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Guideline Adherence and Outcome in Neurosurgical Treatment of Traumatic Acute Subdural Hematoma

Ranjit D. Singh,^{1–4,*} Samuel A. Corper,^{1–4} Rick J.G. Vreeburg,^{1–4} Jeroen T.J.M. van Dijk,^{1–4} Hugo F. den Boogert,^{1–4} Godard C.W. de Ruiter,^{1–4} Wilco C. Peul,^{1–4} and Thomas A. van Essen^{1–4}

Abstract

An acute subdural hematoma (ASDH) is the most common focal injury in traumatic brain injury (TBI) and a major cause of death and morbidity worldwide. The decision to perform neurosurgical evacuation of the ASDH is complex. The Brain Trauma Foundation (BTF) issued guidelines in 2006, recommending evacuation for ASDHs >1 cm or with >5 mm midline shift regardless of patients' Glasgow Coma Scale (GCS) score, and in cases of neurological deterioration, abnormal pupillary reaction, or high intracranial pressure (ICP). Despite their global recognition, the evidence supporting these guidelines is weak. This study assesses adherence to BTF guidelines in a European cohort and determines the effect on mortality and functional outcomes. Data from the prospective observational Collaborative European Neurotrauma Effectiveness Research in Traumatic Brain Injury (CENTER-TBI) study were analyzed. Patients presenting after a TBI with an ASDH on the initial computed tomography scan across 65 trauma centers in Europe and Israel between 2014 and 2018 were included. Patients with concomitant epidural hematoma were excluded. Adherence to BTF guidelines for ASDH surgery and ICP monitoring was assessed, including subgroup analyses based on age and TBI severity. Multivariable logistic regression models examined the association between guideline adherence and outcomes, adjusting for prespecified confounders. Among 985 patients with traumatic ASDH, overall guideline adherence was 74% ($n = 724$), with higher adherence to conservative treatment (95% [$n = 533$]) compared with surgical recommendations (45% [$n = 191$]). Adherence varied by age and TBI severity, being lower in elderly and severely injured patients. ICP monitoring adherence in comatose patients was 63% ($n = 240$). Adherence to surgical ASDH guidelines was not significantly associated with in-hospital mortality (odds ratio [OR]: 0.72 [0.43–1.2]) or 6-month functional outcome (OR: 0.73 [0.47–1.1]). Overall adherence to BTF guidelines for surgical ASDH management was low. The current surgical thresholds do not align with clinical practice. Elderly patients and those with severe TBI were less likely to be treated per guidelines. Incorporating patient age, GCS and hematoma volume into the guidelines may enhance their relevance and adherence in clinical practice.

Keywords: acute subdural hematoma; guideline adherence; neurosurgery; traumatic brain injury

Introduction

An acute subdural hematoma (ASDH) is the most common focal injury in patients with traumatic brain injury (TBI), which is a major cause of death and morbidity worldwide.¹

Besides the well-known high incidence in young patients, ASDHs are increasingly encountered in elderly, especially in high-income countries with aging populations.² Immediate neurosurgical evacuation of the hematoma, with or without subsequent decompressive craniectomy (DC), is

¹Department of Neurosurgery, University Neurosurgical Centre Holland (UNCH), Leiden and The Hague, The Netherlands.

²Department of Neurosurgery, Leiden University Medical Centre, Leiden (LUMC), The Netherlands.

³Department of Neurosurgery, Haaglanden Medical Center (HMC), Leiden, The Netherlands.

⁴Department of Neurosurgery, Haga Teaching Hospital (Haga), Leiden, The Netherlands.

*Address correspondence to: Ranjit D. Singh, MD, MSc, Department of Neurosurgery, University Neurosurgical Centre Holland (UNCH), Albinusdreef 2, 2300 RC Leiden J11-63, The Netherlands E-mail: r.d.singh@lumc.nl

often warranted. However, the decision to perform acute surgery for an ASDH is not always straightforward. While acute surgery can be lifesaving for patients with a severe injury, it may result in survival with debilitating neurological sequelae.^{3,4} On the other end of the clinical spectrum, initial conservative treatment with the possibility of a delayed burr-hole drainage after several weeks may be safe in patients with less severe injury but should be balanced against the chance of—potentially irreversible—secondary neurological deterioration that could have been prevented by acute surgery.^{5–7}

The Brain Trauma Foundation (BTF) published its first evidence-based guidelines on TBI in 1996, which have been updated three times since then.⁸ For the surgical management of an ASDH, the first BTF guidelines appeared in 2006 and have not been updated until today.⁹ These guidelines state that:

“An acute subdural hematoma (SDH) with a thickness greater than 10 mm or a midline shift greater than 5 mm on computed tomography (CT) scan should be surgically evacuated, regardless of the patient’s Glasgow Coma Scale (GCS) score.”

Furthermore, surgery is recommended in case of neurological deterioration, abnormal pupillary reaction, or an initial intracranial pressure (ICP) higher than 20 mmHg:

“A comatose patient (GCS score less than 9) with an SDH less than 10-mm thick and a midline shift less than 5 mm should undergo surgical evacuation of the lesion if the GCS score decreased between the time of injury and hospital admission by 2 or more points on the GCS and/or the patient presents with asymmetric or fixed and dilated pupils and/or the intracranial pressure (ICP) exceeds 20 mmHg.”

The BTF guidelines are less specific with regard to the timing and methodology of the surgery. When an indication for surgery exists, evacuation of the hematoma ought to be performed “as soon as possible” and should be done using “a craniotomy with or without bone flap removal and duraplasty.”

For patients presenting in a comatose state who do not match the above-mentioned criteria for evacuation of the hematoma, it is recommended that “all patients with acute SDH in coma (GCS score less than 9) should undergo ICP monitoring.”

Although the BTF guidelines are currently considered the global standard in the field of TBI, their evidence base is rather weak, consisting mainly of retrospective non-comparative studies conducted in the 1990s on selected patient groups.^{9–12} As such, the acute surgical versus initially conservative treatment of patients with a traumatic ASDH remains an important clinical dilemma, forcing neurosurgeons to rely more on their intuition and habitual practices than existing guidelines, resulting in considerable practice variation for TBI care in general.^{13–18} No study

has systematically investigated the adherence to BTF guidelines for the surgical treatment of an ASDH on an individual-patient level. Therefore, the aim of our study was to assess the adherence to the BTF guidelines regarding the neurosurgical management of a traumatic ASDH in a large European patient cohort and to determine the effect on in-hospital mortality and functional outcome at 6 months.

Materials and Methods

Study population

Data from the Collaborative European Neurotrauma Effectiveness Research in Traumatic Brain Injury (CENTER-TBI) were analyzed. CENTER-TBI was a prospective observational cohort study including patients presenting to one of 65 participating level-1 trauma centers across Europe and Israel between 2014 and 2018 who sustained TBI and had an indication for brain CT scan.¹⁹ Patients with preexisting cognitive impairments such as dementia, severely injured patients who died in the emergency room prior to imaging, and patients presenting more than 24 h after injury were excluded from CENTER-TBI.²⁰ For the current study, consecutive patients who presented with TBI and showed an ASDH on the first CT scan were included in the study. Patients with a concomitant epidural hematoma (EDH) were excluded to ensure clarity regarding the primary surgical indication. Inclusion of these cases could obscure whether the indication was attributable to the EDH, the SDH, or both, thereby potentially compromising the reliability of the results. CENTER-TBI was conducted in accordance with Good Clinical Practice (CPMP/ICH/135/95). Informed written or oral consent by patients or legal representative was obtained according to local legislation. Ethical approval for the CENTER-TBI study was obtained from the medical ethics committees of all participating centers.

Data collection

Patient variables were collected by local clinical research teams. The variables were defined in accordance with common data elements (CDE).²¹ Variables used for this study included demographics (age and sex), overall health status defined by the American Society of Anesthesiologists score, anticoagulant or antiplatelet use, neurological condition at admission (GCS score, pupillary reactions, focal neurological deficits) and CT-scan characteristics. Furthermore, placement of an ICP monitor or surgical evacuation of the ASDH were reported. Data were collected on pre-specified timepoints and derived from the clinical charts. Interpretable admission CT datasets were forwarded to a neuroimaging repository and centrally assessed by trained investigators using National Institute of Neurological Disorders and Stroke (NINDS) CDE based standardized templates, under the supervision of

expert neuroradiologists.²² For the purpose of this study a structured methodology was employed. Subdural hematoma thickness was measured at the level of the septum pellucidum or the thickest representative slice. If the majority of the SDH lesion was either high rostral or caudal to the septum pellucidum (e.g., solely temporal or high frontal), it was measured at the thickest representative slice orthogonal to the skull (i.e., using appropriate CT plane). Thickness for tentorial or interhemispheric lesions was not measured, and such cases were therefore not included in the study. Midline shift was measured according to the A/2-B method, where A is the width of the intracranial space and B is the distance from the tabula interna to the septum pellucidum at the level of the foramen of Monro.²³

To assess interobserver agreement, 100 unread CT examinations were randomly collected from the imaging repository, and the Intraclass Correlation Coefficient (ICC) with 95% confidence intervals (CI) using a two-way model was calculated. Data were entered into a web-based electronic case report form (Quesgen Systems Inc., Burlingame, USA) in an anonymized format. Data were hosted on the International Neuroinformatics Coordinating Facility (INCF) platform and extracted by a bespoke data management tool, *Neurobot* (RRID: SCR_01700) (INCF, Sweden). Imaging data collection was facilitated and hosted on the icometrix platform (*icometrix*, Leuven).²⁴ The core dataset CENTER-TBI version 3.0 was used for this study.

Statistical analysis

For all patients, it was determined whether surgical evacuation of the ASDH or ICP monitoring was indicated according to the BTF guidelines. Next, this was compared with the actual observed treatment. Overall guideline adherence was defined as the proportion of patients treated according to the guideline recommendation, which was calculated by dividing the total number of patients treated according to the guideline recommendation by the total number of patients eligible for the guideline. Guideline adherence for surgical ASDH evacuation as well as for ICP monitoring placement was calculated. Adherence was also analyzed stratified for the patient's age (pediatric ≤ 17 years, adult 18–64 years, elderly ≥ 65 years) and TBI severity (mild GCS 13–15), moderate (GCS 9–12) or severe (GCS 3–8). To explore whether a higher surgical threshold for ASDH size would better align with clinical practice, sensitivity analyses were conducted to assess hypothetical guideline adherence using a 2 cm threshold for ASDH surgery instead of the current 1 cm threshold. Binary multivariable logistic regression models were used to investigate the association between guideline adherence and in-hospital mortality and functional outcome at 6 months,

with covariate adjustment for age, GCS, pupillary reactivity at admission, largest ASDH thickness, and the presence of an intraparenchymal hemorrhage. Functional outcome was dichotomized based on the Extended Glasgow Outcome Scale score (GOSE) into favorable (GOSE 5–8) and unfavorable (GOSE 1–4) outcomes.

Results

Included patients and baseline characteristics

A total of 958 patients with an ASDH were analyzed (Fig. 1). The majority of patients were male ($n = 673$ [68%]) with a median age of 60 years (interquartile range [IQR]: 40–72) (Table 1). Most patients had a healthy pre-injury condition ($n = 452$ [46%]) or mild systemic disease ($n = 371$ [38%]). Anticoagulants ($n = 90$ [9%]), antiplatelets ($n = 130$ [13%]), or both ($n = 13$ [1%]) were used in a minority of patients. Patients presented with mild TBI in 44% ($n = 428$), moderate TBI in 14% ($n = 137$), and severe TBI in 39% ($n = 382$) of cases. At hospital presentation, 891 (76%) patients had both pupils reacting to light, 67 (6%) patients had one light-reactive pupil, and 159 (14%) patients had bilaterally non-reactive pupils. A focal neurological deficit was present in 103 (11%) patients, dysphasia in 47 (5%) patients, and paresis in 69 (7%) patients.

The first CT scan showed a median thickness of the ASDH of 0.7 cm (IQR: 0.4–1.1) (Table 2). An ASDH greater than 1 cm was present in 227 (23%) patients, and 223 (23%) patients had a midline shift greater than 5 mm, while 142 (14%) patients had both an ASDH greater than 1 cm and a midline shift greater than 5 mm. Traumatic subarachnoid hemorrhage was present in 761

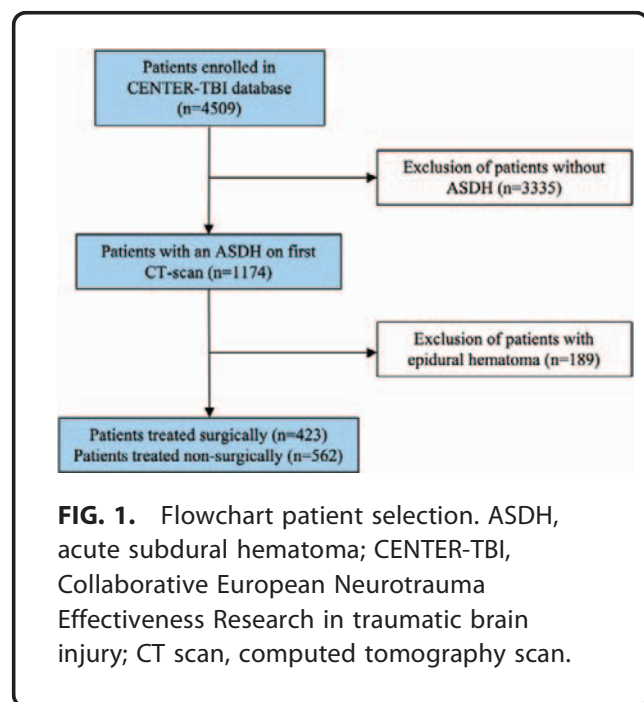


Table 1. Baseline Characteristics

<i>Baseline characteristics (n = 985)</i>	
Age (median [IQR])	60 (40–72)
Age group (<i>n</i> [%])	
Pediatric	33 (3)
Adult	551 (56)
Elderly	401 (41)
Male sex (<i>n</i> [%])	673 (68)
ASA classification (<i>n</i> [%])	
Healthy	452 (46)
Mild systemic disease	371 (38)
Severe systemic disease	119 (12)
Severe systemic disease with constant threat to life	7 (1)
Unknown	36 (4)
Anticoagulant or antiplatelet use (<i>n</i> [%])	
Anticoagulants	90 (9)
Antiplatelets	130 (13)
Both	13 (1)
None	704 (72)
Unknown	48 (5)
TBI severity (<i>n</i> [%])	
Mild	428 (44)
Moderate	137 (14)
Severe	382 (39)
Unknown/missing	38 (4)
Injury severity score (median [IQR])	25 (16–34)
Pupillary reaction (<i>n</i> [%])	
Both reacting	891 (76)
One reacting	67 (6)
Both unreacting	159 (14)
Unknown	57 (5)
Focal neurological deficit (<i>n</i> [%])	
Yes	103 (11)
No	650 (66)
Unknown	232 (24)
Dysphasia (<i>n</i> [%])	
Yes	47 (5)
No	35 (4)
Unknown	903 (92)
Paresis (<i>n</i> [%])	
Yes	69 (7)
No	29 (3)
Unknown	5 (1)

ASA, American Society of Anesthesiologists; IQR, interquartile range; TBI, traumatic brain injury.

(77%) patients and an intraparenchymal hemorrhage in 575 (58%) patients. Skull fractures were observed in 557 (57%) patients, and brain herniation was present in 256 (26%) patients.

Interrater agreement

An agreement of ICC = 0.65 (95% CI: 0.51–0.75) was found between reviewers. The median difference between ASDH measurements was 0.18 cm (IQR: 0.00–0.27) (Supplementary Fig. S1).

Guideline adherence

ASDH surgery. Overall adherence to the BTF treatment guidelines for ASDH was 74% (*n* = 724). For patients where the guideline recommended a conservative treatment, adherence was 95% (*n* = 533), while for patients where the guideline recommended surgery, adherence

Table 2. CT-Scan Characteristics

<i>CT-scan characteristics (n = 985)</i>	
ASDH thickness, cm (median [IQR])	0.7 (0.4–1.1)
ASDH greater than 1 cm (<i>n</i> [%])	
Present	227 (23)
Absent	758 (77)
Midline shift greater than 5 mm (<i>n</i> [%])	
Present	223 (23)
Absent	762 (77)
ASDH greater than 1 cm and midline shift greater than 5 mm (<i>n</i> [%])	
Present	142 (14)
Absent	843 (86)
Traumatic SAH (<i>n</i> [%])	
Present	761 (77)
Intermediate	2 (0.2)
Absent	222 (23)
Intraparenchymal hemorrhage (<i>n</i> [%])	
Present	575 (58)
Intermediate	5 (0.5)
Absent	405 (41)
Skull fracture (<i>n</i> [%])	
Present	557 (57)
Intermediate	7 (1)
Absent	421 (43)
Penetrating brain injury (<i>n</i> [%])	
Present	4 (0)
Absent	981 (100)
Brain herniation (<i>n</i> [%])	
Present	256 (26)
Intermediate	4 (0.4)
Absent	725 (74)

ASDH, acute subdural hematoma; CT, computed tomography; IQR, interquartile range; SAH, subarachnoid hemorrhage.

was 45% (*n* = 191). A total of 423 (43%) patients were eligible for ASDH surgery according to the BTF guidelines, while in reality 220 (22%) patients received a craniotomy (156 [71%]) or (primary) DC (64 [29%]) with ASDH evacuation (Table 3). Of the 232 patients eligible for ASDH surgery according to the guidelines but treated conservatively, 60 (26%) patients were considered to have an unsalvageable prognosis according to the treating neurosurgeon.

For patients presenting with mild TBI, guideline adherence for ASDH treatment was 88% (*n* = 376), while it was 77% (*n* = 106) and 56% (*n* = 213) for patients with moderate and severe TBI, respectively (Fig. 2). Adherence to the ASDH treatment guidelines was 91% (*n* = 30) in pediatric patients, 75% (*n* = 412) in adults, and 70% (*n* = 282) in the elderly (Fig. 3).

Table 3. Guideline Adherence to ASDH Surgery

	<i>Actual treatment</i>		<i>Total</i>
	<i>Conservative</i>	<i>ASDH surgery</i>	
Treatment according to guideline			
Conservative	533 ^a	29	562
ASDH surgery	232	191 ^a	423
Total	765	220	985

^aGuideline adherence.

ASDH, acute subdural hematoma.



FIG. 2. ASDH surgery guideline adherence stratified on TBI severity. ASDH, acute subdural hematoma; TBI, traumatic brain injury.

Sensitivity analyses assessing hypothetical guideline adherence when the threshold for ASDH surgery would be 2 cm rather than 1 cm showed a somewhat higher guideline adherence across all age groups (pediatric 94% [$n = 31$], adult 76% [$n = 421$], elderly 75% [$n = 299$]) and all TBI severities (mild 92% [$n = 394$], moderate 79% [$n = 108$], severe 58% [$n = 221$]). Raising the threshold for ASDH surgery to 3 cm did not increase adherence rates further for age groups (pediatric 94% [$n = 31$], adult 76% [418], elderly 74% [$n = 296$]) or TBI severity (mild 91% [$n = 391$], moderate 78% [$n = 107$], severe 58% [$n = 220$]).

ICP monitoring in comatose patients with ASDH. Out of 382 patients presenting with a GCS <9 and thus having an indication for ICP monitoring according to the BTF guidelines, 240 (63%) patients received an ICP monitor. Among the 142 eligible patients who did not receive monitoring, 50 (35%) patients were considered unsalvageable due to a very poor prognosis.

Functional outcome. Overall, in-hospital mortality was 18% ($n = 215$), and six-month mortality was 24% ($n = 238$) (Table 4). An unfavorable outcome at six months was experienced by 406 (41%) patients, while 459 (47%) patients obtained a favorable outcome. After excluding patients who were considered unsalvageable,

adherence to the BTF guidelines for ASDH surgery was not significantly associated with in-hospital mortality (odds ratio [OR]: 0.72 [0.43–1.2]) or six-month unfavorable outcome (OR: 0.73 [0.47–1.1]) after covariate adjustment. Similarly, in salvageable patients with a GCS <9 , no association was found between ICP monitoring guideline adherence and in-hospital mortality (OR: 1.0 [0.5–2.1]) or six-month unfavorable outcome (OR: 1.5 [0.78–2.9]) (Table 5).

Sensitivity analyses including patients who were considered unsalvageable showed a significant association between adherence to the BTF guidelines for ASDH surgery and lower odds of in-hospital mortality (OR: 0.48 [0.30–0.76]) and also lower odds of unfavorable outcome at six months (OR: 0.66 [0.42–1.0]). For patients with a GCS <9 , including those considered unsalvageable, adherence to the BTF ICP monitoring guidelines was associated with significantly lower odds of in-hospital mortality (OR: 0.47 [0.26–0.86]) after covariate adjustment, but not significantly with six-month unfavorable outcome (1.1 [0.57–2.0]).

Discussion

Overall adherence to the BTF guidelines regarding neurosurgical treatment of a traumatic ASDH was 74%. Adherence to the conservative treatment recommendation was higher (95%) compared with the surgical recommendation

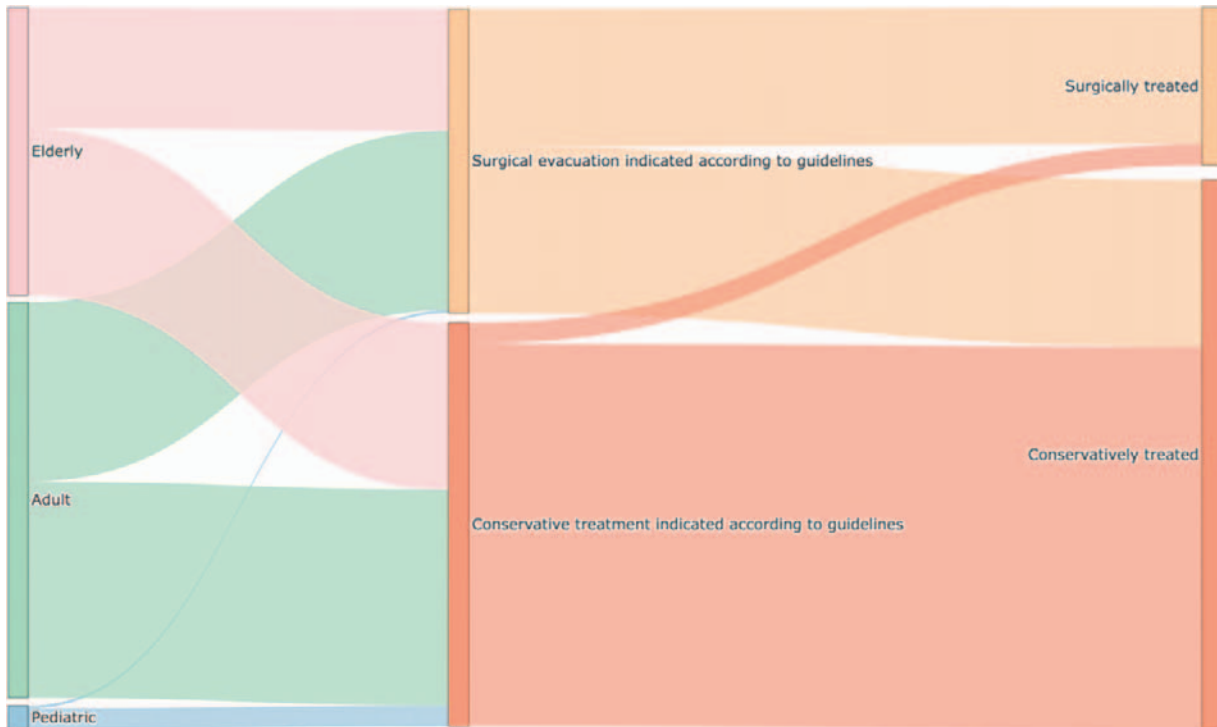


FIG. 3. ASDH surgery guideline adherence stratified on age group. ASDH, acute subdural hematoma.

(45%). For ICP monitoring in comatose patients with ASDH, adherence was 63%. Guideline adherence for ASDH surgery or ICP monitor placement was not significantly associated with in-hospital mortality or with six-month functional outcome.

Adherence variability

Guideline adherence in TBI care in general has been reported to vary considerably, ranging from 18 to 100%.¹⁸ Recommendations based on strong evidence typically see

better adherence than those based on weaker evidence.²² Despite the BTF guidelines' low-level evidence base, overall adherence to neurosurgical ASDH guidelines was not particularly low (74%). However, there was a large discrepancy between adherence to conservative (95%) and surgical (45%) treatment recommendations. This discrepancy may indicate that the thickness thresholds in the guidelines are rather low and do not necessarily align with clinical practice. This may reflect that in practice, patients with ASDHs smaller than this threshold (<1 cm) or with less midline shift (<5 mm) are highly unlikely to be operated upon, while patients in a relatively good neurological condition with an ASDH eligible for evacuation according to these thresholds are also not necessarily operated upon. For example, a frail elderly patient in a good neurological condition with an ASDH >1 cm will often be treated non-surgically, despite meeting the guideline criteria.^{14,25} Neurosurgeons may require more convincing evidence supporting surgical recommendations before performing invasive neurosurgical procedures based on them. This is in line with previous literature showing that adherence to guidelines on invasive interventions—such as craniotomy or DC—is generally lower compared with less invasive treatments.¹⁸

Patient age and TBI severity

Subgroups of elderly patients and patients with severe TBI were less likely to be treated according to the BTF

Table 4. Functional Outcome

<i>Functional outcome (n = 985)</i>	
In-hospital mortality (n [%])	215 (18)
Death cause (n [%])	
Initial head injury	126 (11)
Secondary intracranial damage	34 (3)
Systemic trauma	3 (0)
Medical complications	25 (2)
Other/unknown	986 (84)
GOS 6 months (n [%])	
1 (dead)	238 (24)
2 (vegetative state) or 3 (lower severe disability)	117 (12)
4 (upper severe disability)	51 (5)
5 (lower moderate disability)	91 (9)
6 (upper moderate disability)	86 (9)
7 (lower good recovery)	129 (13)
8 (upper good recovery)	153 (16)
Unknown	120 (12)

GOS, Glasgow outcome scale extended.

Table 5. Mortality and Functional Outcome

	<i>Adjusted odds ratio (OR)^a (95% CI) without unsalvageable patients</i>	<i>Adjusted odds ratio (OR)^a (95% CI) including unsalvageable patients</i>
In hospital mortality		
ASDH surgery guideline adherence	0.72 (0.43–1.2)	0.48 (0.30–0.76)*
ICP monitoring guideline adherence	1.0 (0.5–2.1)	0.47 (0.26–0.86)*
Six-month unfavorable outcome		
ASDH surgery guideline adherence	0.73 (0.47–1.1)	0.66 (0.42–1.0)
ICP monitoring guideline adherence	1.5 (0.78–2.9)	1.1 (0.57–2.0)

*Statistically significant ($p \leq 0.05$).

^aThe odds ratio was adjusted for age, baseline GCS, pupillary reactivity, the ASDH thickness and presence of an intraparenchymal hemorrhage. ASDH, acute subdural hematoma; CI, confidence interval; ICP, intracranial pressure; OR, odds ratio.

guidelines compared with younger and less severely injured patients.

Age and GCS have previously been associated with guideline adherence in TBI care.¹⁸ The progressive atrophy of the aging brain leads to an enlarged subdural space, allowing for a thicker ASDH to accumulate before neurological symptoms manifest, which may increase the surgical threshold. Furthermore, elderly patients, often with multiple comorbidities and anticoagulant/antiplatelet use, have an increased surgical risk,²⁶ potentially leading to more conservative treatment decisions despite meeting surgical guideline criteria. Similarly, severely injured patients may not be operated upon due to a presumed poor prognosis, despite meeting criteria for surgical ASDH evacuation. Of note, neurosurgeons should remain vigilant of this practice, as not operating on old or severely injured patients based on a prognostic estimation may lead to self-fulfilling prophecies that can further enforce therapeutic nihilism in these patient groups.²⁷

Functional outcome

No significant associations were found between guideline adherence and in-hospital mortality or functional outcome at six months. However, when including patients who were considered unsalvageable, surgical guideline adherence was associated with lower adjusted odds of in-hospital mortality. This is likely due to the fact that the presumed poor prognosis of certain patients will affect both their treatment allocation and outcome. Therefore, deviation from the (surgical) guideline recommendations in these patients will lead to negative associations with in-hospital mortality. This rationale is supported by the non-significant ORs after excluding patients with an unsalvageable prognosis. Similar caution should be applied to the significantly lower odds of in-hospital mortality in the ICP monitoring adherence group, as it may reflect neurosurgeons' reluctance to monitor presumably unsalvageable patients, even if guidelines recommend it.

Associations between BTF guideline adherence in TBI, particularly regarding ICP monitoring, and reduced mortality have been reported previously, although the authors also advised caution in interpreting these findings due to

the high risk of confounding by indication and (performance) bias in the studies.¹⁸ Furthermore, the rationale for ICP monitoring has been challenged by the BEST-TRIP trial, which found no benefit of a management protocol based on ICP monitoring compared with one based on serial imaging and clinical examination.²⁸

Strengths and limitations

Strengths of this study include the large sample size from multiple centers across Europe, though generalizability to other regions may be limited. Another strength is the structured and consistent manner of reading the CT scans, limiting the possibility of information bias. One limitation is the observational nature of the data, with potential unmeasured confounding (by indication) influencing the associations between guideline adherence and outcome. This includes patients considered unsalvageable, who in fact received neither surgical nor conservative treatment, but only best supportive care. Additionally, while guideline adherence was quantified, reasons for (non)adherence were not analyzed. Patients with a EDH were excluded from this study, which limits the generalizability of the findings to this specific subgroup. Finally, mortality and GOS-E at six months were used as the primary outcome measure in this study, although recovery after (severe) TBI has been shown to continue beyond six months in a subset of patients.²⁹ As such, it is possible that additional patients may have achieved a favorable outcome with longer-term follow-up.

Future perspectives

The low adherence to surgical guideline recommendations may suggest that the unidimensional focus on thickness of the ASDH does not resonate with current neurosurgical practice, with the additional challenge of a lack of uniform manner of measuring. Our findings also show variable guideline adherence across different age groups and TBI severities. The current BTF guidelines acknowledge the multifactorial nature of the decision to operate on an ASDH in the "scientific foundation": "the decision to operate on an SDH is based on the patient's GCS score, pupillary exam, comorbidities, CT findings,

age, and in delayed decisions, ICP. Neurological deterioration over time is also an important factor influencing the decision to operate.” However, patient age and GCS are still not included in the primary guideline recommendations. Similarly, the recent best practice guidelines of the American College of Surgeons Trauma Quality Improvement program also did not incorporate patient age or GCS but stated that a large (>25 ml) traumatic hematoma—whether epidural or subdural—should be evacuated irrespective of the patient’s GCS. Incorporating a volume threshold in the BTF guidelines may be more reflective of the clinically relevant hematoma size than the current thickness threshold, especially considering that volume measurements are likely less susceptible to inter-observer variability than thickness measurements.

Elderly patients are at a higher risk for ASDH due to the enlarged subdural space and common use of anticoagulants/antiplatelets, even after mild or moderate TBI.³⁰ The decision to operate on an ASDH in relation to GCS may differ for elderly patients compared with adults or pediatric patients. A recent multicenter randomized controlled trial (RCT) on surgical versus conservative treatment of ASDHs in the elderly was halted due to insufficient patient recruitment.^{25,31} Given the challenges of conducting RCTs in elderly and severely injured patients with TBI, the BTF guidelines could benefit from observational studies on ASDH treatment differences across age groups and injury severities.^{16,32}

Therefore, incorporating age, GCS, and hematoma volume into the primary BTF guideline recommendations may improve their relevance and adherence in clinical practice. Further research, especially well-designed observational studies evaluating heterogeneous treatment effects using individual patient data meta-analysis of large available databases including CT images, is needed to refine these guidelines and reflect the complexities of patient care in traumatic ASDH.

Conclusion

Overall adherence to the BTF guidelines regarding the neurosurgical management of a traumatic ASDH was 74%, with a large discrepancy between adherence to conservative (95%) and surgical (45%) recommendations. Guideline adherence for ASDH surgery or ICP monitor placement was not associated with in-hospital mortality or functional outcome at six months. Incorporating age, GCS, and hematoma volume into the primary BTF guideline recommendations may improve their relevance and adherence in clinical practice.

Transparency, Rigor, and Reproducibility Statement

CENTER-TBI is pre-registered at clinicaltrials.gov (number NCT02210221). The analysis plan for the

current study was presented in a protocol available on: <https://www.center-tbi.eu/data/approved-proposals>. CENTER-TBI included patients between 2014 and 2017. The sample size for the current study was 885 after excluding patients without an ASDH and patients with an additional epidural hematoma. Interpretable admission CT datasets were forwarded to a neuroimaging repository and centrally assessed by trained investigators using NINDS CDE based standardized templates, under the supervision of expert radiologists. Extensive methodology statements of CENTER-TBI are publicly available, as referenced in the methods. For this study, a structured methodology was employed. Subdural hematoma thickness was measured at the level of the septum pellucidum or the thickest representative slice. If the majority of the SDH lesion was either high rostral or caudal to the septum pellucidum (e.g., solely temporal or high frontal), it was measured at the thickest representative slice orthogonal to the skull (i.e., using appropriate CT plane). Thickness for tentorial or interhemispheric lesions was not measured. Midline shift was measured according to the A/2-B method, where A is the width of the intracranial space and B is the distance from the tabula interna to the septum pellucidum at the level of the foramen of Monro. The study conceptualization and statistical analysis were supervised by two epidemiologists with ample experience in the field of TBI research. Data and analyses for this study are available upon request to the study authors, after approval by the management team of CENTER-TBI. The authors agree to provide the full content of the article on request by contacting the corresponding author, r.d.singh@lumc.nl.

Authors’ Contributions

G.C.W.d.R., T.A.v.E., and W.C.P.: Conceptualization. S.A.C., T.A.v.E., R.D.S., and W.C.P.: Methodology. R.D.S., S.A.C., R.J.G.V., and T.A.v.E.: Formal analysis. R.D.S.: Writing—original draft. R.D.S., R.J.G.V., J.T.J.M.v.D., H.F.d.B., G.C.W.d.R., and W.C.P.: Writing—review and editing. G.C.W.d.R., T.A.v.E., and W.C.P.: Supervision.

Author Disclosure Statement

The authors have no competing interest to disclose.

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Supplementary Material

Supplementary Figure S1

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