Use of Hematocrit for Short-Term Prognosis of Patients with Traumatic Brain Injury After Decompressive Craniectomy

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OBJECTIVE: **To discuss the effects of the hematocrit (Hct) in patients with traumatic brain injury after decompressive craniectomy (DC).**

METHODS: **Demographic data, inspection and treatment procedures, and 30-day prognosis were obtained for 158 patients with head injury who underwent unilateral DC in our hospital between January 2013 and June 2018. Uni- and multivariate logistic regression was applied to analyze independent risk factors for 30-day outcome. The quantitative analysis of postoperative Hct, ΔHct (postoperative Hct minus initial Hct), and their combination for the prognosis of patients with TBI was displayed graphically using receiver operating characteristic (ROC) curves. Multiple linear regression was used to explore factors influencing postoperative Hct and ΔHct.**

RESULTS: **Short-term mortality was 29.7%. Uni- and multivariate logistic regression analysis showed that age (odds ratio [OR], 1.064; $P = 0.024$), Glasgow Coma Scale score (OR, 0.711; $P = 0.027$), Injury Severity Score (ISS) (OR, 1.156; $P = 0.047$), midline shift in millimeters (OR, 1.809; $P < 0.001$), postoperative Hct (OR, 0.743; $P = 0.001$), and ΔHct (OR, 1.242; $P = 0.048$) were independent risk factors for short-term death. In ROC curves, a combination of postoperative Hct and ΔHct showed the highest sensitivity (77.5%) and highest specificity (89.4%). When using this combination to predict prognosis, we could achieve an accuracy of 94.5%. ISS ($\beta = -0.172$, $P = 0.022$), initial Hct ($\beta = 0.243$, $P = 0.001$), principal hematoma location ($\beta = -2.628$, $P < 0.001$), hours of operation ($\beta = -0.884$, $P = 0.048$), and colloid quantity ($\beta = -0.002$, $P = 0.001$) were independent contributing factors for ΔHct, which was similar to postoperative Hct.**

CONCLUSIONS: **A combination of postoperative Hct and ΔHct could better predict short-term survival of patients with TBI. Developing an appropriate treatment strategy to increase postoperative Hct and reduce the ΔHct may be good for the short-term prognosis of patients with TBI after DC.**

INTRODUCTION

Traumatic brain injury (TBI) is the focal point for trauma care because of its high mortality and disability. Many clinicians are exploring risk factors associated with recovery,[1] especially for the patients who undergo decompressive craniectomy (DC). DC is a lifesaving operation for patients with TBI[2,3] and involves removing a part of the skull to reduce intracranial pressure quickly and restore cerebral perfusion for refractory intracranial hypertension. Many studies have found many independent risk factors for patients with TBI who undergo DC, such as initial Glasgow Coma Scale (GCS) score, age, and

Key words
- Decompressive craniectomy
- Hematocrit
- Prognosis
- Traumatic brain injury

Abbreviations and Acronyms
CI: Confidence interval
CT: Computed tomography
DC: Decompressive craniectomy
GCS: Glasgow Coma Scale
Hct: Hematocrit
ISS: Injury Severity Score
OR: Odds ratio
ROC: Receiver operating characteristic
SBP: Systolic blood pressure
TBI: Traumatic brain injury

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anemia.[4,5] For anemia, in which blood volume and oxygen-carrying capacity of the blood are reduced, how the change of red cell mass influences prognosis of patients is still unclear.[6] Hematocrit (Hct) is the proportion of erythrocyte volume in the blood and increases the oxygen-carrying capacity. Thorson et al.[7] found that the change of Hct values over several hours could indicate a traumatic patient with continuing bleeding that needs surgery. Bleeding or dilution through infusion liquid would decrease the Hct, and consequently affect cerebral oxygen delivery by inducing decompensation in brain blood circulation.[8]

A large amount of bleeding occurs during DC and varies greatly based on the severity of injury and different surgical operation. When many infusion or much bleeding, the Hct would change a lot as the compensatory response for the body. Brain tissue is very sensitive to anoxia, especially in patients with TBI.[9] Patients may develop an imbalance in oxygen supply if their Hct changes too much or becomes too low, which may influence prognosis by aggravating secondary brain injury. The objective of this exploratory study is to evaluate the impact of the Hct on short-term prognosis of patients receiving DC, and elucidate factors influencing the Hct.

METHODS

This retrospective cohort study was performed at the Second Affiliated Hospital of Shantou University Medical College. After obtaining consent from the institutional review board, we collected information on 158 patients who had undergone DC for TBI between January 2013 and June 2018. Patients who died within 30 days after TBI were considered as short-term deaths. Standards for inclusion included the following: 1) unilateral hemicraniectomy performed without blood transfusion before or during the operation; 2) closed brain injury, with other regions having an Abbreviated Injury Scale score of no more than 3[10]; 3) no cardiac arrest before or during the operation; 4) an Hct greater than 30% and without shock (systolic blood pressure [SBP] greater than 100 mm Hg and diastolic blood pressure greater than 70 mm Hg) before the DC; 5) had no organ dysfunction or related medical history; 6) did not give up treatment or undergo a secondary brain operation within the initial month; and 7) had a complete medical record.

Transfusion Policy

The infusion liquid was designed for goal-directed therapy to stabilize vital signs (SBP greater than 90 mm Hg and diastolic blood pressure greater than 60 mm Hg). All patients had blood for transfusion prepared before the operation, but whether or not transfusion was performed was based on the estimated blood loss in the operation. The included patients were not transfused blood before or during DC.

We collected detailed clinical data, including patients' demographic information, underlying medical conditions, SBP and heart rate before the operation, crystal and colloid quantity in the operation, mechanisms of injury, Injury Severity Score (ISS), and GCS scores from computerized or paper medical records in the emergency and neurosurgery department. Operation duration was from patients being sent to the operation room to patients being sent back to the inpatients ward. The degree of midline shift was measured as the deviation of the septum pellucidum from the central position in their brain computed tomography (CT) scans. The main hematoma locations were divided into subdural hematoma or epidural hematoma according to intraoperative findings. The clinical indications of DC for TBI were as follows: evacuation of an intradural lesion and lowering of elevated and medically refractory intracranial pressure. The judgment of whether the patients met the criteria was mainly according to intracranial hemorrhaging and exacerbated symptoms of intracranial hypertension, and we did not perform intracranial monitoring for these patients. The operations were performed by experienced attendees who were on duty at the second line (the doctor who is responsible for guiding the treatment for a group patients and performing advanced operation) and who used relaxation sutured dura in DC. All patients received similar treatment after the operation without special treatment such as hypothermia therapy. The initial Hct was determined on admission from the emergency department, and the postoperative Hct was determined within 12 hours after DC from the neurosurgery department. The ΔHct was defined as postoperative Hct minus initial Hct.

Data were analyzed using SPSS software (version 22.0 [IBM SPSS Statistics, Armonk, New York, USA]). Descriptive statistics are presented as frequency (%) or as mean ± SD. To evaluate the risk factors for 30-day mortality in patients who underwent craniectomy after TBI, uni- and multivariate binary logistic regressions were performed. The results are expressed as odds ratios with 95% confidence intervals, and univariate data with $P < 0.05$ were entered into the multivariate model. The receiver operating characteristic (ROC) curve was used to evaluate the optimal cutoff values for ΔHct, postoperative Hct, and both for prediction of short-term outcome. A cutoff point on the curves was chosen to attain the best compromise between sensitivity and specificity for short-term death. Then multiple linear regression was applied to analyze pre- and intraoperative factors that may influence ΔHct and postoperative Hct. All $P < 0.05$ values presented are 2-tailed, and $P < 0.05$ was considered statistically significant.

RESULTS

Baseline Characteristics

A total of 337 cases were obtained between January 2013 and June 2018. One hundred and seventy-nine patients were excluded in the retrospective review: 27 patients were excluded because of incomplete medical records, 54 patients were excluded because of transfuse blood before or in operation, 25 patients were excluded because of withdrawal from treatment within 30 days after the operation, and the rest were excluded because of secondary DC (n = 23), bifrontal craniectomy (n = 17), severe polytrauma (n = 19), organ dysfunction other than brain (n = 9), and moderate anemia (Hct less than 30%, n = 5) before operation. There were 158 patients that met our criteria, including 119 men and 39 women. The mean age of the patients was 44.10 ± 13.78 years (range, 17–74 years). At admission, the mean ISS was 23.13 ± 4.55 (range, 18–34) and the mean initial Hct was 40.29% ± 4.55% (range, 30.6%–50.1%). The GCS scores which were assessed when patients entered the emergency department showed that the mean GCS score was 6.23 ± 2.97. The individual CT scanning feature was midline shifted, and its mean value was 9.12 ± 3.38 mm (range, 3–28 mm). All patients received emergency surgery within 24 hours and underwent unilateral craniectomy. The mean SBP was 141 ± 24 mm Hg before the

operation. The mean duration of operation (from being sent to the operation room to return to the ward) was 3.38 ± 0.68 hours. In the operation, there were 113 patients (71.5%) exhibiting subdural hematoma and 45 patients (28.5%) exhibiting epidural hematoma according to their main hematoma locations. Transfusion fluid volume of crystal and colloid was 2023 ± 578 and 1015 ± 490 mL, respectively. After the operation, the mean postoperative Hct was 27.06% ± 5.03%, and the mean ΔHct was 13.41% ± 4.54%. Forty-seven patients who underwent DC died within 30 days after TBI, indicating a short-term mortality incidence of 29.7%. Clinical features and results for all patients have been presented in Table 1.

Risk Factors for Short-Term Mortality

The results of uni- and multivariate logistic regression models for variables are shown in Tables 2 and 3. Univariate analysis identified the following significant parameters: age, GCS score, ISS, transfusion volume of colloid in the operation, midline shift in millimeters, main hematoma location, postoperative Hct, and ΔHct (Table 2). Univariate data analysis with $P < 0.05$ was entered into the multivariate model and showed that age (odds ratio [OR], 1.064; 95% confidence interval [CI], 1.008–1.124; $P = 0.024$), GCS score (OR, 0.711; 95% CI, 0.526–0.962; $P = 0.027$), ISS (OR, 1.156; 95% CI, 1.000–1.351; $P = 0.047$), midline shift in millimeters (OR, 1.809; 95% CI, 1.369–2.391; $P < 0.001$), postoperative Hct (OR, 0.743; 95% CI, 0.619–0.891; $P = 0.001$), and ΔHct (OR, 1.242; 95% CI, 1.002–1.539; $P = 0.048$) were independent risk factors (Table 3).

Table 1. Baseline Characteristics of 158 Patients with Head Injury Who Underwent Decompressive Craniectomy

Parameters	Value
Sex	
Male	119 (75.3)
Female	39 (24.7)
Age (years)	44.10 ± 13.78
GCS score	6.23 ± 2.97
ISS	23.13 ± 4.44
Initial Hct (%)	40.29 ± 4.55
Main hematoma location	
Subdural hematoma	113 (71.5)
Epidural hematoma	45 (28.5)
Midline shift in millimeters	9.12 ± 3.38
SBP (mm Hg)	141 ± 24
Operation duration (hours)	3.38 ± 0.68
Crystal quantity (mL)	2023 ± 578
Colloid quantity (mL)	1015 ± 490
Postoperative Hct (%)	27.06 ± 5.03
ΔHct (%)	13.41 ± 4.54
Short-term prognosis (30 day)	
Alive	111 (70.3)
Death	47 (29.7)

Values are mean ± SD or number of patients (%).
GCS, Glasgow Coma Scale; ISS, Injury Severity Score; Hct, hematocrit; SBP, systolic blood pressure.

Table 2. Univariate Analysis of Significant Factors Associated with 30-Day Mortality

Factors	OR (95% CI)	*P* Value
Sex	0.800 (0.368–1.737)	0.573
Age (years)	1.031 (1.005–1.058)	0.020
GCS score	0.686 (0.570–0.826)	<0.001
ISS	1.249 (1.143–1.365)	0.001
Midline shift in millimeters	1.547 (1.330–1.800)	<0.001
Main hematoma location	0.211 (0.077–0.577)	0.002
Initial Hct (%)	0.950 (0.880–1.025)	0.189
SBP (mm Hg)	0.997 (0.983–1.012)	0.729
Operation duration (hours)	1.152 (0.696–1.907)	0.583
Crystal quantity (mL)	1.000 (1.000–1.001)	0.422
Colloid quantity (mL)	1.001 (1.000–1.001)	0.044
Postoperative Hct (%)	0.748 (0.673–0.831)	<0.001
ΔHct	1.344 (1.207–1.496)	<0.001

OR, odds ratio; CI, confidence interval; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; Hct, hematocrit; SBP, systolic blood pressure.

ROC Curves for ΔHct, Postoperative Hct, and Both for Prediction of Short-Term Prognosis

The quantitative analysis of postoperative Hct, ΔHct, and both for the prognosis of patients with TBI was displayed graphically using ROC curves. After being adjusted to predict patient survival rate,

Table 3. Multivariate analysis of significant factors associated with 30-day mortality

Factors	OR (95% CI)	*P* Value
Age (years)	1.064 (1.008–1.124)	0.024
GCS score	0.711 (0.526–0.962)	0.027
ISS	1.156 (1.000–1.351)	0.047
Main hematoma location	0.291 (0.041–2.006)	0.217
Midline shift in millimeters	1.809 (1.369–2.391)	<0.001
Colloid quantity (mL)	1.000 (0.998–1.001)	0.525
Postoperative Hct (%)	0.743 (0.619–0.891)	0.001
ΔHct	1.242 (1.002–1.539)	0.048

OR, odds ratio; CI, confidence interval; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; Hct, hematocrit.

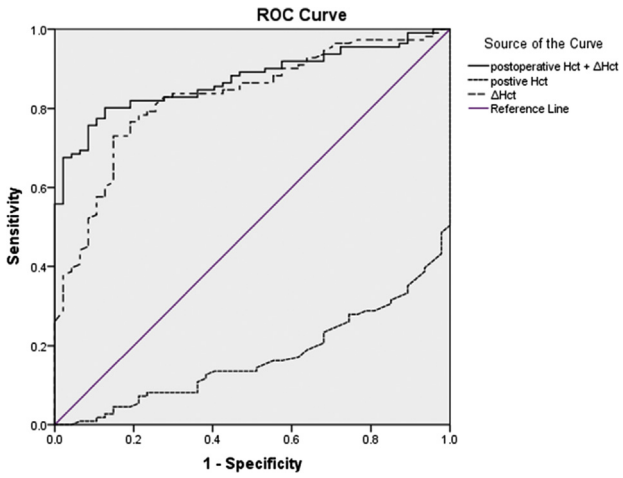

Figure 1. Receiver operator characteristic curves of change in hematocrit (Hct), postoperative Hct, and both for predicting short-term survival of patients with TBI. ROC, receiver operator characteristic.

combinations of postoperative Hct and ΔHct demonstrated the highest sensitivity (77.5%) and highest specificity (89.4%), and the best accuracy was 94.5% when used to predict prognosis for those patients. When calculated separately from the 2 values, the accuracy of the short-term survival rates for postoperative Hct and ΔHct was 87.4% with a cutoff value of 26.2% and 91.1% with a cutoff value of 13.3%, respectively (Figure 1 and Table 4).

Factors Influencing Postoperative Hct and ΔHct

Pre- and intraoperative factors were included in the multiple linear regression model to identify influential factors for postoperative Hct and ΔHct (Tables 5 and 6). The analysis showed that ISS ($\beta = -0.169$, $P = 0.021$), initial Hct ($\beta = 0.675$, $P < 0.001$), main hematoma location ($\beta = 2.863$, $P = 0.001$), operation hours ($\beta = -0.969$, $P = 0.027$), and colloid quantity ($\beta = -0.002$, $P < 0.001$) were independent influential factors for postoperative Hct. ISS ($\beta = -0.172$, $P = 0.022$), initial Hct ($\beta = 0.243$, $P = 0.001$), principal hematoma location ($\beta = -2.628$, $P < 0.001$), hours of the operation ($\beta = -0.884$, $P = 0.048$), and colloid quantity ($\beta = -0.002$, $P = 0.001$) were independent influential factors for ΔHct.

DISCUSSION

TBI is an important cause of mortality and morbidity in trauma victims. According to an analysis of 11,937 patients with TBI from 47 hospitals in the China Craniocerebral Trauma Database,[11] mortality from severe TBI was 27.23% and the rate of death, vegetative state, and severe disability was 53.17% in total, which is similar to large-scale reports in the United States and Europe.[12] To find factors influencing prognosis for better treatment, several researchers have found that age, GCS score were independent risk factors for poor prognosis, and including some proteins such as S100, Hsp70, and tumor necrosis factor-α,[13,14] and for better treatment, some of those factors banded with few symptoms or signs had been used to build models to predict the prognosis of TBI.[15-17]

The core treatment of patients with TBI is to prevent ischemia hypoxia of the brain,[18,19] a result of increasing intracranial hypertension. The significant decrease in erythrocyte count could make it worse. Liquid exchange between the inside and outside of the blood vessels is quick and reaches balance within 10 seconds in infusion therapy.[7,20] Massive transfusion in a short time would cause acute hypervolemic hemodilution, which would worsen the ischemia hypoxia of the brain in patients with TBI because of the significant decrease in erythrocyte count. Bellapart et al.[8] and Fletcher et al.[21] suggested that improper fluid resuscitation could aggravate secondary craniocerebral injury by influencing brain tissue oxygen delivery in the treatment of TBI. The sufficiently high Hct is important to the tissue oxygen delivery in the brain, which could aggravate secondary brain injury in patients with TBI.[22] Especially, the change of Hct is too much in a short time period, and the body can not change to adapt to it in time, which would make matters worse. We retrospectively collected information on 158 patients with TBI in our hospital over 5 years, and the mortality of those patients was 29.7%. In previous studies, age, GCS score, ISS, and midline shift were found to be significant risk factors for poor prognosis of patients with TBI.[22,23] This statistical analysis found that age, GCS score, ISS, midline shift, postoperative Hct, and ΔHct were independent risk factors for short-term prognosis in patients with TBI after DC. Tolerance to damage in older people is worse than in younger people,[23] and older people have worse short-term prognosis at similar injury levels in TBI. The GCS score, ISS, and midline shift in brain CT scan show the severity of brain trauma,[23-25] which indicated worse short-term prognosis. To

Table 4. Receiver Operating Characteristic Analysis of Change in Hematocrit, Postoperative Hematocrit, and Both

Parameter	Area Under the Curve (95% CI)	Youden Index	Sensitivity (%)	Specificity (%)	Accuracy (%)*
Postoperative Hct	0.169 (0.108–0.231)	−0.545	30.6	14.9	87.4
ΔHct	0.828 (0.761–0.894)	0.581	73	85.1	91.1
Postoperative Hct and ΔHct	0.873 (0.819–0.926)	0.669	77.5	89.4	94.5

CI, confidence interval; Hct, hematocrit.
*Accuracy shows the best survival to predict short-term survival of the patients.

Table 5. Multiple Linear Regression Analysis of Factors Influencing Postoperative Hematocrit

Factors	β (95% CI)	*P* Value
Age (years)	0.043 (−0.001 to 0.088)	0.057
GCS score	0.191 (−0.016 to 0.397)	0.070
ISS	−0.169 (−0.312 to −0.025)	0.021
Main hematoma location	2.283 (0.930–3.636)	0.001
Midline shift in millimeters	−0.102 (−0.281 to 0.078)	0.264
Initial Hct (%)	0.675 (0.536–0.813)	<0.001
Operation duration (hours)	−0.969 (−1.828 to −0.109)	0.027
Crystal quantity (mL)	−0.001 (−0.002 to 0.000)	0.054
Colloid quantity (mL)	−0.002 (−0.004 to −0.001)	<0.001

CI, confidence interval; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; Hct, hematocrit.

better compare the validity of the Hct for prognosis, we decided to present quantitative analysis using ROC curves for ΔHct, postoperative Hct, and both to predict the short-term survival of patients with TBI. The results of the ROC analysis suggested that integration of ΔHct with postoperative Hct gets the highest sensitivity and specificity compared with each alone in diagnosing short-term prognosis, indicating the best predicting performance.

To analyze the factors that influenced the Hct, multiple linear regressions were carried out for postoperative Hct and ΔHct. The postoperative Hct was determined within 12 hours after DC, and the ΔHct was postoperative Hct minus initial Hct, with the former reflecting pathologic and physiologic status after DC, and the ΔHct reflecting the change of pathologic and physiologic conditions before and after DC. This analysis showed that initial Hct, ISS, main hematoma location, duration of the operation, and colloid infusion were independent influential factors. The initial

Table 6. Multiple Linear Regression Analysis of Factors Influencing Change in Hematocrit

Factors	β (95% CI)	*P* Value
Age (years)	−0.036 (−0.082 to 0.009)	0.116
GCS score	−0.135 (−0.346 to 0.075)	0.206
ISS	0.172 (0.025–0.318)	0.022
Initial Hct (%)	0.243 (0.102–0.384)	0.001
Main hematoma location	−2.628 (−4.009 to −1.248)	<0.001
Midline shift in millimeters	0.150 (−0.033 to 0.333)	0.106
Operation duration (hours)	0.884 (0.006–1.761)	0.048
Crystal quantity (mL)	0.001 (0.000–0.002)	0.118
Colloid quantity (mL)	0.002 (0.001–0.003)	0.001

CI, confidence interval; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; Hct, hematocrit.

Hct of patients was no less than 30%, and the patients who had a higher initial Hct, because of a greater reserve of erythrocytes before the operation, had a higher postoperative Hct. However, the result is the opposite for the ΔHct, with a higher initial Hct leading to a larger change in ΔHct. For this phenomenon, Naqash et al.[26] found that in craniocerebral operations, diluting the Hct to near 30% is safe and could decrease bleeding when compared with patients with higher Hct in operation, and Barile et al.[27] also found a similar effect for cardiac surgery. This result suggested that diluted blood viscosity appropriately could improve the function of thrombocyte and clotting factors. The ISS reflects the severity of trauma, and a higher score indicates larger hemorrhage volume and lower Hct. We found the ISS was an independent risk factor for postoperative Hct and ΔHct. The GCS score and midline shift in brain CT scan mainly reflect the severity of brain injury. The low GCS score and severe midline shift may indicate that the patient had more severe brain injury, which was larger hemorrhage volume in the operation. There is different vascular injury, injury severity of brain tissue and operation time between epidural hematoma and subdural hematoma, which may lead to different amounts of bleeding in the operation.[28] This study showed that the patients with epidural hematoma possessed a higher postoperative Hct and had less change in ΔHct. However, we did not find hematoma location in the brain to be a significant risk factor for short-term mortality. The most plausible reason was that we only collected information about the principal hematoma location and ignored other injuries, such as brain contusion and laceration and subarachnoid hemorrhage. The duration of operation is mainly associated with the energy and experience of the surgeon and the severity of trauma.[29] Longer operation time will lead to larger amounts of bleeding, which would cause a larger change in the Hct. However, this study did not find that the duration of operation had any impact on postoperative Hct. The most probable reasons were that the time was from send-off to the operation room and then return back to the inpatients ward, which may have included extra time, such as transporting patients, which was not real operative time. In addition, the difference in results indicated that ΔHct was more sensitive than postoperative Hct among the factors. Fluid infusion could increase blood volume, especially for colloids, which caused hemodilution and decreased the Hct. Better resuscitation for patients with TBI requires appropriate dilution of the blood before the operation, skillful surgery to ensure short operating times, and proper fluid infusion to achieve a higher postoperative Hct and less change in ΔHct, which may improve short-term prognosis.

There are some limitations in our study. First, this is a retrospective analysis and the sample size is not large, and we could not exclude the influence of surgeon skill and experience. However, our surgeons regularly meet to mutually exchange information and perform according to strict protocols, which we think minimizes the impact on the level of training on blood loss and prognosis. In addition, the study was performed in a single large urban medical center. Hence, the study may not be representative of all patients who undergo craniectomy after TBI at other institutions. We found Hct was an independent risk factor for short-term prognosis of patients with TBI after DC, especially the change of it. Even with the issues in the preliminary analysis, we

consider that the results are useful for clinicians to improve treatment.

CONCLUSIONS

The mortality rate of TBI of patients after DC within 30 days is high. The postoperative Hct and the change in Hct before and after DC were independent risk factor for short-term prognosis of patients with TBI after DC. Combining postoperative Hct with ΔHct may better predict short-term survival of patients with TBI. Developing an appropriate treatment strategy to increase postoperative Hct and reduce the change of the Hct may be useful in the short-term prognosis of patients with TBI after DC.

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