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ORIGINAL ARTICLE

Secondary Insults and Adverse Events During Intrahospital Transport of Severe Traumatic Brain-Injured Patients

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Abstract

Background Our aim was to assess the occurrence of secondary insults (SIs) or adverse events (AEs) during intrahospital transport (IHT) of severe traumatic brain injury (TBI) patients for head computed tomography (CT) scanning.

Methods A prospective study based on severe TBI patients admitted from June 2011 through June 2013 in a level I trauma center. Patients received an IHT to perform a control CT scan in the first 3 days following trauma. The occurrence of SIs and AEs was assessed during the IHT for a control CT scan. The frequency of SIs was compared to the periods "before," "during," and "after" IHT. SI was defined by an intracranial pressure (ICP) >30 mmHg, a cerebral perfusion pressure (CPP) <50 mmHg, systolic blood pressure (SBP) <90 mmHg, or saturation pulse O_2 (SpO_2) <90 % for more than five consecutive minutes. An AE was defined as failures of hardware or ventilator asynchrony requiring therapeutic intervention during transport. In addition, we assessed the therapeutic benefit of a CT scan control.

Results The final analysis included 31 patients and 31 IHTs. The median duration of IHT was 29 min [25;37]. SIs occurred in 16 patients (52 %) during transport, whereas it was observed in 4 patients (13 %) before ($p = 0.002$) and 4 patients (13 %) after IHT ($p = 0.001$). Twenty-four AEs occurred during transport of 19 patients (61 %). One patient benefited from hematoma evacuation after implementation of control CT.

Conclusion IHT carries significant SIs and AEs in severe TBI patients. To improve a risk/benefit ratio favorable for patients, a program focusing on IHT complications regarding therapeutic impact of control CT scan is needed.

Keywords Traumatic brain injury · Head computed tomography · Intrahospital transport

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Introduction

Traumatic brain injury (TBI) remains one of the main causes of death for people under 30 and represents a significant health problem within France, with more than 8500 cases suffering an invalidating aftermath each year [1].

Head computed tomography (CT) is the reference imaging examination for initial diagnosis and early follow-up of TBI. CT highlights the presence of hemorrhagic and/or bone lesions and guides the surgical or medical treatment. Some authors suggest that during the initial management of TBI, routine follow-up head CT scanning has to be done, even without clinical deterioration or increased intracranial hypertension (ICH) [2, 3]. The goal is to eliminate the appearance or increase of a bleeding lesion indicating a surgical treatment in an emergency. In over 40 % of cases, brain injury increases in number or in size in 48 h after the initial trauma [4]. This risk is higher if the initial imaging is performed early, i.e., in the 2 h following the trauma. The relevance of this attitude remains questionable, due to a low therapeutic impact of decoupled imaging data of the clinical examination or monitoring of multimodal data [5, 6]. In this context, immediate and delayed risks associated with intrahospital transport (IHT) should be assessed to justify conducting systematic and repeated examinations. Indeed, several studies reported complications related to the transport of critically ill patients. In these series, the incidence of serious adverse events (AE) accounts for up to 30 %–50 % of IHT and led to major physiological derangement, increased intensive care unit (ICU) length of stay, or increased mortality [7, 8]. They relate mainly to failures of hardware, organizational, and communication flaws.

For head-injured patients, IHT-related adverse events may lead to secondary brain insults [9]. Up to date, no study accurately describes the frequency of these events during IHT for imaging the initial phase of severe TBI.

Our aim was to assess the occurrence of secondary insults (SIs) or AEs during IHT of severe TBI patients for head CT scanning.

Patients and Methods

Study Design

This prospective study is based on 31 IHT realized on 31 severe TBI patients admitted from June 2011 through June 2013 to our surgical ICU. The inclusion criteria were the following: severe TBI defined by a Glasgow Coma Scale (GCS) score ≤ 8, medical support within 6 h following injury, requiring mechanical ventilation and monitoring of the intracranial pressure (ICP) in accordance with international recommendations and patients requiring a medical IHT to perform a control CT scan in the first 3 days following trauma. Exclusion criteria were pregnancy and age younger than 18 years.

During study protocol, a systematic follow-up head CT scan was performed for all severe TBI in the first 3 days postinjury. If there was a clinical modification or an increase in ICP justifying the control CT scan, examination was classified as "oriented CT-scan"; otherwise, it was considered as "systematic CT-scan."

The choice of the indication and the deadline for completion of the CT was left to the discretion of the physician responsible for the patient.

IHT Modalities

IHTs were conducted according to a protocol established in the surgical ICU, occurring under the medical supervision of at least one ICU staff member (junior or senior physician). Patient monitoring during transport was identical to that present in the ICU (Table 1). The level of alarm was checked before departure. The doses of sedative, analgesic, and cardiovascular drugs were maintained and adapted during the transport phase. There was no systematic increase in doses of sedatives or muscle relaxants in preparation for transport. Our sedation protocol (included in the ICH treatment protocol) is described in Table 1. In the ICU and during IHT, we used a 30° head-of-bed position. A 0° head-of-bed position was performed only in the radiology room. Transporting the patient from the ICU to the CT room required a level change (lift) without building change.

Table 1 ICH treatment protocol [implementation of the external ventricular drain (EVD) as soon as possible]

Level I	Level II	Level III
Midazolam and/or propofol	Hypothermia (33°–35°)	Barbiturates
Sufentanil		
CPP optimization		
Osmotherapy (if indicated)		

Study Objectives and Definitions

The aim of this study was to assess the frequency of SIs and AEs occurring during IHT for a control CT scan. The frequency of SIs was compared to the periods "before," "during," and "after" IHT. SI was defined by an ICP >30 mmHg, a cerebral perfusion pressure (CPP) <50 mmHg, systolic blood pressure (SBP) <90 mmHg, or saturation pulse O_2 (SpO_2) <90 % for more than five consecutive minutes. An AE was defined as the occurrence of a failure, disconnection, unplanned withdrawal of material, or ventilator asynchrony requiring therapeutic intervention during transport.

Secondary objectives were to evaluate the frequency of neurological immediate consequences of the occurrence of a SI during IHT defined by the appearance of a pupillary anomaly, frequency of treatment modifications during and after CT implementation. In addition, we assessed factors associated with the occurrence of a SI or an AE during transport and the therapeutic benefit of a CT scan control defined using an unscheduled evacuation surgery within 6 h after the CT implementation.

Data Collection

Data collection was performed prospectively. Monitoring data were recorded continuously before, during, and after transport by Infinity Acute Care System monitor (Dräger Antony, France) equipped with the M540 module for patient monitoring and data storage during transport.

Monitoring of the ICP was provided by a catheter Codman Microsensor connected to Codman ICP Express monitor connected to the Dräger monitor. An acquisition sheet allowed identifying AEs, clinical, and therapeutic changes surrounding transport. The data from the continuous monitoring were retrieved every minute during the 30 min preceding the CT, during IHT, and in the 30 min following the return. The parameters measured were heart rate (HR), SBP, diastolic blood pressure (DBP), mean arterial pressure (MAP), SpO_2, fraction expired CO_2 ($FeCO_2$), ICP, and CPP. The immediate therapeutic interventions and therapeutic modifications within 12 h of the CT were reported.

The interval between initial and control CT scan was specified. Traumatic lesions were defined by the score of Marshall et al.[10]. During control CT, the increase in injuries in size or number was recorded, to conclude the CT aggravation of injuries between the two exams.

Statistical Analysis

Statistical analysis was performed using Excel software (Microsoft Office Excel 2003 SP3) and SPSS 17.0 (IBM, Chicago, IL, USA). Quantitative variables were expressed as median and interquartile range. Categorical variables were expressed as numbers and percentages. For the analysis of changes in monitoring parameters before, during, and after transport, the Friedman test was used for quantitative variables and the Cochran Q test for categorical variables. Post-hoc analyses were performed using the Wilcoxon signed rank test for paired quantitative variables and using the McNemar test for paired categorical variables, with a correction of significance level according to the Bonferroni method ($p < 0.017$). When the groups were independent, categorical variables were compared by the Fisher exact test and quantitative variables by the Mann–Whitney–Wilcoxon test, with an usual significance level of 0.05.

Results

During the study period, 62 severe TBI patients have benefited from ICP monitoring. The inclusion process was stopped between July and December 2012 because of an inability to continuously extract the patient monitoring data. Twelve patients met criteria of inclusion during this period. Eight patients without ICH were awakened and had no ICP probe during the implementation of CT control.

Finally, 42 patients met the criteria for inclusion. Six patients could not be included due to technical failures occurring during the period of inclusion, preventing recovery of data during transport. Five patients were excluded due to a loss of monitoring data before recovering. The final analysis included 31 patients and 31 IHTs.

General Characteristics of Population

The median age was 33 years [24; 49] with a sex ratio of 2 women for 29 men. Twenty-eight (90 %) patients suffered multiple trauma. Simplified Acute Physiology Score II (SAPS II) and Injury Severity Score (ISS) were, respectively, 34 [25; 52] and 26 [21; 34]. GCS median was 6 [3; 8]. All patients were receiving intubation with mechanical ventilation and sedation prior to hospital admission. In ICU, all patients were sedated, ventilated, and benefited from ICP monitoring within 12 h post trauma.

Secondary Insults Incidence

The CT scan was performed with a median of 3 days [2; 3]. It was prescribed systematically in 24 patients (77 %), for an increased ICP in 6 patients (19 %), and the consequences of a change in the clinical examination (anisocoria) in 1 patient (3 %). In 13 cases (42 %), worsening of the lesions from baseline CT was recorded. The median duration of IHT was 29 min [25; 37]. SIs occurred in 16 patients (52 %) during transport, whereas it was observed in 4 patients (13 %) before ($p = 0.002$) and 4 patients (13 %) after IHT ($p = 0.001$) (Table 2).

The main factors associated with the occurrence of SIs during IHT are summarized in Table 3.

Adverse Events Incidence

Twenty-four AEs occurred during transport of 19 patients (61 %), and 4 patients (13 %) had more than one AE during the same transport. It was a ventilator asynchrony in 11 cases (46 %), a hardware failure in 7 cases (29 %) (4 infusion pumps, 1 ICP monitor, and 2 portable ventilators), an unplanned withdrawal of equipment in 3 cases (13 %) (drainage line, peripheral venous access, dressing) and in 3 cases (13 %) an equipment disconnection (2 disconnections of the ventilator and a disconnection of the PIC sensor). No case of unplanned extubation was reported.

The "systematic" or "oriented" nature of the CT, as well as the schedule for its completion (day or night), were not significantly associated with the occurrence of an AE during transport ($p = 0.565$ and $p = 0.143$, respectively).

Similarly, the depth of sedation and paralysis of patients was not associated with the occurrence of an AE ($p = 0.963$ and $p = 0.247$, respectively).

Therapeutic Impacts of Adverse Events

The occurrence of increased ICP, decreased CCP, or a ventilator asynchrony during transport required administration of a sedation drug bolus in 20 patients (65 %), increased FiO_2 in 6 patients (19 %), and modification of

Table 2 Secondary insults incidence, sedative, and norepinephrine doses before, during, and after IHT

	Before IHT	During IHT	After IHT	p
MAP (mmHg)	86 [81; 99]	94 [86; 100]	89 [82; 93]**	0.005
HR (c/min)	84 [69; 93]	79 [70; 97]	81 [73; 97]	0.943
SpO_2 (%)	99 [97; 100]	99 [97; 100]	99 [97; 100]	0.028
$FeCO_2$ (mmHg)	30 [28; 35]	31 [28; 35]	31 [28; 35]	0.321
Max ICP (mmHg)	21 [16; 31]	35 [24; 46]*	23 [19; 35]**	<0.001
Mean ICP (mmHg)	16 [12; 23]	23 [16; 30]*	15 [11, 20]**	<0.001
Time with ICP > 20 mmHg (min)	1 [0; 17]	13 [6; 23]*	3 [0; 10]**	<0.001
Time % with ICP > 20 mmHg	3 [0; 57]	38 [19; 86]*	8 [0; 33]**	<0.001
No. of patients with ICP >20 mmHg >5 min	12 (39 %)	23 (74 %)*	9 (29 %)**	<0.001
Min CPP (mmHg)	64 [54; 72]	50 [43; 65]*	57 [45; 70]	0.015
Mean CPP (mmHg)	73 [63; 79]	70 [62; 76]	72 [66; 80]	0.082
Time with CPP <60 mmHg (min)	0 [0; 10]	3 [0; 15]	1 [0; 8]	0.127
Time % with CPP <60 mmHg	0 [0; 33]	11 [0; 41]	3 [0; 27]	0.151
No. of patients with CPP <60 mmHg >5 min	6 (19 %)	13 (42 %)	7 (23 %)	0.013
No. of patients with secondary insults	4 (13 %)	16 (52 %)*	4 (13 %)**	<0.001
No. of patients with ICP >30 mmHg >5 min	4 (13 %)	14 (45 %)*	3 (10 %)**	0.001
No. of patients with CPP <50 mmHg >5 min	2 (7 %)	6 (19 %)*	2 (7 %)**	0.030
Propofol dose (mg/h)	100 [0;200]	121 [0;225] *	100 [0;200] **	0.001
Midazolam dose (mg/h)	20 [4;25]	20 [5;26]	18 [0;25] **	0.001
Sufentanil dose (µg/h)	20 [15;25]	21 [18;25]	20 [15;25]	0.41
Norepinephrine dose (mg/h)	0.6 [0;1.4]	0.6 [0;14.5]	0.5 [0;1.5]	0.89

MAP mean arterial pressure, *HR* heart rate, *SpO_2* Saturation pulse O_2, *$FeCo_2$* Fraction expired CO_2, *ICP* intracranial pressure, *CPP*:cerebral perfusion pressure

* $p < 0.017$ versus before IHT data; ** $p < 0.017$ versus during IHT data

Table 3 Factors associated with the occurrence of a secondary cerebral aggression during IHT

	SI during CT scan	Ø secondary insult during CT scan	p
Age (years)	40 [33; 54]	26 [21; 34]	0.015
GCS	9 [4; 12]	4 [3; 6]	0.030
ISS	25 [16; 31]	34 [25; 34]	0.188
SAPS II	40 [22; 59]	34 [26; 51]	0.682
No. of patients requiring muscle relaxants before CT scan	4 (13 %)	0 (0 %)	0.101
Propofol dose before CT scan (mg/h)	150 [0; 250]	100 [0; 100]	0.119
Midazolam dose before CT scan (mg/h)	20 [13; 25]	15 [0; 20]	0.093
No. of patients requiring hypothermia or barbiturates	10 (32 %)	3 (10 %)	0.029
Noradrenaline dose before CT scan (mg/h)	1 [06; 175]	0 [00; 1]	0.004
ICP >20 mmHg (min)	13 [1; 26]	0 [0; 1]	0.006
Mean ICP before CT scan (mmHg)	21 [16; 26]	13 [11; 15]	0.001
Max ICP before CT scan (mmHg)	13 [1; 26]	0 [0; 1]	0.001
Min CPP before CT scan (mmHg)	56 [33; 49]	68 [58; 73]	0.033
Systematic CT scan	11 (35 %)	13 (42 %)	0.224

GCS Glasgow Coma Scale, *ISS* Injury Severity Score, *SAPS II* Simplified Acute Physiology Score II, *CT* computed tomography, *ICP* intracranial pressure, *CPP* cerebral perfusion pressure vasopressor infusion doses in 6 patients (19 %). One patient (3 %) received a muscle relaxant bolus, 1 patient benefited from intravenous crystalloid loading (3 %), and 1 required osmotherapy.

Clinical Impact of Secondary Insults or Adverse Events

Monitoring data of patients with SIs or AEs during IHT are summarized in Table 4.

Ten patients (32 %) required increased sedation within 12 h of the CT. One patient (3 %) required an increase in the medical treatment of ICH (introduction of barbiturates). These patients had a mean ICP before the CT of 20 mmHg [17; 23 mmHg] vs 14 mmHg [12; 16 mmHg] ($p = 0.027$).

Therapeutic Benefit of a CT Scan Control

Thirteen patients (42 %) had worsening brain damage on the control CT (Fig. 1). One patient benefited from subdural hematoma evacuation after implementation of control CT. For this patient, the subdural hematoma was diagnosed on the initial CT and the surgical evacuation was decided before the completion of the CT scan on a medically uncontrolled ICH. The CT scan highlighted a volume increase of subdural hematoma and operative indication was confirmed.

Discussion

This study shows a high incidence of SIs (52 %) and AEs (61 %) during IHT of patients hospitalized for TBI (Table 2). These complications occurred in the most severe patients, those requiring the highest therapeutic levels.

The immediate consequences during IHT were the increase in therapeutic levels (sedation, vasopressors, and ventilation) and the association of prolonged ICU length of stay in case an AE occurred, but no causal link can be demonstrated.

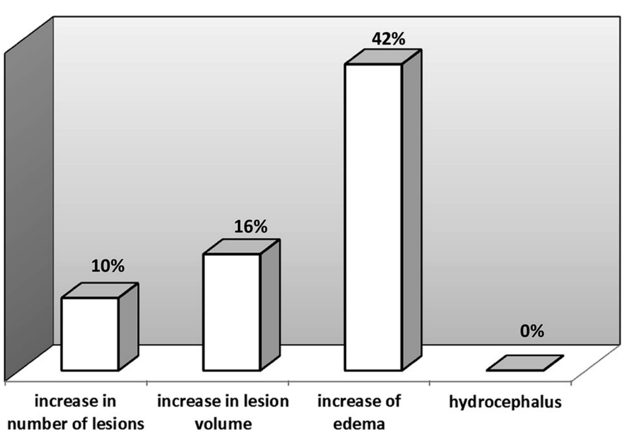

Fig. 1 CT deterioration of the initial lesions

In patients transported for a systematic CT scan, there was no indication for surgery on the imaging results. To date, this is the largest study concerned with this population analyzing the risk/benefit ratio of the systematic control CT implementation *versus* IHT-related risks.

The demographic characteristics of this series and injury mechanisms involved were comparable to previously published studies for TBI patients [6, 9, 11].

In this study, only patients benefiting from ICP monitoring were included in order to monitor it during transport. The population consisted of patients with a median GCS of 6 [3–8].

The only study with an interest in IHT of TBI patients described a less homogeneous population in terms of severity of patients (52 % with GCS <8, 28 % GCS between 9 and 12, and 20 % GCS >12). In addition, a part of them did not require mechanical ventilation or invasive monitoring of the ICP [9]. Our analysis included only one type of transport (control CT). The terms of this IHT were thus reproducible in time with a well-established procedure within the service. Then, transport times were short and dispersal was low (29 min [26–37]). Transport times for other major studies on IHT of ICU patients were variable and longer (133 min [40–420]), for TBI patients [9] 62 min ± 30 [12], and 73 min [35–200] [13] for ventilated critically ill patients).

Secondary Insults

SIs occurred in 16 (52 %) patients during IHT, whereas it was only observed in 4 patients before ($p = 0.002$) and 4 patients after ($p = 0.001$) (Table 2).

Patients experiencing SIs were the most severe and had higher average values of ICP and higher therapeutic levels or vasopressor doses before IHT. With the exception of two prolonged hypoxemia, all secondary insults were increased ICP or alteration of CPP.

Andrews et al., in their cohort of 35 TBI patients, found similar data with the occurrence of a SI in 51 % of IHT. However, there was no difference in the number of insults before, during, and after IHT, contrary to this series, which proves the involvement of IHT in degradation of ICP and CPP (Table 2). The severity of the events was also different. The choice of a 30-cm H2O threshold allowed categorizing SIs with certainty, unlike the threshold of 20 mmHg defining ICH for which tolerance may be permitted based on multimodal monitoring parameters. Lee et al. retrospectively reported IHT-related risks on 117 TBI patients. SIs occurred in 17 % of IHT for control CT completion (hemodynamic instability, increased ICP, hypoxia, and patient's agitation) [14]. This was a lower frequency than that of the present work or work of Andrew et al. However, the study population included 42 % of patients with mild head injury (initial GCS between 9 and 12), and the retrospective collection of data did not allow sufficient completeness to characterize the occurrence of complications.

Adverse Events

In this study, 61 % of the IHT were complicated by an AE. The rate of AE was comparable to previously published data for similar severity of patients [12, 15]. It is difficult to compare studies, because AE rate varies depending on the population and also the type and severity of the reported events. Thus, the impact of AE on the patient's outcome is difficult to assess [16, 17].

Ventilator asynchrony was the most frequent AE (35 % of cases). Damm et al. found similar data in 2005 [15]. More recently, in a cohort of 1659 ventilated patients, IHT was at higher risks of respiratory events such as pneumothorax, atelectasis, and ventilator-associated pneumonia (VAP) [8]. A VAP rate of 74 % during the ICU stay was found. The design of our study did not allow establishing a link between occurrence of VAP and IHT.

The technical failure was not uncommon with 7 equipment failures, 3 disconnections, and 3 dressings ripped off. Nine patients (29 %) had at least a hardware problem during transport. This was a similar rate to those already published. Evans et al., on 36 ventilated patients, reported a hardware complication in 11 % of cases [12]. Beckman et al., in their multicenter study analyzing 176 reports of incidents between 1993 and 1999, found 39 % hardware problems including the difficulty accessing to lifts, problems with infusion lines, or lack of battery [7].

A bolus of sedation was achieved during transport in 20 patients. Moreover, the cumulative dose of propofol was greater during versus before IHT. Bolus of propofol was especially justified by the ICP rises when transferring the patient onto the CT table. For example, we describe the CPP, ICP, and SpO_2 changes in a patient before, during, and after IHT (Fig. 2). An increase of vasopressors and FiO_2 was noted in 6 patients. One patient benefited from intravenous crystalloid loading and 1 required osmotherapy.

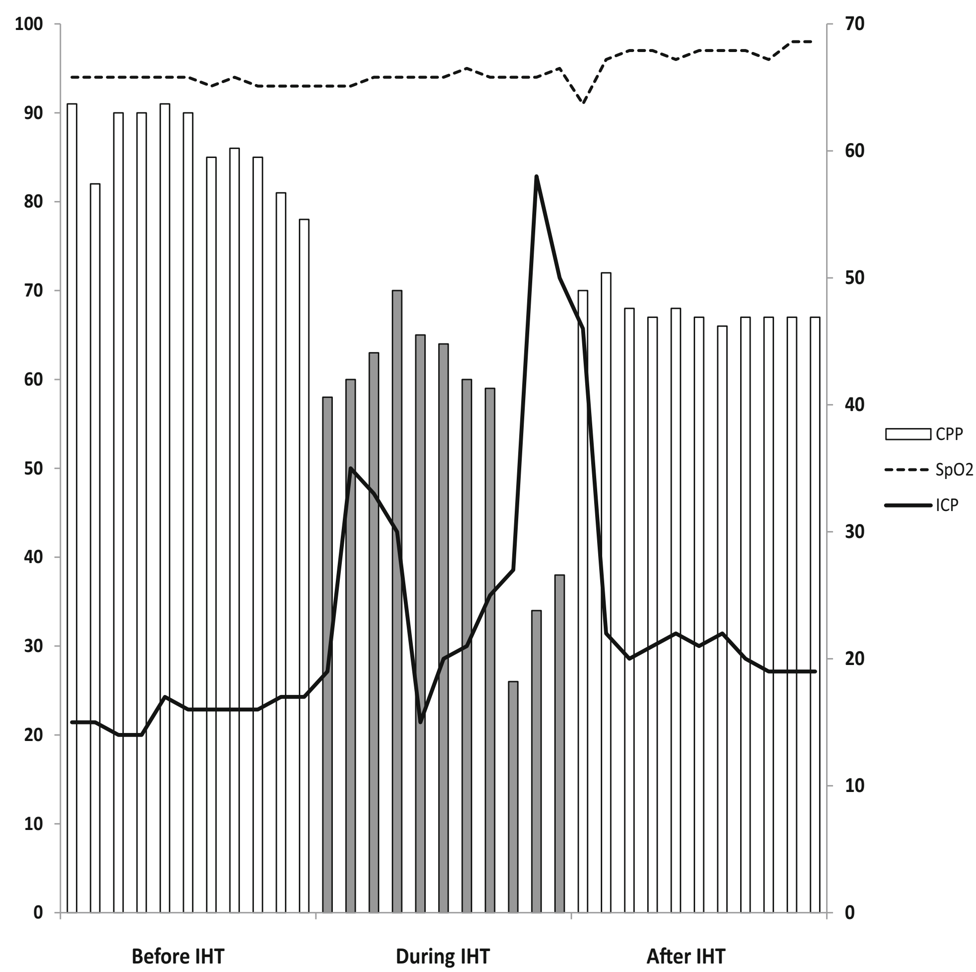

Fig. 2 Graph of a 34-year-old man who suffered from SIs (ICP >30 mmHg during 5 min and CPP <50 mmHg during 5 min). IHT duration: 26 min. The two peaks on the curve characterize the patient's transfer on the CT table and the patient's transfer on his bed. In both cases, a bolus of sedation was achieved. *SI* secondary insults, *ICP* intracranial pressure, *CPP* cerebral perfusion pressure, *IHT* intrahospital transport, *CT* computed tomography

Table 4 Clinical impact of SIs or AEs occurred during IHT

	Secondary insult $n = 16$	Ø secondary insult $n = 15$	P	Adverse event $n = 19$	Ø adverse event $n = 12$	P
Duration of sedation (days)	9 [6; 13]	10 [7; 17]	0.281	12 [7; 17]	8 [6; 10]	0.53
Duration of ventilation (days)	10 [8; 15]	12 [9; 20]	0.119	13 [9; 21]	9 [6; 12]	0.220
Death (no. of patients)	8	3	0.085	5	6	0.169
VAP (no. of patients)	12	11	0.618	15	8	0.362
Length of stay in ICU (days)	11 [8; 26]	20 [11; 26]	0.216	20 [12; 28]	10 [8; 21]	0.016
Length of stay in hospital (days)	15 [8; 46]	28 [26; 47]	0.078	31 [20; 47]	15 [8; 37]	0.059

VAP ventilator-associated pneumonia, *ICU* intensive care unit

On 123 IHTs, Damm et al. reported 22 cases of deeper sedation, 3 cases of paralysis, 11 cases of changes in vasopressor doses, and 10 cases of intravenous fluid loading [15]. This was the therapeutic intervention rate in relation to the occurrence of much lower AEs. Population of patients was less severe; only 66 % were sedated and 45 % required vasopressors. (The subgroup analysis found a higher complication rate among sedated patients.) Moreover, only 20 % of IHTs concerned patients suffering from neurological injuries (monitoring of ICP in 14 % of cases).

But the poor tolerance of ICH-patients with episodes of awakening or ventilator asynchrony often justifies faster and more systematic therapeutic intervention.

Finally, the lowest rate of complications in this study could be explained by the fact that the therapeutic response to SIs or AEs during IHT was left to the discretion of the physician who provided transport. The therapeutic intervention thresholds could be different depending on transport. Changes in variables related to SIs were significant only when comparing the data before and during transportation. No difference (except a lower DAP) was found on comparing data 30 min before and 30 min after transportation (Table 2).

These SIs will be a quickly resolved "one-time phenomenon" after optimizing the patient on his return to the ICU. However, the subsequent impact of these episodes is still possible even if its assessment is difficult. Morbidity caused by IHT, the length of hospitalization, neuropsychological sequelae, and mortality rate are all factors that remain poorly documented. Further clinical studies are necessary in order to evaluate their incidence, nature, and severity in the short, medium, and long term.

Therapeutic Benefit of a CT Scan Control

Only one patient underwent a surgical evacuation of a hematoma within 12 h of the CT scan. For this patient, the nature of the bleeding lesion had been known since the initial scan and control CT scan were performed because of an increase in uncontrolled ICP. This is in contrast to a high frequency of aggravation of CT lesions (42 %) (Fig. 1). Yet many authors base their interest for control CT on the high frequency of radiologic lesions worsening [2, 4], especially when the initial CT is realized in the first 3 h post trauma. Our results are consistent with previous work, highlighting the low benefit in a population of ICP-monitored TBI, of systematic control CT for screening lesions requiring surgical evacuation [5, 6].

Thirty-two percent of patients benefit from an increase in medical treatment (sedation) of ICP within 12 h after the CT scan. According to the meta-analysis by Wang et al., it appears that therapeutic changes after control CT scan would represent approximately 38 % of patients, a rate similar to that of our study [18]. If there is a strong association between the increase of sedation within 12 h of the CT scan and aggravation of injuries to the scanner, it is unlikely that this increase in sedation was motivated by the radiological data but more by data from multimodal monitoring including ICP. Indeed, patients who received an increase in sedation were those for which the ICP values before CT was highest (20 mmHg [17; 23 mmHg] versus 14 mmHg [12; 16 mmHg] ($p = 0.027$)). We cannot, based on our results, assert any therapeutic benefit of systematic control of imaging. The small number of patients does not allow us to determine the incidence of lesion worsening and requiring surgery without clinical abnormality or ICP increase. It is also difficult to predict the impact of CT scan on medical treatment decisions. However, we can assess that changes in medical treatment are mainly guided by the multimodal monitoring data rather than by imaging. Thus, strengthening the means of monitoring and surveillance, rather than the systematic control of imaging, appears as essential when the impact on therapeutic management is taken into account. On mild TBI patients, a recent literature review concluded that routine follow-up CT scans rarely alter treatment for patients. Their data support that serial neurological examinations and close observation may be sufficient to identify the need for intervention [19].

Optimize IHT Safety

We suggest that changes in medical treatment are mainly guided by the multimodal monitoring data rather than by imaging. SIs and AEs still remain too high. One of them is probably avoidable. Integration of standardized operating procedures (SOP) for IHT could reduce this incidence. Recently, on 1637 trauma patients, Cuschieri et al. reported the overall positive effect of implementing SOPs for severely injured patients. Over the course of the study, there were improvements in hospital morbidity and mortality and increased compliance with SOPs [20]. In 2016, Sherren et al. argued for development of SOP and a checklist for rapid sequence induction (RSI) in the critically ill. The SOP consisted of an RSI equipment set-up sheet, pre-RSI checklist, and failed airway algorithm. The SOP improved RSI preparation, crew resource management, and first pass intubation success while minimizing adverse events [21]. The benefit of similar procedures (who should accompany critical patients, which medication to leave in the unit, educational programs for transport monitors/ventilators, etc.) should be evaluated for IHT, especially if they do not become systematic (decrease in the number of transports, less usual, more AEs, etc.).

The main limitation of the study is the small number of patients included; yet it is similar to the Andrews study, whose main work reported IHTs in head-injured patients [9].

On the specific issue of IHT in severe TBI patients monitored by ICP, it is the largest number of patients published to our knowledge.

The prospective nature of the study, with a continuous compilation of all monitoring parameters during transport, allowed us to accurately report the occurrence of SIs, view the systemic and cerebral hemodynamic changes during the different phases, and accurately identify episodes of increased ICP. We were able to remove all the AEs that may occur during transport without loss of information.

The small number of patients does not allow a conclusion regarding the longer term consequences for our patients. However, we demonstrate that IHT of severe TBI patients is associated with a high incidence of SIs and AEs. In ICP-monitored patients, the benefice of routine repeat CT scan should be proved by prospective studies that consider the potential SIs and AEs occurring during IHT.

Conclusion

IHT carries significant SIs and AEs in severe TBI patients. To improve patient safety and maintain a risk/benefit ratio favorable to the patient, prospective studies focusing on IHT complications regarding therapeutic impact of control CT scan are needed.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval The study design was approved by the "CPP Ile-de-France I" research and ethics committee-HOTEL DIEU University Hospital-1, place du Parvis Notre Dame-75181-PARIS Cedex 04-France.

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