Original Investigation

The Surgical Outcome of Traumatic Extraaxial Hematomas Causing Brain Herniation

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ABSTRACT

AIM: The aim of this study was to assess the surgical outcome and the prognostic importance of clinical and radiological data of patients operated emergently for an extraaxial hematoma causing brain herniation.

MATERIAL and METHODS: This retrospective study comprised 108 adult patients who were operated due to herniated traumatic extraaxial hematomas from January 2000 to January 2013.

RESULTS: Of 108 patients, 63 patients (58.3%) were diagnosed as subdural hematoma (SDH), and 45 patients (41.7%) as epidural hematoma (EDH). An unfavorable outcome was significantly increased for patients who were diagnosed as SDH (90.4%) compared with EDH patients (33.3%). Mortality rate for herniated SDH patients was 65.1%, and 26.6% for herniated EDH patients. High mortality and unfavorable outcome ratios were associated with Glasgow Coma Scale scores at admission, mean postoperative intracranial pressure (ICP) values, type of the brain herniation, interval from the time of trauma to the time of hematoma decompression, the duration of the brain herniation, intraoperative acute brain swelling, hematoma volume and thickness, degree of the midline shift and the obliteration of the basal cisterns.

CONCLUSION: Our data showed that, postoperative ICP values were one most important predictor of the mortality. We recommended postoperative ICP monitoring for all patients presenting with the brain herniation due to traumatic extraaxial hematoma.

KEYWORDS: Epidural hematoma, Herniation, Intracranial pressure, Outcome, Subdural hematoma

■ INTRODUCTION

Accident is the leading cause of death among individuals younger than 45 years. Traumatic brain injury (TBI) accounts for approximately 70% of these traumatic deaths and most of the unfavorable outcomes (2). The most important complication of TBI is the development of intracranial hematomas. It is estimated that intracranial hematomas occur in 25-45% of severe TBI, 3-12% of moderate cases and approximately 1 in 500 patients with mild TBI (40). As a result, acute traumatic extraaxial hematomas (epidural hematoma (EDH) and subdural hematoma (SDH)), are among the most common clinical entities encountered by any neurosurgical service.

Brain herniation due to posttraumatic hematoma remains one of the most difficult situation faced by neurosurgeons, and causes significant mortality and morbidity. To our knowledge there were only few past studies focused especially into the herniated subgroup of traumatic extraaxial hematomas (31,37,43,44).

The aim of this retrospective study was to assess the surgical outcome and the prognostic importance of clinical and

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radiological data of patients operated emergently upon for an extraaxial hematoma causing brain herniation.

■ MATERIAL and METHODS

This retrospective study comprised 108 adult patients who were operated due to herniated traumatic extraaxial hematomas from January 2000 to January 2013 in two neurosurgical clinics (Diskapi Education and Research Hospital and Oncology Training and Research Hospital). Clinical and imaging information was obtained through a retrospective review of the medical records and the radiographs. The criteria for inclusion were the patients accepted to the hospital with head injury and who underwent surgery due to extraaxial hematomas, causing brain herniation. Extraaxial hematomas were diagnosed by non-contrast computed tomography (CT) and the patients were classified due to having EDH or SDH. Anisocoria and lack of pupil reaction with midline shift in the admission CT were determined as the indicators of a brain herniation.

Demographic data, mechanism of the trauma, Glasgow Coma Scale (GCS) score at the time of admission, pupillary reactivity, and the duration of the intensive care unit (ICU) stay were reviewed from medical records. A ventricular or parenchymal fiberoptic intracranial pressure (ICP) monitoring catheter (Camino, Integra Life Science Corporation, Plainsboro, NJ, USA or Codman, Codman and Shurtleff Incorporation, Raynham, MA, USA) was inserted during the surgery in all patients to assist postoperative management. Patients whose postoperative ICP data were missing or to whom no ICP monitor was inserted were excluded from the study. The ICP data were recorded in the patients' documentation, on an hourly basis, by the ICU nurses. In the case of a high ICP peak, this was recorded as well and included in the data analysis for that hour. We evaluated the mean values of the entire ICP monitoring period postoperatively depending on hourly measurements.

Brain herniation syndromes, as evidenced by radiologic and neurologic examinations, were classified into three categories as follows: ipsilateral uncal herniation, bilateral uncal herniation and Kernohan's herniation. Uncal herniation was defined as cases of mydriasis ipsilateral to the clot along with contralateral hemiplegia. Kernohan's herniation represented a state with both mydriasis and hemiplegia ipsilateral to the clot (17).

The intervals from the time of trauma to the time of hematoma decompression as well as the entire operation time needed and the length of the period of brain herniation were recorded. The decompression time was defined as 30 minutes after the scalp incision, which represents an estimated time of hematoma evacuation. The length of the period of brain herniation, defined as the time period between the onset of anisocoria and the decompression time.

All patients were operated on by four senior surgeons with evacuation of the hematoma via craniotomy (CO) or crani-ectomy (CE) with duraplasty due to surgeon's intraoperative judgment. Operative records were also reviewed to determine if intraoperative brain swelling was recognized.

The location of the lesions were verified and recorded from both CT and operative findings. Hematoma volume was measured by the empirical formula of volume (0.5 x height x depth x length) on the basis of distance measurements of the depth and length on the CT slice having the largest area of clot (28). The hematoma thickness was measured as the largest vertical distance between the cortex and the tabula interna (Figure 1A) and the midline shift as the largest perpendicular distance between an imaginary reference joining the frontal crest and the protuberantia occipitalis interna and the most shifted point of the septum pellucidum (Figure 1B). The other variables analyzed by CT scanning included associated lesions and the obliteration of the basal cisterns (Figure 2A). Associated lesions were defined as subarachnoid hemorrhage (SAH) or brain contusion (Figure 2B).

Functional outcome was evaluated 6 months after injury by Glasgow Outcome Scale (GOS) score as follows: 5= good recovery, 4= moderate disability, 3= severe disability,
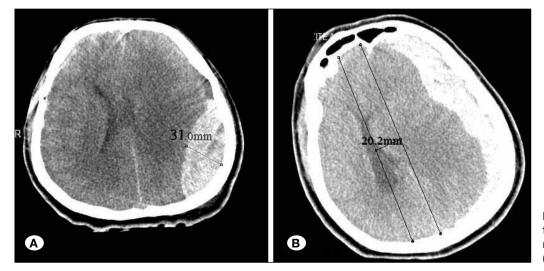

Figure 1: The thickness of the hematoma **(A)** and the midline shift measurements **(B)** showed on the CT scans.

2= vegetative state, and 1= death (15). Good recovery or moderate disability is referred to in terms of "favorable outcome", whereas the remaining three categories are classified as "unfavorable outcome".

Statistical Analysis

Data analysis was performed by using SPSS for Windows, version 11.5 (SPSS Inc., Chicago, IL, United States). Whether the distributions of continuous variables were normally or not was determined by Shapiro-Wilk test. Data were shown as mean ± SD or median (min-max), where applicable. The mean differences between groups were evaluated by Student's t test, while the Mann-Whitney U test was applied for the comparisons of the median values. Nominal data were analyzed by Pearson's Chi-square or Fisher's exact test, where appropriate. Whether the potential risk factors were statistically significant affect on mortality going on or not was evaluated by Multiple Logistic Regression Analysis Backward LR method. Any variable whose univariable test had a p value <0.25 was accepted as a candidate for the multivariable model along with all variables of known clinical importance. Odds ratios and 95% confidence intervals for each independent variable were also calculated. A p value less than 0.05 was considered statistically significant.

■ RESULTS

Of 108 patients, 63 patients (58.3%) were diagnosed as SDH and 45 patients (41.7%) as EDH. Only 36 of the 108 patients (33.3%) showed a favorable outcome. An unfavorable outcome was significantly increased for patients who were diagnosed as SDH (90.4%) compared with EDH patients (33.3%) (p<0.001). The mortality rate was 65.1% for herniated SDH patients and 26.6% for herniated EDH patients. This high mortality rate for SDH patients was statistically significant when compared to the mortality rate of herniated EDH patients (p<0.001).

The age of the patients ranged from 18 to 78 years old, with a median of 36 years old. No statistically significant difference

was determined between age groups both for mortality and functional outcome rates. There were 87 males (80.5%) and 21 females (19.5%). The mortality and functional outcome rates were not significantly different between sexes among all study cohorts (p=0.302). On the other hand mortality was determined to be higher in females with EDH (p=0.043).

Motor vehicle accidents were the leading cause of trauma (n=61, 56.5%) followed by falls (n=15, 13.9%), pedestrian injuries (n=13, 12%), assaults (n=10, 9.2%), motorcycle accidents (n=7, 6.5%), and bicycle accidents (n=2, 1.9%). Trauma mechanism showed no significance in both mortality and functional outcome rates. The demographic values of the patients are summarized in Table I.

Mortality and unfavorable outcome were highly correlated with GCS scores at admission (p<0.001 for both). The median GCS score was 4 (range 3-8) for the patients who died, and 6 (range 3-9) for the patients who were alive; patients who died showed statistically significantly lower median GCS scores. Patients in whom a favorable outcome was achieved had a median GCS of 7 (range 4-9), and patients who had unfavorable outcome showed a lower median GCS score (4, range 3-8).

Patients who had bilateral unreactive pupils before surgery had significantly higher mortality (p=<0.001) and unfavorable outcome (p=0.009). However, bilateral unreactive pupils did not show any statistical significance regarding mortality (p=0.145) and unfavorable outcome (p=1) when the subgroup of SDH patients was analyzed.

The duration of ICU did not affect mortality (p=0.248) or favorable outcome (0.837). In the EDH subgroup, the longer ICU stays were associated with more mortality (p=0.025) and more unfavorable outcome (p=0.038). In contrast, the duration of ICU stay was longer in those who survived (p=0.002) and those in whom a favorable outcome was achieved p=0.015) in the SDH subgroup.

Mortality was highly correlated with mean postoperative ICP values (p<0.001). Patients who died showed significantly
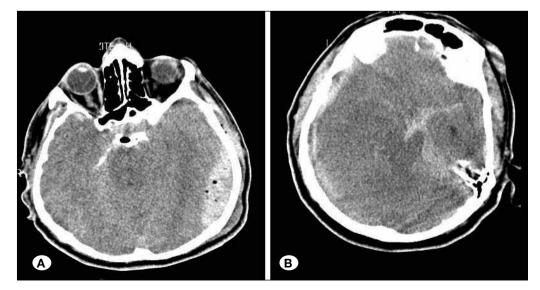

Figure 2: Obliteration of the basal cisterns **(A)** and coincident lesion as SAH **(B)** are shown on the CT scans. Both these entities were associated with high mortality and unfavorable outcome.

Table I: Demographic Features of the Patients

	Number	%
Sex		
Male	87	80.5
Female	21	19.5
Diagnosis		
SDH	63	58.3
EDH	45	41.7
Mechanism of the injury		
Motor vehicle accidents	61	56.5
Falls	15	13.9
Pedestrian injuries	13	12
Assaults	10	9.2
Motorcycle accidents	7	6.3
Bicycle accidents	2	1.9
Location of the hematoma		
Frontoparietal and frontotemporal	61	56.5
Temporal	29	26.9
Parietooccipital	9	8.3
Posterior Fossa	9	8.3

EDH: Epidural hematoma; SDH: Subdural hematoma.

higher ICP values (mean= 29 mmHg, range 21-36 mm Hg) compared with the patients who were alive (mean= 19 mmHg, range 12-33 mm Hg). The favorable outcome was also highly correlated with mean postoperative ICP values (p<0.001). Patients with favorable outcome showed significantly lower ICP values (mean= 15.5 mmHg, range 12-28 mmHg) compared with patients with unfavorable outcome (mean= 29 mmHg, range 16-36 mmHg).

Type of brain herniation significantly affected the mortality. Bilateral uncal herniation represented a strong predictor for mortality with 93.3% mortality rate when compared with ipsilateral uncal herniation (42.2% mortality) and with Kernohan's herniation syndrome (33.3% mortality) (p<0.001). Also, the presence of bilateral uncal herniation is one of the predictors of an unfavorable outcome (p=0.018). In the SDH subgroup, the type of the herniation did not affect the mortality (p=0.14) and unfavorable outcome (p=0.315).

The longer interval from the time of the trauma to the time of the hematoma decompression was significantly correlated with high mortality rate (p<0.001) and high unfavorable outcome rate (p<0.001).

The length of the operation time was correlated with both mortality and unfavorable outcome; where the longer the operation time, higher the incidence of mortality and

unfavorable outcome (p=<0.001 for both). There was no statistically significant association between the length of the operation time and mortality (p=0.485) or unfavorable outcome (p=0.882) in the SDH subgroup.

The duration of the brain herniation strongly correlated with mortality and unfavorable outcome, i.e., the longer the period of brain herniation the higher the incidence of mortality (p<0.001) and unfavorable outcome (p<0.001).

In the CE group, mortality was higher (75%) compared to the CO group (5%) (p<0.001). A favorable outcome was achieved in only 4.4% of patients in the CE group and 82.5% of the patients in the CO group. Craniotomy was highly correlated with a favorable outcome (p<0.001).

Intraoperative brain swelling was highly correlated both with high mortality (p<0.001) and unfavorable outcome (p<0.001).

The most common hematoma location was frontoparietal and frontotemporal regions (n=61, 56.5%) followed by the temporal (n=29, 26.9%), parietooccipital (n=9, 8.3%) and posterior fossa (n=9, 8.3%). As for hematoma location, our data showed data patients with hematoma in temporal location had statistically significant lower mortality rates (p=<0.001).

Hematoma volume was closely related to mortality and functional outcome, i.e., the larger the hematoma volume the higher the incidence of mortality (p<0.001) and unfavorable outcome (p<0.001). Similarly, thickness of hematoma was also closely related to mortality and functional outcome, i.e., the thicker the hematoma the higher the incidence of mortality (p<0.001) and unfavorable outcome (p<0.001).

The degree of midline displacement measured on CT significantly correlated with both mortality and functional outcome. More displacement showed significantly higher mortality rates (p<0.001) and higher unfavorable outcome (p<0.001). However, the degree of the midline displacement was shown to have no affect in the mortality of the EDH patients (p=0.135)

Twenty-five patients (23.1%) had associated SAH in CT scans, and all of these patients had an unfavorable outcome. Associated SAH was correlated with high mortality (p=<0.001) and high unfavorable outcome (p=<0.001) rates. Coincidental contusions were detected in 14.8% of patients and neither correlated with mortality (p=0.699) nor with unfavorable outcome (p=1.00). Coincidental lesions including SAH were neither correlated with mortality (p=0.513) nor with the unfavorable outcome (p=0.105) in the SDH subgroup.

The obliteration of the basal cisterns also significantly correlated with both high mortality (p<0.001) and unfavorable outcome (p<0.001). The patients in whom basal cisterns were obliterated showed 71.2% mortality and 93.9% unfavorable outcome; patients in whom basal cisterns were not obliterated showed 14.2% mortality and 23.8% unfavorable outcome.

Variables of mortality and functional outcome were analyzed in Table II and Table III respectively.

Results from the multivariable logistic regression analysis examining the association between mortality and significant

Table II: Variables Related to Mortality among all Study Cohorts

Variables	Survived (n=55; 50.9%)	Death (n=53; 49.1%)	p-value
Diagnosis			<0.001
SDH	22 (40%)	41 (77.4%)	
EDH	33 (60%)	12 (22.6%)	
Age (year)	37.3±17.3	42.6±15.5	0.1
Sex			0.736
Male	45 (81.8%)	42 (79.2%)	
Female	10 (18.2%)	11 (20.8%)	
Admission GCS	6 (3-9)	4 (3-8)	<0.001
Pupil Reactivity			<0.001
Bilateral unresponsive	1 (1.8%)	16 (30.2%)	
Unilateral unresponsive	54 (98.2%)	37 (69.8%)	
Duration of ICU Stay (day)	7 (2-22)	6 (1-26)	0.248
Postoperative ICP (mmHg)	19 (12-33)	29 (21-36)	<0.001
Herniation Type			<0.001
Bilateral uncal herniation	1 (1.8%)	14 (26.4%)	
Ipsilateral uncal herniation	52 (94.5%)	38 (71.7%)	
Kernohan's herniation	2 (3.6%)	1 (1.9%)	
Time to Surgery			<0.001
≤ 2 hours	30 (54.5%)	7 (13.2%)	
2-4 hours	10 (18.2%)	14 (26.4%)	
≥4 hours	15 (27.3%)	32 (60.4%)	
Operation Time (h)	1.5 (1-3)	2 (1-4)	<0.001
Herniation Duration (h)	1 (0.5-4)	2 (0.5-5)	<0.001
Surgery			<0.001
CE	17 (30.9%)	51 (96.2%)	
CO	38 (69.1%)	2 (3.8%)	
Intraoperative Brain Swelling			<0.001
Available	20 (36.4%)	51 (96.2%)	
None	35 (63.6%)	2 (3.8%)	
Location			<0.001
Frontoparietal and frontotemporal	24 (43.6%)	37 (69.3%)	
Temporal	24 (43.6%)	5 (9.4%)	
Parietooccipital	1 (1.8%)	8 (15.1%)	
Posterior fossa	6 (10.9%)	3 (5.7%)	
Hematoma volume (mL)	105 (70-171)	145 (95-200)	<0.001
Hematoma thickness (mm)	17 (10-32)	26 (16-34)	<0.001

Table II: Cont.

Variables	Survived (n=55; 50.9%)	Death (n=53; 49.1%)	p-value
Midline Shift (mm)	12 (5-28)	19 (5-33)	<0.001
Co-incidental lesion			<0.001
None	42 (76.4%)	25 (47.2%)	
SAH	5 (9.1%)	20 (37.7%)	
Contusion	8 (14.5%)	8 (15.1%)	
Obliteration of Basal Cisterns			<0.001
Effaced	19 (34.5%)	47 (88.7%)	
Not effaced	36 (65.5%)	6 (11.3%)	

EDH: *Epidural hematoma,* **SDH:** *Subdural hematoma,* **GCS:** *Glasgow coma scale,* **ICU:** *Intensive care unit,* **ICP:** *Intracranial pressure,* **CE:** *Craniectomy,* **CO:** *Craniotomy,* **SAH:** *Subarachnoid hemorrhage.*

Table III: Variables Related to Functional Outcome among all Study Cohorts

Variables	Unfavorable outcome[1] (n=72, 66.7%)	Favorable outcome[2] (n=36, 33.3%)	p-value
Diagnosis			<0.001
SDH	57 (79.2%)	6 (16.7%)	
EDH	15 (20.8%)	30 (83.3%)	
Age (year)	40.4±16.0	39±17.8	0.693
Sex			0.302
Male	56 (77.8%)	31 (86.1%)	
Female	16 (22.2%)	5 (13.9%)	
Admission GCS	4 (3-8)	7 (4-9)	<0.001
Pupil Reactivity			0.009
Bilateral unresponsive	16 (22.2%)	1 (2.8%)	
Unilateral unresponsive	56 (77.8%)	35 (97.2%)	
Duration of ICU Stay (day)	7.5 (1-26)	7 (2-22)	0.837
Postoperative ICP (mmHg)	29 (16-36)	15.5 (12-28)	<0.001
Herniation Type			0.018
Bilateral uncal herniation	14 (19.4%)	1 (2.8%)	
Ipsilateral uncal herniation	57 (79.2%)	33 (91.7%)	
Kernohan's herniation	1 (1.4%)	2 (5.6%)	
Time to Surgery			<0.001
≤ 2 hours	10 (13.9%)	27 (75%)	
2-4 hours	18 (25%)	6 (16.7%)	
≥4 hours	44 (61.1%)	3 (8.3%)	
Operation Time (h)	2 (1-4)	1.5 (1-2.5)	<0.001
Herniation Duration (h)	2 (0.5-5)	0.5 (0.5-2)	<0.001

Table III: Cont.

Variables	Unfavorable outcome[1] (n=72, 66.7%)	Favorable outcome[2] (n=36, 33.3%)	p-value
Surgery			<0.001
CE	65 (90.3%)	3 (8.3%)	
CO	7 (9.7%)	33 (91.7%)	
Intraoperative Brain Swelling			<0.001
Available	66 (91.7%)	5 (13.9%)	
None	6 (8.3%)	31 (86.1%)	
Location			<0.001
Frontoparietal and frontotemporal	49 (68%)	12 (33.4%)	
Temporal	8 (11.1%)	21 (58.3%)	
Parietooccipital	9 (12.5%)	-	
Posterior fossa	6 (8.3%)	3 (8.3%)	
Hematoma volume (mL)	144 (95-200)	96 (70-145)	<0.001
Hematoma thickness (mm)	25 (10-34)	15 (11-30)	<0.001
Midline Shift (mm)	18 (5-33)	10 (5-20)	<0.001
Co-incidental lesion			<0.001
None	37 (51.4%)	30 (83.3%)	
SAH	25 (34.7%)	-	
Contusion	10 (13.9%)	6 (16.7%)	
Obliteration of Basal Cisterns			<0.001
Effaced	62 (86.1%)	4 (11.1%)	
Not effaced	10 (13.9%)	32 (88.9%)	

[1]Unfavorable outcome was determined as Glasgow Outcome Scale score 1, 2, and 3.
[2]Favorable outcome was determined as Glasgow Outcome Scale score 4, and 5.
EDH: Epidural hematoma, **SDH:** Subdural hematoma, **GCS:** Glasgow coma scale, **ICU:** Intensive care unit, **ICP:** Intracranial pressure, **CE:** Craniectomy, **CO:** Craniotomy, **SAH:** Subarachnoid hemorrhage.

predictors are shown in the Table IV. One of the most important predictors of mortality was the postoperative ICP value; where every 1 mmHg raise in the postoperative ICP increased the mortality 1.64 times (95% CI: 1.246-2.172). Despite postoperative ICP, interval from the time of the trauma to the time of the hematoma decompression, thickness of the hematoma, the duration of the brain herniation and presence of SAH were determined to be the significant independent predictors of mortality.

The subgroup analyses of the EDH patients that are relevant to mortality and functional outcome are summarized in Table V and Table VI. Also, the subgroup analyses of the SDH patients that are relevant to mortality and functional outcome are summarized in Table VII and Table VIII.

■ **DISCUSSION**

The most important neurosurgical complication of head injury is the rapidly expanding intracranial hematoma causing brain herniation (33,34). Despite early diagnosis and adequate surgery, mortality and morbidity of both EDH and SDH remain considerable. The majority of studies have reported a mortality rate of approximately 12% for acute traumatic EDH (4,9,22,30) and 50-70% for acute SDH (12,36,39,46,47). In this retrospective study of more than one decade of herniated head injured patients harboring an EDH or SHD, we reported our surgical results.

The results of our study demonstrated that overall mortality was 49.1% and only 34.4% of patients showed favorable outcome. Mortality rates for herniated SDH and EDH were 65.1% and 26.6% respectively. For SDH, 90.4% of the patients showed an unfavorable outcome; however only 33.3% of EDH

Table IV: Multiple Logistic Regression Analysis Results for Variables Related to the Mortality

| Variables | Odds Ratio | 95% CI | | p-value |
		Lower Limit	Upper Limit	
Time to Surgery	0.655	0.435	0.987	**0.043**
Postoperative ICP	1.645	1.246	2.172	**<0.001**
Hematoma Thickness	1.282	1.047	1.569	**0.016**
Herniation Duration	3.529	1.315	9.474	**0.012**
Co-incidental lesion - SAH	11.234	1.594	79.189	**0.015**

CI: Confidence interval, **ICP:** *Intracranial pressure,* **SAH:** *Subarachnoid hemorrhage.*

Table V: Variables Related to Mortality among Herniated Epidural Hematoma Patients

Variables	Survived (n=33; 73.4%)	Death (n=12; 26.6%)	p-value
Age (year)	34.8±16	41.4±13.3	0.211
Sex			0.043
Male	29 (87.9%)	7 (58.3%)	
Female	4 (12.1%)	5 (41.7%)	
Admission GCS	7 (4-9)	3.5 (3-7)	<0.001
Pupil Reactivity			<0.001
Bilateral unresponsive	-	7 (58.3%)	
Unilateral unresponsive	33 (100%)	5 (41.7%)	
Duration of ICU Stay (day)	6 (2-22)	12 (2-26)	0.025
Postoperative ICP (mmHg)	16 (12-33)	31 (25-35)	<0.001
Herniation Type			<0.001
Bilateral uncal herniation	-	5 (41.7%)	
Ipsilateral uncal herniation	32 (97%)	7 (58.3%)	
Kernohan's herniation	1 (3%)	-	
Time to Surgery			0.02
≤ 2 hours	25 (75.8%)	4 (33.3%)	
2-4 hours	4 (12.1%)	2 (16.7%)	
≥4 hours	4 (12.1%)	6 (50%)	
Operation Time (h)	1.5 (1-2)	2 (1-4)	0.017
Herniation Duration (h)	0.5 (0.5-3)	1.5 (1-4)	<0.001
Surgery			<0.001
CE	3 (9.1%)	12 (100%)	
CO	30 (90.9%)	-	
Intraoperative Brain Swelling			<0.001
Available	6 (18.2%)	12 (100%)	
None	27 (81.8%)	-	
Location			<0.001

Table V: Cont.

Variables	Survived (n=33; 73.4%)	Death (n=12; 26.6%)	p-value
Frontoparietal and frontotemporal	10 (30.3%)	11 (91.7%)	
Temporal	21 (63.6%)	1 (8.3%)	
Parietooccipital	1 (3%)	-	
Posterior fossa	1 (3%)	-	
Hematoma volume (mL)	96 (75-154)	166 (100-200)	<0.001
Hematoma thickness (mm)	16 (11-32)	25 (16-33)	<0.001
Midline Shift (mm)	10 (5-22)	16 (5-21)	0.135
Co-incidental lesion			<0.001
None	28 (84.8%)	3 (25%)	
SAH	5 (9.1%)	20 (37.7%)	
Contusion	1 (3%)	7 (58.3%)	
Obliteration of Basal Cisterns			<0.001
Effaced	4 (12.1%)	12 (100%)	
Not effaced	29 (87.9%)	-	

EDH: *Epidural hematoma,* ***SDH:*** *Subdural hematoma,* ***GCS:*** *Glasgow coma scale,* ***ICU:*** *Intensive care unit,* ***ICP:*** *Intracranial pressure,* ***CE:*** *Craniectomy,* ***CO:*** *Craniotomy,* ***SAH:*** *Subarachnoid hemorrhage.*

showed an unfavorable outcome. Our study demonstrated that herniated SDH patients showed the highest mortality and the most unfavorable outcome.

Several authors reported that older age is associated with a higher mortality for TBI (10,14,18,19,27,29,46). Our age data conflicts with prior studies. Thus, in our study of the herniated subgroup of traumatic extraaxial hematomas, age does not appear to be associated either with mortality or an unfavorable outcome.

We found the motor vehicle accidents as the leading cause of trauma followed by falls, pedestrian injuries, assaults, motorcycle accidents, and bicycle accidents; the mechanism of the trauma showed no significant effect on mortality or functional outcome rates.

Initial GCS scores have been reported to be a good predictor of outcome for patients both with EDH (4,5,15,20,22,23,43,45) and with SDH (6,7,29,33,42). In our study, almost all patients with herniated extraaxial hematoma were comatose and had GCS scores equal to or lower than 9. Like other studies, we also found that mortality and unfavorable outcome were highly correlated with low GCS scores.

Pupils that are bilaterally unresponsive to light are associated with a high mortality (4,8,9,25,30,45). Patients with bilateral fixed and dilated pupils at surgery had 0-13% favorable outcome and 64-93% mortality rate (13,29,31,38,46). In our series, mortality was 94.1% for patients with bilateral unresponsive pupils; and only one of these patients (6.9%) had a favorable outcome. Statistically, we showed that having bilateral unresponsive pupils was significantly correlated with high mortality and unfavorable outcome. In the SDH subgroup,

bilateral unresponsive pupils were not correlated with high mortality and unfavorable outcome.

Monitoring of ICP is an important treatment option for patients with severe TBI. ICP monitoring is recommended by all available guidelines for management of severe TBI (1,3). There are a few studies available in which postoperative ICP and its relation to outcome was structured (23). In this study, all our patients were monitored with a continuous postoperative ICP monitor. Mean postoperative ICP values for patients who died was 29 mmHg (range 21-36 mmHg) while it was 19 mmHg (range 12-33 mmHg) for patients who survived. We therefore concluded that mortality was highly correlated with high mean postoperative ICP values. Similarly, patients with favorable outcome showed lower postoperative ICP values (mean 15.5 mmHg; range 12-28 mmHg) compared to patients with unfavorable outcome (mean 29 mmHg; range 16-36 mmHg). As a result of multivariable logistic regression analysis, our study demonstrated that one of the most important predictors of mortality was the postoperative ICP values. Every 1 mmHg raise in the postoperative ICP increased the probability of mortality 1.64 times.

Brain herniation is most commonly recognized clinically by deterioration in consciousness with unilateral or bilateral papillary dilatation (37), and hemiparesis (22). The type of the brain herniation was also associated with mortality. Bilateral herniation was reported to cause 64-88% mortality (29,31,35,41). Similarly, in our study, bilateral uncal herniation caused 93.3% mortality whereas mortality of unilateral uncal herniation was 42.2%. Furthermore, the type of brain herniation was not associated with mortality and functional outcome rates in the SDH subgroup.

Table VI: Variables Related to Functional Outcome among Herniated Epidural Hematoma Patients

Variables	Unfavorable outcome[1] (n=15, 33.3%)	Favorable outcome[2] (n=30, 66.7%)	p-value
Age (year)	38.1±13.9	35.9±16.3	0.658
Sex			0.135
Male	10 (66.7%)	26 (86.7%)	
Female	5 (33.3%)	4 (13.3%)	
Admission GCS	4 (3-8)	7 (4-9)	<0.001
Pupil Reactivity			<0.001
Bilateral unresponsive	7 (46.7%)	-	
Unilateral unresponsive	8 (53.3%)	30 (100%)	
Duration of ICU Stay (day)	12 (2-26)	6 (2-22)	0.038
Postoperative ICP (mmHg)	29 (19-35)	15 (12-28)	<0.001
Herniation Type			0.02
Bilateral uncal herniation	5 (33.3%)	-	
Ipsilateral uncal herniation	10 (66.7%)	29 (96.7%)	
Kernohan's herniation	-	1 (3.3%)	
Time to Surgery			0.006
≤ 2 hours	5 (33.3%)	24 (80%)	
2-4 hours	3 (20%)	3 (10%)	
≥4 hours	7 (46.7%)	3 (10%)	
Operation Time (h)	2 (1-4)	1.2 (1-2)	<0.001
Herniation Duration (h)	1.5 (1-4)	0.5 (0.5-2)	<0.001
Surgery			<0.001
_CE_	13 (86.7%)	2 (6.7%)	
_CO_	2 (13.3%)	28 (93.3%)	
Intraoperative Brain Swelling			<0.001
Available	14 (93.3%)	4 (13.3%)	
None	1 (6.7%)	26 (86.7%)	
Location			<0.001
Frontoparietal and frontotemporal	12 (80%)	9 (30%)	
Temporal _Parietooccipital_	2 (13.3%) 1 (6.7%)	20 (66.7%) -	
Posterior fossa	-	1 (3.3%)	
Hematoma volume (mL)	154 (100-200)	96 (75-145)	<0.001
Hematoma thickness (mm)	25 (16-33)	15 (11-30)	<0.001
Midline Shift (mm)	16 (5-22)	10 (5-20)	0.023
Co-incidental lesion			<0.001
None	5 (33.3%)	26 (86.7%)	

Table VI: Cont.

Variables	Unfavorable outcome[1] (n=15, 33.3%)	Favorable outcome[2] (n=30, 66.7%)	p-value
SAH	8 (53.3%)	-	
Contusion	2 (13.3%)	4 (13.3%)	
Obliteration of Basal Cisterns			<0.001
Effaced	14 (93.3%)	2 (6.7%)	
Not effaced	1 (6.7%)	28 (93.3%)	

[1]*Unfavorable outcome was determined as Glasgow Outcome Scale score 1, 2, and 3.*
[2]*Favorable outcome was determined as Glasgow Outcome Scale score 4, and 5.*
EDH: *Epidural hematoma,* **SDH:** *Subdural hematoma,* **GCS:** *Glasgow coma scale,* **ICU:** *Intensive care unit,* **ICP:** *Intracranial pressure,*
CE: *Craniectomy,* **CO:** *Craniotomy,* **SAH:** *Subarachnoid hemorrhage.*

The Brain Trauma Foundation and the Congress of Neurological Surgeons have recommended that surgical evacuation must be performed "as soon as possible" in patients with herniation syndromes (5). Time from trauma until surgical decompression affects the mortality. Many authors have observed that the sooner surgery is performed in cases of acute head trauma, the better the final results are (6,12,14,16,21,41,46). Seelig et al. (32) reported considerable decline in the rates of mortality and morbidity of the patients operated in the first four hours after the trauma compared to those operated upon later. Our data also showed that a longer interval from the time of the trauma to the time of the hematoma decompression was significantly correlated with high mortality and high unfavorable outcome rates.

In the case of brain herniation, immediate surgery can be life saving. With delay to decompression, patients who suffered from brain herniation syndromes have increased rates of permanent disability and death (5). Some authors also reported that the critical time is not the time from injury, but the time from the onset of symptomatic brain compression (8,12,22,26). Haselsberger et al. (12) reported that mortality rose from 17% to 65% and good recovery dropped from 67% to 13% when the time from the onset of coma to operation was more than 2 hours. In a prospective study, Lee et al. (22), showed that favorable outcomes dropped progressively through herniation time. We also demonstrated that the longer the period of brain herniation, the higher the incidences of both mortality and unfavorable outcome. In other words, our study demonstrated that in patients with both herniated SDH and EDH, the prognosis is affected by the timing of the operation and the duration of the brain herniation. Those operated soon after the trauma and soon after the onset of brain herniation have lower mortality and increased rate of favorable outcome.

Mortality and unfavorable outcome in our study was higher in the patients for whom CE was performed than the patients for whom CO was performed but this difference was likely to be caused by the high proportion of patients with the signs of the acute brain swelling and bilateral brain herniation in the CE group.

Intraoperative acute brain swelling seems to be a strong predictor of poor outcome for the patients with TBI (18,24,41).

Similarly, our data showed that intraoperative brain swelling was highly correlated both with mortality and unfavorable outcome.

CT is the imaging study of choice for the diagnosis of an extraaxial hematoma. CT also allows the identification of additional features that affect outcome such as hematoma volume, thickness of the hematoma, midline shift, SAH and obliteration of the basal cisterns (5). In a series of 200 patients who were treated surgically for EDH, Lee et al. (22), found that a hematoma volume greater than 50 cm³ was significantly related to high mortality and unfavorable functional outcome. Yanaka et al. (48), showed that greater hematoma volume and the thickness of SDH was associated with poor outcome and mortality. Many other authors reported similar findings for both EDH and SDH (11,22,30,45). We also demonstrated in our study that the larger the hematoma volume and the thickness, the higher the incidence of mortality and unfavorable outcome.

The presence and the degree of the midline shift were reported to be associated with worse recovery and high mortality (2,10,25,44). Our data also concluded that more displacement of the midline structures was associated with high mortality and unfavorable functional outcome.

The association of traumatic SAH with extraaxial hematoma was determined in 23.1% of the study patients, and all of these patients had an unfavorable outcome. Detection of traumatic SAH in the initial CT was strongly correlated with high mortality and unfavorable outcome. We also found that obliteration of the basal cisterns was significantly correlated both with high mortality and unfavorable outcome.

According to our data, the most important predictors of mortality were the interval from time of the trauma to the time of hematoma decompression, postoperative ICP, thickness of the hematoma, the duration of the brain herniation and the presence of SAH.

■ **CONCLUSION**

Brain herniation due to traumatic EDH and SDH causes catastrophic consequences. High mortality and unfavorable outcome rates are associated with GCS scores at admission,

mean postoperative ICP values, type of the brain herniation, interval from the time of trauma to the time of hematoma decompression, the duration of the brain herniation, intraoperative acute brain swelling, hematoma volume and thickness, degree of the midline shift and the obliteration of the basal cisterns.

Postoperative ICP values are the most important predictors of the mortality. We recommend postoperative ICP monitoring for all patients presenting with brain herniation due to traumatic extraaxial hematoma.

Table VII: Variables Related to Mortality among Herniated Subdural Hematoma Patients

Variables	Survived (n=22; 34.9%)	Death (n=41; 65.1%)	p-value
Age (year)	41.1±19	42.9±16.2	0.684
Sex			0.314
Male	16 (72.7%)	35 (85.4%)	
Female	6 (27.3%)	6 (14.6%)	
Admission GCS	6 (3-8)	4 (3-8)	<0.001
Pupil Reactivity			0.145
Bilateral unresponsive	1 (4.5%)	9 (22%)	
Unilateral unresponsive	21 (95.5%)	32 (78%)	
Duration of ICU Stay (day)	11 (2-22)	5 (1-25)	0.002
Postoperative ICP (mmHg)	23 (14-32)	29 (21-36)	<0.001
Herniation Type			0.14
Bilateral uncal herniation	1 (4.5%)	9 (22%)	
Ipsilateral uncal herniation	20 (90.9%)	31 (75.6%)	
Kernohan's herniation	1 (4.5%)	1 (2.4%)	
Time to Surgery			0.008
≤ 2 hours	5 (22.7%)	3 (7.3%)	
2-4 hours	6 (27.3%)	12 (29.3%)	
≥4 hours	11 (50%)	26 (63.4%)	
Operation Time (h)	2 (1-3)	2 (1-4)	0.485
Herniation Duration (h)	1 (0.5-4)	2 (0.5-5)	0.002
Surgery			0.002
CE	14 (63.6%)	39 (95.1%)	
CO	8 (36.4%)	2 (4.9%)	
Intraoperative Brain Swelling			0.002
Available	14 (63.6%)	39 (95.1%)	
None	8 (36.4%)	2 (4.9%)	
Location			0.047
Frontoparietal and frontotemporal	14 (63.7%)	26 (63.4%)	
Temporal	3 (13.6%)	4 (9.8%)	
Parietooccipital	-	8 (19.5%)	
Posterior fossa	5 (22.7%)	3 (7.3%)	
Hematoma volume (mL)	114.5 (70-171)	143 (95-190)	0.005

Table VII: Cont.

Variables	Survived (n=22; 34.9%)	Death (n=41; 65.1%)	p-value
Hematoma thickness (mm)	21 (10-29)	26 (20-34)	<0.001
Midline Shift (mm)	13 (5-28)	19 (10-33)	<0.001
Co-incidental lesion			0.513
None	14 (63.6%)	22 (53.7%)	
SAH	4 (18.2%)	13 (31.7%)	
Contusion	4 (18.2%)	6 (14.6%)	
Obliteration of Basal Cisterns			0.190
Effaced	15 (68.2%)	35 (85.4%)	
Not effaced	7 (31.8%)	6 (14.6%)	

EDH: _Epidural hematoma,_ **SDH:** _Subdural hematoma,_ **GCS:** _Glasgow coma scale,_ **ICU:** _Intensive care unit,_ **ICP:** _Intracranial pressure,_ **CE:** _Craniectomy,_ **CO:** _Craniotomy,_ **SAH:** _Subarachnoid hemorrhage._

Table VIII: Variables Related to Functional Outcome among Herniated Subdural Hematoma Patients

Variables	Unfavorable outcome[1] (n=57, 90.4%)	Favorable outcome[2] (n=6, 9.6%)	p-value
Age (year)	41±16.6	54.8±17.6	0.058
Sex			1
Male	46 (80.7%)	5 (83.3%)	
Female	11 (19.3%)	1 (16.7%)	
Admission GCS	4 (3-8)	7.5 (4-8)	0.003
Pupil Reactivity			1
Bilateral unresponsive	9 (15.8%)	1 (16.7%)	
Unilateral unresponsive	48 (84.2%)	5 (83.3%)	
Duration of ICU Stay (day)	6 (1-25)	12.5 (10-22)	0.015
Postoperative ICP (mmHg)	28 (16-36)	19.5 (14-25)	<0.001
Herniation Type			0.315
Bilateral uncal herniation	9 (15.8%)	1 (216.7%)	
Ipsilateral uncal herniation	47 (82.5%)	4 (66.7%)	
Kernohan's herniation	1 (1.8%)	1 (16.7%)	
Time to Surgery			0.002
≤ 2 hours	5 (8.8%)	3 (50%)	
2-4 hours	15 (26.3%)	3 (50%)	
≥4 hours	37 (64.9%)	-	
Operation Time (h)	2 (1-4)	2 (1-2.5)	0.882
Herniation Duration (h)	2 (0.5-5)	1 (0.5-1)	0.009

Table VIII: Cont.

Variables	Unfavorable outcome[1] (n=57, 90.4%)	Favorable outcome[2] (n=6, 9.6%)	p-value
Surgery			<0.001
CE	52 (91.2%)	1 (16.7%)	
CO	5 (8.8%)	5 (83.3%)	
Intraoperative Brain Swelling			<0.001
Available	52 (91.2%)	1 (16.7%)	
None	5 (8.8%)	5 (83.3%)	
Location			0.44
Frontoparietal and frontotemporal	37 (64.9%)	3 (50%)	
Temporal	6 (10.5%)	1 (16.7%)	
Parietooccipital	8 (14%)	-	
Posterior fossa	6 (8.3%)	2 (33.3%)	
Hematoma volume (mL)	143 (95-190)	100 (70-115)	<0.001
Hematoma thickness (mm)	25 (10-34)	14.5 (13-29)	0.005
Midline Shift (mm)	18 (5-33)	11 (7-14)	<0.001
Co-incidental lesion			0.105
None	32 (56.1%)	4 (66.7%)	
SAH	17 (29.8%)	-	
Contusion	8 (14%)	2 (33.3%)	
Obliteration of Basal Cisterns			0.014
Effaced	48 (84.2%)	2 (33.3%)	
Not effaced	9 (15.8%)	4 (66.7%)	

[1]*Unfavorable outcome was determined as Glasgow Outcome Scale score 1 and 2.*
[2]*Favorable outcome was determined as Glasgow Outcome Scale score 3, 4, and 5.*
EDH: *Epidural hematoma,* **SDH:** *Subdural hematoma,* **GCS:** *Glasgow coma scale,* **ICU:** *Intensive care unit,* **ICP:** *Intracranial pressure,* **CE:** *Craniectomy,* **CO:** *Craniotomy,* **SAH:** *Subarachnoid hemorrhage.*

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