis in trauma patients with TBI (GCS≤8 and head AIS ≥) and surgical long bone fracture	EPO (*n*=22)	12 EVD (26%) 18 ICPM (38%)	2 CO (EDH or ASH)	2 (9%): LAP, TY	-	Post-operative: 9 (40.9%)/3 (13.6%)/4 (18.2%)	≤24 h: 2 CO and peripheric osteosyntheses
		DPO (*n*=25)		4 CO (EDH or ASH)	5 (20%): LAP, TY	25 PO	Post-operative: 6 (24%)/1 (4%)/6 (24%)	-
2001 Sarrafzadeh *et al.*	Neurological outcome in TBI patients (aged 6–75, GCS≤8) without or with peripheric injuries (ISS≥30)	†(*n*=36)	100% ICPM/ EVD	20 CO (55.6%)	0	6 (16.7%): Maxillo	In-hospital occurrence: 9.1%/31.1%/59.2%	-
		*(*n*=44)		24 CO (54.5%)	14 (31.8%): SPI, PO, Mx, pelvis, fasciotomies, LAP, and tendon rupture	24 (54.5%): PO, Mx, and laparoscopy (second look)	In-hospital occurrence: 12.4%/18%/39.7%	-
2018 Watanabe *et al.*	Neurological outcome in TBI patients (head AIS≥3) without or with peripheric injuries (peripheric AIS≥3)	†(*n*=343)	-	105 CO (30.6%)	22 (6.4%)		-	-
		*(*n*=142)	-	31 CO (21.8%)	62 (43.7%) (*P*<0.001)			
2019 Crawford *et al.*	Neurological worsening and in-hospital mortality in TBI patients (head AIS≥3) without or with chest trauma (chest AIS≥1)	† (*n*=38) TBI with chest trauma (*n*=19)	46 EVD (80.7%) 11 ICPM (19.3%)	13 CO (22.8%)	-	-	-	-
2021 Liu *et al.*	Clinical and biological characteristics for prediction of prognosis in polytrauma patients (ISS≥16, peripheric AIS≥2) with TBI (head AIS≥3)	Favorable outcome group (GOS 4–5) (*n*=134)	-	15 CO/DC (11.2%)	-	-		-
		Unfavorable outcome group (GOS 1–3) (*n*=48)	-	17 CO/ DC (35.4%) (*P*<0.01)	-	-		-

A: Abdomen, AIS: Abbreviated injury scale, ASH: Acute subdural hematoma, CO: Craniotomy, DPO: Delayed peripheric osteosynthesis group, DC: Decompressive craniectomy, E: Extremity/ orthopedics, EDH: Epidural hematoma, EPO: Early peripheric osteosynthesis group, EVD: External ventricular drain, GCS: Glasgow Coma Scale, GOS: Glasgow Outcome Scale, ICPM: Intracranial pressure monitor, IHT: Intracranial hypertension, ISS: Injury Severity Score, LAP: Laparotomy/visceral surgery, Mx: Maxillafacial surgery, OPH: Ophthalmologic surgery, PO: Peripheric osteosynthesis, SBP: Systolic blood pressure, SPI: Spinal fracture, T: Thorax, TBI: Traumatic brain injury, TRC: Tracheotomy, TY: Thoracotomy, †patients with isolated severe TBI, *patients with concomitant severe TBI and extracranial injuries

Table 4: Outcome.

Author year	Inclusion criteria and study goal	Main studied parameters/groups	Glasgow Outcome Scale							Mortality		
			5	4	3	2	1	Significant ($P<0.05$)	Other significant parameters	Number (percentage)	Cause	Influencing parameters
1888 Martens and Ectors	Neurological outcome in TBI patients depending on timing of peripheric surgery	- Timing of peripheric osteosynthesis - Hypoxia			-			-	-	- 33 (43.3%) - 15 early (43.8%) - 18 delayed (54.5%)	- Early: 11 neurologic, four hemorrhagic shock - Delayed: 10 septic, five neurologic, three pulmonary embolism, and one UK	-
1990 Kotwica *et al.*	Timing of peripheric osteosynthesis in TBI patients with pelvis/lower limbs fracture	EPO (*n*=51)	47%	16%	22%	2%	13%	-	-	7 (13.7%)	Four neurologic and three hemorrhagic shock	
		DPO (*n*=49)	49%	12%	14%	2%	23%			11 (22.4%)	Five neurologic, three hemorrhagic shock, and three fat embolism	- 3 (6.1%) fat embolism (NS)
1993 Wisner *et al.*	Timing of cranial or abdominal surgery in trauma patients with TBI	Total (*n*=800) Craniotomy group (*n*=52) Therapeutic laparotomy group (*n*=40)	83% 35% 52%	6% 21% 15%	5% 23% 13%	1% 8% 2%	5% 13% 18%	- Worse for craniotomy compared to no craniotomy ($P<0.001$) - Worse for therapeutic abdominal surgery compared to no abdominal surgery	-	37 (5%) 7 (13.5%) 7 (17.5%)	-	-
1996 Heinzelmann *et al.*	Neurological outcome in patients with EDH depending on peripheric injuries and hospital complications	†(*n*=82) *(*n*=57)	50% 40%	32% 30%	6% 16%	5% 2%	7% 12%	-	- Other associated TBI - Complications during hospital stay (both groups)	6 (7.3%) 7 (12.3%)	-	-

(Contd...)

Table 4: *(Continued).*

Author year	Inclusion criteria and study goal	Main studied parameters/ groups	Glasgow Outcome Scale							Mortality		
			5	4	3	2	1	Significant (*P*<0.05)	Other significant parameters	Number (percentage)	Cause	Influencing parameters
1998 Kalb *et al.*	Secondary brain injuries and neurological outcome depending on timing of peripheric osteosynthesis in polytrauma patients (ISS≥16) with TBI (head AIS≥2) and surgical orthopedic fracture (AIS≥2)	EPO (*n*=84)	(mean GCS 14 at last follow-up)					-	Higher needs for blood transfusion (*P*=0.01) and fluid resuscitation (*P*=0.01) during first 24h in early osteosynthesis group	8 (9.5%)	Four neurologic, two multisystem failure, one myocardial infarction, and one pulmonary embolism	-
		DPO (*n*=39)	(mean GCS 14 at last follow-up)							3 (8%)	Two neurologic and one pulmonary embolism	
1998 Velmahos *et al.*	Mortality and neurological outcome depending on timing of peripheric osteosynthesis in trauma patients with TBI (GCS≤8 and head AIS ≥) and surgical long bone fracture	EPO (*n*=22)	(mean GCS 12 on discharge)					-	More patients transfused (*P*=0.05) and higher volumes of blood transfused (*P*=0.01) during the first 24 h in early osteosynthesis group	1 (4.5%)	-	-
		DPO (*n*=25)	(mean GCS 12 on discharge)							2 (8%)		
2001 Sarrafzadeh *et al.*	Neurological outcome in TBI patients (aged 6–75, GCS≤8) without or with peripheric injuries (ISS≥30)	peripheric injuries group (*n*=39)	75%		20%		5%	-Worse for * and † compared with peripheric injuries solely (*P*=0.046) -No difference between * and † (*P*=0.301)	- Older patients (*P*=0.003) - Duration of IHT (*P*=0.004) - Hypotension (*P*=0.037)	1 (3%)	One pulmonary embolism	-
		† (*n*=36)	54%		17%		29%			11 (29%)	Nine neurologic and two cardiac failures	
		* (*n*=44)	55%		15%		30%			10 (25%)	Six neurologic and four cardiac failures	

(Contd...)

Table 4: *(Continued)*.

Author year	Inclusion criteria and study goal	Main studied parameters/ groups	Glasgow Outcome Scale							Mortality		
			5	4	3	2	1	Significant (P<0.05)	Other significant parameters	Number (percentage)	Cause	Influencing parameters
2018 Watanabe *et al.*	Neurological outcome in TBI patients (head AIS≥3) without or with peripheric injuries (peripheric AIS≥3)	† (*n*=343) * (*n*=142)	46.9% 30.3%	28% 36.6%	4.4% 5.6%	2.9% 5.6%	17.8% 21.8%	Worse for * compared with † (p=0.002)	- Older patients (P<0.001) -GCS (P<0.001)	61 (17.8%) 31 (21.8%) (P=0.042 multivariate analysis)	-	- SEI (P=0.042) - Older patients (P<0.001) - GCS (P<0.001) - length hospital stay (P<0.001)
2019 Crawford *et al.*	Neurological worsening and in-hospital mortality in TBI patients (head AIS≥3) without or with chest trauma (chest AIS≥1)	† (*n*=38) TBI with chest trauma (*n*=19)				- 7 (36.8%) (in-hospital) NS				5 (13.2%) (in-hospital)	-	IL-4 (P=0.0001) NSE (P=0.003)
2021 Liu *et al.*	Clinical and biological characteristics for prediction of prognosis in polytrauma patients (ISS≥16, peripheric AIS≥2) with TBI (Head AIS≥3)	Favorable outcome group (GOS 4–5) (*n*=134)	100% (1 month after discharge)					-	-Older patients (P=0.007) -Admission GCS score (P=0.019) -Heart rate (P=0.028) -Tracheotomy (P=0.00, OR 15.2) -Platelet count (P=0.02)	25 (13.7%) (1 month after discharge)	-	-

AIS: Abbreviated Injury Scale, DPO: Delayed peripheric osteosynthesis group, EPO: Early peripheric osteosynthesis group, GCS: Glasgow Coma Scale, ISS: Injury Severity Score, NS: Not significant, OR: Odds ratio, SEI: Severe extracranial injuries, TBI: Traumatic brain injury, UK: Unknown, †patients with isolated severe TBI, *patients with concomitant severe TBI and extracranial injuries

Table 5: Relevant concepts and level of evidence.

Author year	Study type	Study goal	Concomitant cranial and extracranial surgeries	Level of evidence	Early peripheric osteosynthesis	Early surgery for thoracic or visceral active bleeding	Invasive cerebral monitoring during peripheric procedures	Extra-cranial injuries predictive of mortality	Severe head injury predictive of neurological outcome independently from extracranial lesions	Level of evidence
1988 Martens and Ectors	Patient series	Timing of osteosynthesis			No (NS)	-	-	-	-	D-IV
1990 Kotwica *et al.*	Patient series	Timing of osteosynthesis			Yes (NS)	-	-	-	-	C-III
1993 Wisner *et al.*	Patient series	Neurological outcome depending on extra-cranial lesions	Yes	D-V	-	Yes (NS)	-	-	-	C-III
1996 Heinzelmann *et al.*	Patient series	Neurological outcome depending on extra-cranial lesions			-	-	Yes (NS because no results analysis)	No (NS)	Yes ($p<0.05$)	C-III
1998 Kalb *et al.*	Patient series	Timing of osteosynthesis			Yes (no difference in GCS at last follow-up $P=0.23$)	-	Yes (better cerebral perfusion pressure in early fixation group $P=0.02$)	-	-	C-III
1998 Velmahos *et al.*	Patient series	Timing of osteosynthesis			Yes (no difference in GCS at last follow-up *P*=NS)	Yes (NS)	Yes (no difference in the management of post-operative IHT episodes *P*=NS)	-	-	C-III
2001 Sarrafzadeh *et al.*	Patient series	Neurological outcome depending on extra-cranial lesions			-	Yes (NS)	Yes (no difference in IHT episodes $P=0.205$, or cerebral perfusion pressure $P=0.369$)	No (NS)	Yes (no difference between * and † $P=0.301$)	C-III
2018 Watanabe *et al.*	Patient series	Neurological outcome depending on extracranial lesions			-	-	-	Yes ($P=0.042$)	Yes ($P<0.001$)	C-III

(Contd...)

Table 5: *(Continued).*

Author year	Study type	Study goal	Concomitant cranial and extracranial surgeries	Level of evidence	Early peripheric osteosynthesis	Early surgery for thoracic or visceral active bleeding	Invasive cerebral monitoring during peripheric procedures	Extra-cranial injuries predictive of mortality	Severe head injury predictive of neurological outcome independently from extracranial lesions	Level of evidence
2019 Crawford *et al.*	Patient series	Neurological outcome depending on extracranial lesions			-	-	-	No (P=0.08)	-	C-III
2021 Liu *et al.*	Patient series	Defining clinical and biological markers predictive of neurological outcome			-	-	-	-	Yes (P=0.019)	C-III
2003 Rosenfeld	Expert opinion	Damage control neurosurgery	Yes	D-V						
2019 Picetti	Guidelines	Management of polytrauma	Yes	D-V						

GCS: Glasgow Coma Scale, IHT: Intracranial hypertension, NS: Not significant, S: Significant

One article showed that extracranial injuries were not predictive of the mortality rate in STP with associated severe (P = 0.08).[38] Another article showed that additional extracranial injuries were predictive of mortality (P = 0.042).[37]

DISCUSSION

Context

As great progress has been made in patient triage,[40] pre-hospital emergency care,[41] and neuroresuscitation over the past 30 years,[6,42] the concept of STP has simultaneously evolved toward more serious and somewhat older patients with greater ISS and higher in-hospital mortality[2,3,43] In the same time, the profile of sTBI patients has also moved to older male patients suffering fall from a height.[16,44] These epidemiologic changes, combined with the reduction of early mortality caused by exsanguination thanks to the implementation of massive blood transfusion protocols,[4,45,46] have opened the door to hospital admission of severely injured patients with simultaneous life-threatening intracranial hematoma and extracranial bleeding. Because such patients are rarely encountered, there is no scientific evidence to guide their emergency surgical management and recommendations are based on studies concerning isolated organ traumatism.

Definition of undelayable traumatic cranial surgical emergencies

ASH is the most frequently encountered traumatic extra-axial lesion. A patient meeting ASH surgical criteria such as hematoma thickness >10 mm or midline shift >5 mm, a drop ≥2 point on the GCS score, abnormal pupil examination, or ICH >20 mmHg should undergo urgent surgical evacuation within 4 h following trauma.[23,25]

EDH is rarely encountered but seems to be more frequent in polytrauma patients with sTBI.[30,32,33,35] A patient meeting EDH surgical criteria such as a volume >30 mL or a thickness >15 mm, a midline shift >5 mm, and a GCS score ≤8 or focal symptoms should undergo immediate surgical evacuation.[22]

More diffuse TBI first requires aggressive neuroresuscitation measures guided by an invasive ICP monitor, such as an EVD which allows cerebrospinal fluid (CSF) drainage.[47] Decompressive craniectomy (DC) should be considered in a 2nd time in case of traumatic ICH refractory to maximal medical treatment. Hence, diffuse TBI rarely requires urgent cranial surgery on admission.[24] Consequently, ASH and EDH constitute the majority of traumatic intracranial lesions requiring undelayable surgical evacuation in STP.

Definition of undelayable extracranial surgical emergencies

In contrary to hemorrhages of the limbs which can be controlled with a tourniquet, non-compressible thoracic, abdominal, and pelvic hemorrhages constitute most of the extracranial undelayable life-threatening lesions. Resuscitation thoracotomy for cross-clamping of the descending aorta is a last resort option that can be performed in the emergency room by general surgeons for STP with <15 min of cardiopulmonary resuscitation. The other undelayable thoracic emergencies include exsufflation and drainage of tension pneumothorax and thoracotomy for massive hemothorax with chest tube blood output >1500 mL.[48,49]

Life-threatening abdominal trauma emergencies are managed by "abbreviated" damage control laparotomy and include bleeding from solid organ (spleen, liver, or kidney) or from mesenteric rupture in hemodynamically unstable patients or which are not accessible to endovascular treatment and hollow organ perforation at high septic risk.[8,50] During the same procedure, pre-peritoneal packing for pelvic fracture-associated hemorrhage can be achieved if necessary.[51] Open Tile C pelvic fracture requires urgent closure with an external fixator given the immediate risk of massive exsanguination in the pelvis.[52]

Damage control principles facing two concomitant surgical emergencies

In face with STP suffering from combined life-threatening intracranial and extracranial lesions, the resuscitation objectives are to maintain a proper cerebral perfusion pressure and, in the same time, to limit exsanguination as much as possible. In such case, neuroresuscitation guidelines recommend to maintain the SBP >110 mmHg even if it may sustain extracranial bleeding,[53] the SpO_2 ≥96, the $PaCO_2$ between 30 and 35 mmHg, the body temperature between 35 and 37 Celsius degrees, and blood sugar level between 8 and 10 mmol/L to limit the occurrence of secondary brain insults.[54] On the same way, the platelet count should be maintained >50 G/L in STP, and >100 G/L in case of life-threatening hemorrhage or sTBI, and the fibrinogen level >1.5–2 g/L.[55]

Aside from the fact that exsanguination eventually leads to hypovolemic shock, the ongoing extracranial bleeding must be stopped as soon as possible because it participates in trauma-induced coagulopathy caused by direct loss of coagulation factors.[56] What is more, TBI is responsible for a brain-induced coagulopathy with releasing of tissue factor and activation of the extrinsic coagulation pathway, with increased consumption of platelets and coagulation factors.[57] These trauma-induced coagulopathies, along with the lethal triad in a hypovolemic STP,[58] sustain the ongoing bleeding. This vicious hemorrhagic circle is the rationale for damage control thoracic or visceral surgery designed to "prioritize short-term physiological recovery over anatomical reconstruction."[59] These procedures' aim is to perform a fast and reproducible exploration of the major sources of bleeding and to achieve temporary hemostasis using drainage, packing, splenectomy, and shunt but also sometimes to perform intestine repair or excision in face with hollow organ perforation.[8,49]

Rotational thromboelastometry is of great support to optimize massive transfusion protocols in such context.[60] What is more, SBP targets are very difficult to reach in face with a persistent uncontrolled hemorrhage, which directly contributes to secondary injuries to the brain, also known as cerebral "second hits."[61] The trauma leader should be aware of the need for early massive transfusion protocol for these patients. Indeed, greater transfusion requirements were clearly highlighted in the present review for patients undergoing EPO.[34,35]

In our opinion, damage control neurosurgery for any compressive ICH can be performed concomitantly to almost any other hemostatic surgery.[14,26] DC represents the fast, standardized, and reproducible damage control neurosurgical procedure to alleviate ICH in this emergency setting.[14,62] Indeed, DC allows both the evacuation of any extra-axial or intraparenchymal hematoma and the optimal control of ICH by allowing brain expansion directly under the skin. Guidelines recommend the use of an invasive ICP monitor in case of sTBI (GCS ≤8) with non-operative brain lesions on the CT scan or after cranial surgery in STP and to maintain a CPP between 60 and 70 mmHg.[19,54,63] For this purpose, an EVD should be preferred because it allows both the surveillance of ICP and CSF drainage in case of ICH.[47,63]

Place for concomitant endovascular embolization (EE)

Nowadays, EE can be considered for any active bleeding in STP. Although the current guidelines and hospital practice still recommend open surgery in case of hemodynamically unstable patients,[64,65] a combined intervention with cranial procedure and EE could theoretically be possible depending on the ability of the resuscitation team to stabilize hemodynamic status, and with the agreement between the surgical and the interventional team before the procedure. As an example, Kataoka *et al*. reported the case of a 24-year-old male patient with an ISS of 57, who successfully underwent DC combined with perihepatic packing closely followed by intraoperative EE of the right renal artery. Finally, the patient underwent embolization of the right portal vein for venous bleeding.[66]

Practical implementation of a combined surgical or interventional treatment

The present review highlights a few concepts [Table 6]:

- Emergency peripheric osteosynthesis can be performed in polytrauma patients with concomitant sTBI.[34,35]
- Invasive ICP monitoring is mandatory during peripheric surgeries in case of concomitant intracranial lesions.[34-36]
- The outcome of polytrauma patients essentially depends on the seriousness of TBI, independently from the presence of extracranial injuries.[33,36,37,39]
- After exclusion of early in-hospital deaths, the impact of extracranial injuries on mortality in patients with concomitant sTBI is uncertain.[37,38]

This review also depicts the typical polytraumatized population from which patients with concomitant life-threatening intracranial and extracranial lesions can be encountered. Nevertheless, it does not provide any concrete evidence concerning the management of patients requiring concomitant life-saving cranial and extracranial surgeries, as the only relevant information available in the literature since 2003 are expert opinions.[13,26]

The main theoretical objectives of combined cranial and extracranial surgery are to reduce the time spent with ICH to optimize neurological outcome and also to hasten the admission in the intensive care unit to facilitate resuscitation. Nevertheless, combining two different procedures in STP can lead to important blood loss exceeding the coagulation capacities of the patient and the supporting capacities of the resuscitation team. Hence, the timing of the beginning of the cranial procedure should be a joint decision between the neurosurgical and the resuscitation team, depending on the necessity of stopping the extracranial source of bleeding before the cranial incision and taking into account the hemorrhagic risk of the cranial surgery itself [Figure 2].

What is more, combining two different procedures in an extreme emergency context imply high adaptation capacities from all the caregivers involved. At least one team must work outside of its usual operating room, and the main operators must have proper access to the patient. That being said, a damage control thoracotomy, a laparotomy, or a femoral endovascular access are usually performed in supine position, which is perfectly suited for DC.[62] As military surgeons, we are specifically trained to stick to damage control procedures and to perform surgery in a low-resource setting, thus making it somewhat easier to orchestrate combined procedures in an acute trauma setting [Figure 3].[67,68]

Particular case of low- and middle-income countries

The management of STP in low- and middle-income countries poses two specific issues. First, in low-income countries, isolated depressed skull fracture from physical assault constitutes most of the sTBI requiring neurosurgical procedure (45%). Indeed, the epidemiology of the mechanism of trauma differs from that of high-income countries, and so do the most serious trauma lesions.[69] Given that fall from high and high-velocity traffic accidents are less frequent compared to high-income countries, STP with combined cranial and extracranial lesions is less likely to be encountered.

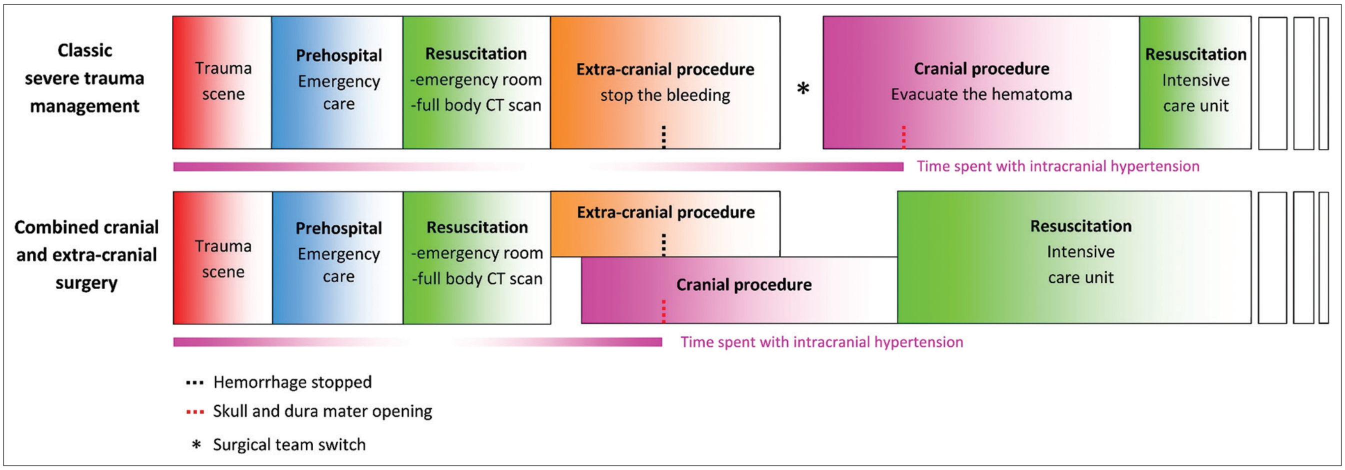

Figure 2: Emergency surgical management of patients with concomitant life-threatening intracranial hematoma and extracranial non-compressible hemorrhage. (Upper diagram) The current guidelines with extracranial procedure first, closely followed by cranial damage-control surgery. (Lower diagram) proposition for a combined cranial and extracranial procedure which allows to reduce the time spent with intracranial hypertension and to hasten admission in the intensive care unit.

Figure 3: Combined cranial and extracranial surgery in a 24-year-old severe trauma male patient. On the left side, splenectomy performed by the visceral team wearing green gowns. On the right side, epidural hematoma evacuation performed by the neurosurgical team wearing blue gowns.

Second, the median time from injury to admission is much longer in low-income (15 h, 5–46) and middle-income countries (8 h, 4–20) compared to high (4, 2–12) and very high-income countries (2, 1–7).[69] This is related to the lack of efficient emergency pre-hospital care in low-income countries, where trauma patients are brought to the hospital directly by private vehicles or by ambulance without medical or paramedical staff. Given these elements, and considering the fact that STP suffering from combined cranial and extracranial life-threatening injuries can only survive massive exsanguination on the trauma scene with the support of exceptional pre-hospital care, it seems very unlikely that such type of very serious trauma patient could reach a Level 1 trauma center alive in low- and middle-income countries. In other words, in low- and middle-income countries, STP with combined cranial and extracranial lesions is more rarely encountered compared to high-income countries, and they usually do not make it to the hospital alive.

Limitations

This review presents a few limitations that include a risk for incomplete retrieval of identified research. Indeed, we conducted a review on Medline database looking for specific terms in the title of the articles, which restricted the number of potentially eligible articles for screening compared to a genuine systematic review using Mesh terms. Besides, the heterogeneity of the subject renders any attempt of systematic review unrealistic. Given the retrospective nature of this work, there was a measurement bias from the authors at the time of writing of the articles retained and a bias during our own collection of data. There was also an attrition bias considering the proportion of missing data.

On the other side, to the best of our knowledge, this review is the first aiming to define a rarely encountered type of SVT requiring undelayable combined cranial and extracranial procedures.

CONCLUSION

Sometimes, thanks to progress in pre-hospital medicine and damage control resuscitation in the early 21th century, STPs suffering from a concomitant life-threatening ICH and a life-threatening extracranial bleeding survive emergency pre-hospital care and are admitted in the emergency room of Level 1 trauma center facilities. The scarce evidence of the current literature is insufficient to guide the initial emergency surgical strategy for these patients. Nevertheless, given that the long-term prognosis of such patients mainly depends on the initial neurological status, we think that there is room for timing optimization between an undelayable damage control procedure for a non-compressible extracranial hemorrhage and a damage control cranial procedure for hematoma evacuation. Going further into the concept of damage control by combining the two procedures is technically feasible and should be considered to reduce the time spent with intracranial hypertension and to hasten admission in the intensive care unit. However, combined surgery requires open dialogue between the different teams involved prior to and during the surgery, and the trauma leader should remain the orchestra conductor to achieve neuroresuscitation objectives. It is up to the surgical and the resuscitation teams locally to define the feasibility of combined procedures in their respective facilities. Such patients may be encountered more often in the next few years. Hence, this work is a call for the future research, which is urgently needed to establish recommendations to guide trauma teams in the management of these particularly demanding STPs.

Ethical approval

This is a literature review; consequently, ethical approval is not required.

Availability of data and materials

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

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

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 non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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SUPPLEMENTARY TABLES

Supplementary Table 1: Traumatic brain injury patterns.

Author year	Total patients	Groups	Skull fracture	Depressed skull fracture	EDH	ASH	Contusion	tSAH	DAI
1888 Martens and Ectors	73	-	-		3 (4.1%) operated	-	-	-	-
1990 Kotwica *et al.*	100	EPO (*n*=51)	-		-	8 (15.7%)	33 (64.7%)	-	-
		DPO (*n*=49)	-		-	8 (16.3%)	41 (83.7%)	-	-
1993 Wisner *et al.*	800	-	-	20 (2.5%) operated	8 (1%) operated	14 (1.8%) operated	20 (2.5%) operated	-	-
1996 Heinzelmann *et al.*	139	†(*n*=82)	56 (68.3%)	6 (7.3%)	82 (100%)	21 (25.6%)	42 (51.2%)	-	-
		*(*n*=57)	40 (70.2%)	7 (12.3%)	57 (100%)	12 (21.1%)	24 (42.1%)	-	-
1998 Kalb *et al.*	123	EPO (*n*=84)	32 (38.1%)	-	13 (15.5%)	34 (40.5%)	22 (26.2%)	34 (40.5%)	-
		DPO (*n*=39)	14 (35.9%)	-	5 (12.8%)	17 (43.6%)	12 (30.8%)	18 (46.2%)	-
1998 Velmahos *et al.*	47	EPO (*n*=22)	-	-	3 (13.6%)	3 (13.6%)	12 (54.5%)	-	4 (18.2%)
		DPO (*n*=25)	-	-	3 (12%)	5 (20%)	13 (52%)	-	4 (16%)
2001 Sarrafzadeh *et al.*	80	-	-	-	-	-	-	-	-
2018 Watanabe *et al.*	485	†(*n*=343)	-	-	180 (52.5%) (*P*<0.01)		73 (21.3%)	46 (13.4%)	38 (11.1%)
		*(*n*=142)	-	-	56 (39.4%)		28 (19.7%)	25 (17.6%)	28 (19.7%) (*P*=0.014)
2019 Crawford *et al.*	57	-	-	-	-	-	-	-	-
2021 Liu *et al.*	182	Favorable outcome (*n*=134)	87 (64.9%) (*P*=0.021)	-	52 (38.8%)	80 (59.7%)	51 (38.1%)	87 (64.9%)	-
		Unfavorable outcome (*n*=48)	22 (45.8%)	-	17 (35.4%)	31 (64.6%)	25 (52.1%)	38 (79.2%)	-

ASH: Acute subdural hematoma, DAI: Diffuse axonal injury, DPO: Delayed peripheric osteosynthesis group, EDH: Epidural hematoma, EPO: Early peripheric osteosynthesis group, tSAH: Traumatic subarachnoid hemorrhage, †patients with isolated severe TBI, *patients with concomitant severe TBI and extracranial injuries

Supplementary Table 2: Complications.

Author year	Inclusion criteria and study goal	Total patients	Patient groups	Total complications	Neurologic complications			Extracranial complications										
					Total	Seizures after peripheric surgery	Other	Total	Nosocomial infection	Sepsis/ septic shock	DVT-PE	Fat embolism	Acute respiratory distress syndrome	Acute pancreatitis	Stress ulcer/ gastrointestinal bleeding	Decubitus ulcer	Acute cholecystitis	Acute renal failure
1988 Martens and Ectors	Timing of peripheric surgery	73	-	-	-	-	-	-	-	10 deaths (13.7%)	2 deaths (2.7%)	-	-	-	-	-	-	-
1990 Kotwica *et al.*	Timing of peripheric osteosynthesis	100	EPO (*n*=51) DPO (*n*=49)	-	-	-	-	-	-	-	-	0 3 (6.1%)	-	-	-	-	-	-
1993 Wisner *et al.*	Timing of cranial or abdominal surgery	800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1996 Heinzelmann *et al.*	Neurological outcome depending on extracranial lesions	139	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1998 Kalb *et al.*	Timing of peripheric osteosynthesis	123	EPO (*n*=84)	47 (56%)	11%	Yes	ICPM INF, CSF leak, MEN, ENC	89%	Yes	-	Yes	-	-	Yes	Yes	Yes	-	Yes
			DPO (*n*=39)	23 (59%)	12%	Yes	ICPM INF, CSF leak, MEN	88%	Yes	-	Yes	-	-	-	Yes	-	Yes	-
1998 Velmahos *et al.*	Timing of peripheric osteosynthesis	47	-	-	-	-	-	-	14 (29.8%)	5 (10.6%)	2 (4.3%)	1 (2.1%)	4 (8.5%)	1 (2.1%)	2 (4.3%)	1 (2.1%)	1 (2.1%)	-
1998 Sarrafzadeh *et al.*	Neurological outcome depending on extra-cranial lesions	119	Peripheric injuries group (*n*=39)	-	-	-	-	-	3 (7.7%) (*P*=0.014)	1 (2.6%)	1 (2.6%)	-	-	-	-	-	-	-
			† (*n*=36)						8 (22.2%)	0	0							
			* (*n*=44)						15 (34%)	4 (9.1%)	0							
2018 Watanabe *et al.*	Neurological outcome depending on extra-cranial lesions	485	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2019 Crawford *et al.*	Neurological outcome depending on extracranial lesions	57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2021 Liu *et al.*	Defining clinical and biological markers predictive of neurological outcome	182	GFO (*n*=134)	-	-	-	-	-	15 (11.2%)	-	25 (18.7%)	-	-	-	-	-	-	-
			GUO (*n*=48)						16 (33.3%) (*P*<0.001)		5 (10.4%)							

CSF: Cerebrospinal fluid, DPO: Delayed peripheric osteosynthesis group, DVT: Deep venous thrombosis, ENC: Encephalitis, EPO: Early peripheric osteosynthesis group, GFO: Group with favorable outcome, GUO: Group with unfavorable outcome, ICPM INF: Intracranial pressure monitor infection, MEN: Meningitis, PE: Pulmonary embolism, †patients with isolated severe TBI, *patients with concomitant severe TBI and extracranial injuries