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Original Article

Trans-base and trans-vault low-velocity penetrating brain injury: A retrospective comparative study of characteristics, treatment, and outcomes

Yun Wu^{a,1}, Tian-Ge Chen^{b,1}, Si-Ming Chen^a, Liang Zhou^a, Meng Yuan^c, Lei Wang^d, Zi-Yuan Liu^a, Chang-Long Bi^a, Xiang-Ying Luo^a, Song Lan^a, Jin-Fang Liu^{a,*}^a Department of Neurosurgery, Xiangya Hospital, Central South University, Changsha, 410008, China^b National Clinical Medical Research Center for Geriatric Diseases, Xiangya Hospital, Central South University, Changsha, 410008, China^c Center for Experimental Medicine, Third Xiangya Hospital, Central South University, Changsha, 410013, China^d Department of Anesthesiology, Xiangya Hospital, Central South University, Changsha, 410008, China

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ABSTRACT

Purpose: Low-velocity penetrating brain injury (LVPBI) caused by foreign bodies can pose life-threatening emergencies. Their complexity and lack of validated classification data have prevented standardization of clinical management. We aimed to compare the trans-base and trans-vault phenotypes of LVPBI to help provide guidance for clinical decision-making of such injury type.

Methods: A retrospective study on LVPBI patients managed at our institution from November 2013 to March 2020 was conducted. We included LVPBI patients admitted for the first time for surgery, and excluded those with multiple injuries, gunshot wounds, pregnancy, severe blunt head trauma, etc. Patients were categorized into trans-base and trans-vault LVPBI groups based on the penetration pathway. Discharged patients were followed up by outpatient visit or telephone. The data were entered into the Electronic Medical Record system by clinicians, and subsequently derived by researchers. The demography and injury characteristics, treatment protocols, complications, and outcomes were analyzed and compared between the two groups. A *t*-test was used for analysis of normally distributed data, and a Mann-Whitney *U* test for non-parametric data. A generalized linear model was further established to determine whether the factors length of stay and performance scale score were influenced by each factor.

Results: A total of 27 LVPBI patients were included in this analysis, comprised of 13 (48.1%) trans-base cases and 14 (51.9%) trans-vault cases. Statistical analyses suggested that trans-base LVPBI was correlated with deeper wounds; while the trans-vault phenotype was correlated with injury by metal foreign bodies. There was no difference in Glasgow Coma Scale score and the risk of intracranial hemorrhage between the two groups. Surgical approaches in the trans-base LVPBI group included subfrontal ($n = 5$, 38.5%), subtemporal ($n = 5$, 38.5%), lateral fissure ($n = 2$, 15.4%), and distal lateral ($n = 1$, 7.7%). All patients in the trans-vault group underwent a brain convex approach using the foreign body as reference ($n = 14$, 100%). Moreover, the two groups differed in application prerequisites for intracranial pressure monitoring and vessel-related treatment. Trans-base LVPBI was associated with higher rates of cranial nerve and major vessel injuries; in contrast, trans-vault LVPBI was associated with lower functional outcome scores.

Conclusion: Our findings suggest that trans-base and trans-vault LVPBIs differ in terms of characteristics, treatment, and outcomes. Further understanding of these differences may help guide clinical decisions and contribute to a better management of LVPBIs.

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Introduction

Penetrating brain injury (PBI) is defined as craniocerebral trauma caused by sharp objects, which often leads to damage along the tract of the piercing foreign body (FB).^{1,2} As a subset of traumatic brain injury (TBI), PBI represents approximately 0.4% of all

* Corresponding author.

E-mail address: jinfang_liu@csu.edu.cn (J.-F. Liu).

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¹ These authors should be considered as co-first authors.

brain injuries but has a high morbidity and mortality rate and remains a significant challenge to neurosurgeons worldwide.^{3–5} According to the causative mechanisms, PBI can be categorized as either high-velocity penetrating brain injury (HVPBI) or low-velocity penetrating brain injury (LVPBI).^{5–7} HVPBI is related to gunshot wounds or blast-type injuries predominant in battlefield settings. LVPBI, which refers to brain injuries caused by the penetration of low-velocity objects, usually occurs in civilian life and often has a better prognosis than HVPBI.^{8–10}

Neurosurgical practice for LVPBI is still in the exploratory stage, as it has not been extensively explored and is mainly presented as case studies.^{11,12} Management of LVPBIs is complex, considering their stab positions, angles and depths, velocity and shape of the FB, and involvement of the vessels, nerves and brain tissues.^{10,12} These abovementioned factors become relevant when considering that the skull base areas differ from the calvaria area in cranium structures, vessels, nerves, and brain function areas. However, for LVPBIs, although anatomical features are the basis of clinical considerations, barely any studies have established classifications based on anatomy.

For the first time, we categorized LVPBIs into trans-base type and trans-vault type based on the penetration pathway. Trans-base LVPBI is majorly characterized by penetration of the brain from below, normally via thin bone areas and anatomical foramen in the skull base. In contrast, the trans-vault type involves FB directly perforating the brain from above or the side via the thick cranial vault. Correspondingly, the clinical features presented are different. By conducting a comparative study, we aimed to elucidate differences with management implications between these two types of injuries.

Methods

Design and setting

We retrospectively analyzed and compared the data of LVPBI patients, encompassing clinical characteristics, treatment methods, and prognosis. Ethical approval was obtained from the Ethical Research Committee of Xiangya Hospital, Central South University (No.202010135).

Subjects

Subjects for this study were drawn from a cohort of patients diagnosed with simple LVPBI at the Xiangya Hospital from November 2013 to March 2020. All cases were selected by inclusion and exclusion criteria. Inclusion criteria were TBI caused by FB penetrating the brain, first diagnosis emergently admitted to our hospital, receiving surgical treatment, and agreeing to participate in this study. While the exclusion criteria included multiple general injuries, gunshot wounds, pregnancy, severe blunt TBI, and taking anticoagulants or antiplatelet medications. Discharged patients were followed up by means of outpatient visits and telephone calls. The data were entered into the Electronic Medical Record system by clinicians and derived by researchers. The recorded data were carefully studied for sex, age, penetration pathway, Glasgow Coma Scale (GCS) score on admission, material properties, areas of intracranial injury, depth of stab (DOS), surgical approach, length of stay (LOS), performance scale score (PSS), and complications. According to the penetration pathway, LVPBIs were classified into trans-base or trans-vault phenotype. We also developed a risk stratification for vessel injury (high-risk or low-risk), in which a spectrum of pathological changes, including invasion, compression,

extravasation, or dissection of vessel structure, would be rated as high risk.

Management and follow-up

LVPBI-specific surgeries were determined by neurosurgeons. After surgery, all patients received standardized management, which included prophylactic anti-infection and anti-epileptic medications, sedation and analgesia, nutritional support, and intracranial pressure (ICP) management. Other treatments and examinations were prescribed by clinical indication. We classified the complications following PBI as early (<1 week) and late (>1 week) complications.¹³ Cranial nerve (CN) injury and DOS were evaluated by CT dimensional reconstruction and physical examination. Intracranial infection was confirmed by bacterial culture of the cerebrospinal fluid (CSF). To evaluate the functional outcome, Lansky performance status score (LPSS) was used for patients ≤ 16 years of age, and Karnofsky performance status score used for patients >16 years of age.¹⁴

Statistical analysis

Categorical variables (injury types, intracranial infection, CN injuries) were described using frequencies and percentages and analyzed using non-parametric and Chi-square tests for comparative analysis between groups. Continuous variables (age, LOS, PSS) were described using medians and interquartile range (IQR) and grouped using clinically meaningful cutoffs: age ≤ 18 years and > 18 years, LOS ≤ 14 days and > 14 days, PSS < 70 and ≥ 70. Significance level was set as $p < 0.05$. A *t*-test was used for measurement data that were normally distributed, and a Mann-Whitney *U* test was used for non-parametric data. A generalized linear model was established to determine whether two continuous variables (LOS and PSS) were influenced by each factor. Descriptive analysis was used to compare the surgical approaches.

Results

Demography and injury characteristics

Data collected from 27 patients are shown in **Table 1**: 22 (81.5%) were male, and 5 (18.5%) were female. Representative CT images are shown in **Fig. 1**. There were 13 (48.1%) trans-base and 14 (51.9%) trans-vault LVPBI patients. Among the trans-base cases, 8 (61.5%) were trans-orbital and 5 (35.7%) were trans-pharyngeal cases. The age range for all the participants was 1–66 years (median, 10 years; IQR, 3–36 years). There were 16 (59.2%) patients under 18 years, accounting for 69.2% (9/13) trans-base cases and 50.0% (7/14) trans-vault cases. There was no intergroup difference in the number of patients under 18 years ($\chi^2 = 1.033$, $p = 0.267$).

Most of the FBs in this study were sharp and rod-shaped, including chopsticks in 10 cases. Other FBs included welding rods (6 cases), metal shards (5 cases), nails (3 cases), eyeglass frames (1 case), toy parts (1 case), and socket tips (1 case). The FB material was categorized into metal and nonmetal (wood or plastic). The trans-base group included 10 (76.9%) cases of nonmetal (8 wood and 2 plastic) and 3 (23.1%) cases of metal FB. In the trans-vault group, only 1 (7.1%) patient was injured by a wooden FB while the remaining 13 (92.9%) patients were injured by metal FBs. The trans-vault phenotype was correlated with metal FB injury ($\chi^2 = 11.143$, $p = 0.001$). The DOS in the trans-base group ranged from 2.3 cm to 13 cm (median, 4.5 cm; IQR, 3.95–7.75 cm), while in

Table 1
Overview of demographic and clinical information of the sample.

Patient serial No./Age(years)/Sex	Material of FB	DOS (cm)	GCS score	Nervous system involvement	Vessel injury (high-risk)	ICP monitor	Surgical approach	LOS (day)	PSS
Trans-base									
1/32/Male	Wood	9.3	15	CN II	No	No	Subfrontal	25	80
2/51/Male	Plastic	9.1	15	Brain stem, CN II, III	CS	No	Subtemporal	22	90
3/3/Male	Wood	5	14	Cerebellum	BA	No	Far lateral	16	70
4/1/Female	Plastic	13	9	Cerebellum, CN III, IV, VI	ICA, CS, TS	Yes	Subtemporal	43	70
5/3/Male	Wood	2.3	5	CN II, III	CS, ICA	Yes	Subtemporal	12	80
6/46/Male	Metal	4.3	14	Temporal lobes	No	Yes	Subtemporal	20	80
7/48/Male	Metal	4.4	15	Frontal lobe	No	Yes	Subfrontal	19	50
8/2/Male	Wood	4.3	15	Frontal lobe	No	Yes	Subfrontal	10	80
9/4/Male	Wood	3.6	15	CN II, III	CS, ICA	No	Trans-sylvian	13	90
10/1/Female	Metal	6.5	15	Frontal lobe	No	Yes	Subfrontal	24	80
11/4/Male	Wood	5.8	5	Brain stem, CN II	ICA	No	Trans-sylvian	3	0
12/3/Male	Wood	4.5	15	Temporal lobes	No	Yes	Subtemporal	10	70
13/2/Male	Wood	2.3	3	Frontal lobe	No	No	Subfrontal convex	40	50
Trans-vault									
14/53/Male	Metal	7.0	6	Frontal, temporal and parietal lobes	ACA	Yes	Frontotemporal convex	19	40
15/59/Female	Metal	2.1	15	Frontal lobe	No	No	Frontal convex	9	90
16/2/Male	Metal	2.0	15	Parietal lobe	No	Yes	Temporoparietal convex	10	80
17/66/Male	Metal	7.3	15	Parietal lobe	No	No	Occipitoparietal convex	32	50
18/11/Female	Metal	2.2	15	Parietal lobe	No	No	Parietal convex	7	90
19/9/Male	Metal	2.3	14	Frontal lobe	No	No	Frontal convex	10	90
20/36/Male	Metal	3.5	15	Parietal lobe	No	No	Parietal convex	12	40
21/10/Female	Metal	5.6	15	Frontal and parietal lobes	No	No	Occipitoparietal convex	17	60
22/36/Male	Metal	4.1	12	Frontal lobe	No	Yes	Frontal convex	35	60
23/24/Male	Metal	2.1	15	Parietal lobe	No	No	Frontotemporal convex	14	80
24/11/Male	Wood	2.5	15	Frontal lobe	No	No	Frontal convex	13	80
25/3/Male	Metal	1.9	15	Temporal lobe	No	No	Temporal convex	6	90
26/2/Male	Metal	1.5	15	Temporal lobe	No	No	Temporal convex	6	90
27/31/Male	Metal	8.5	7	Frontal and temporal lobes	No	Yes	Frontotemporal convex	23	0

FB: foreign body; DOS: depth of stab; GCS: Glasgow Coma Scale; CN: cranial nerve; ICA: internal carotid artery; CS: cavernous sinus; BA: basilar artery; TS: transverse sinus; ACA: anterior cerebral artery; ICP: intracranial pressure; LOS: length of stay; PSS: performance status score; GOS: Glasgow Outcome Scale.

the trans-vault group, the DOS ranged from 1.5 to 8.5 cm (median, 2.4 cm; IQR, 2.08–5.95 cm). Trans-base cases presented deeper stabs than trans-vault cases did ($U = 46.000, p = 0.029$). There was no significant difference in GCS scores between the groups

($U = 73.500, p = 0.327$). Only 5 (38.5%) patients of the trans-base group presented with low GCS score, and 4 (28.6%) patients of the trans-vault group had impaired GCS. All remaining patients had a GCS score of 15.

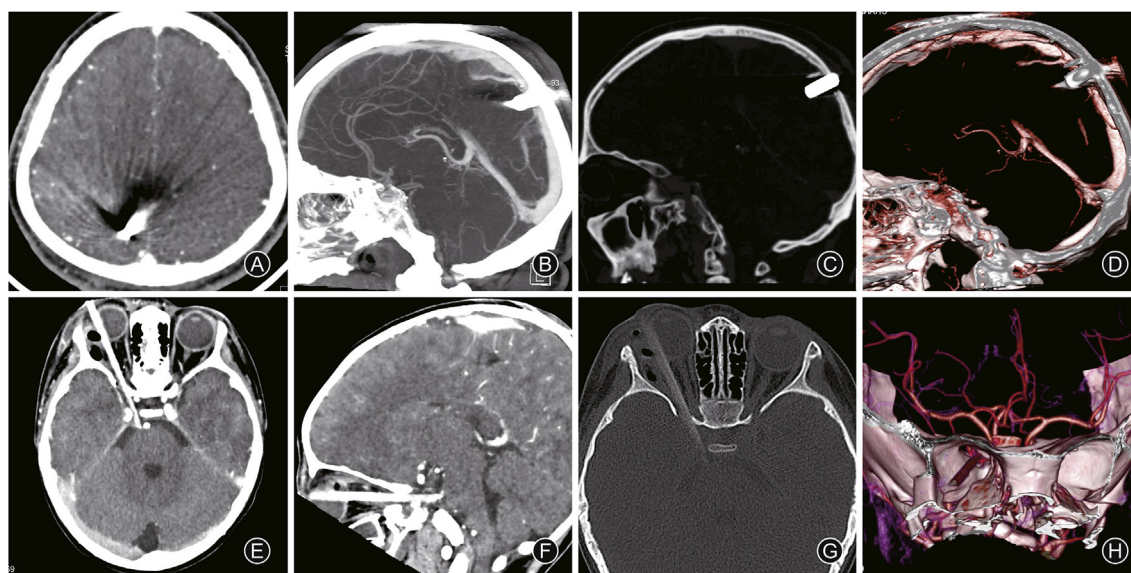


Fig. 1. Typical case display of the trans-base and trans-vault phenotypes. (A-D) CT images of a trans-vault low-velocity penetrating brain injury (LVPBI), showing the parietal skull vault and lobe penetrated by a high-density foreign body. (E-H) CT images of a trans-base LVPBI, showing a foreign body penetrating the skull base via the orbital apex and migrating toward the deeper brainstem.

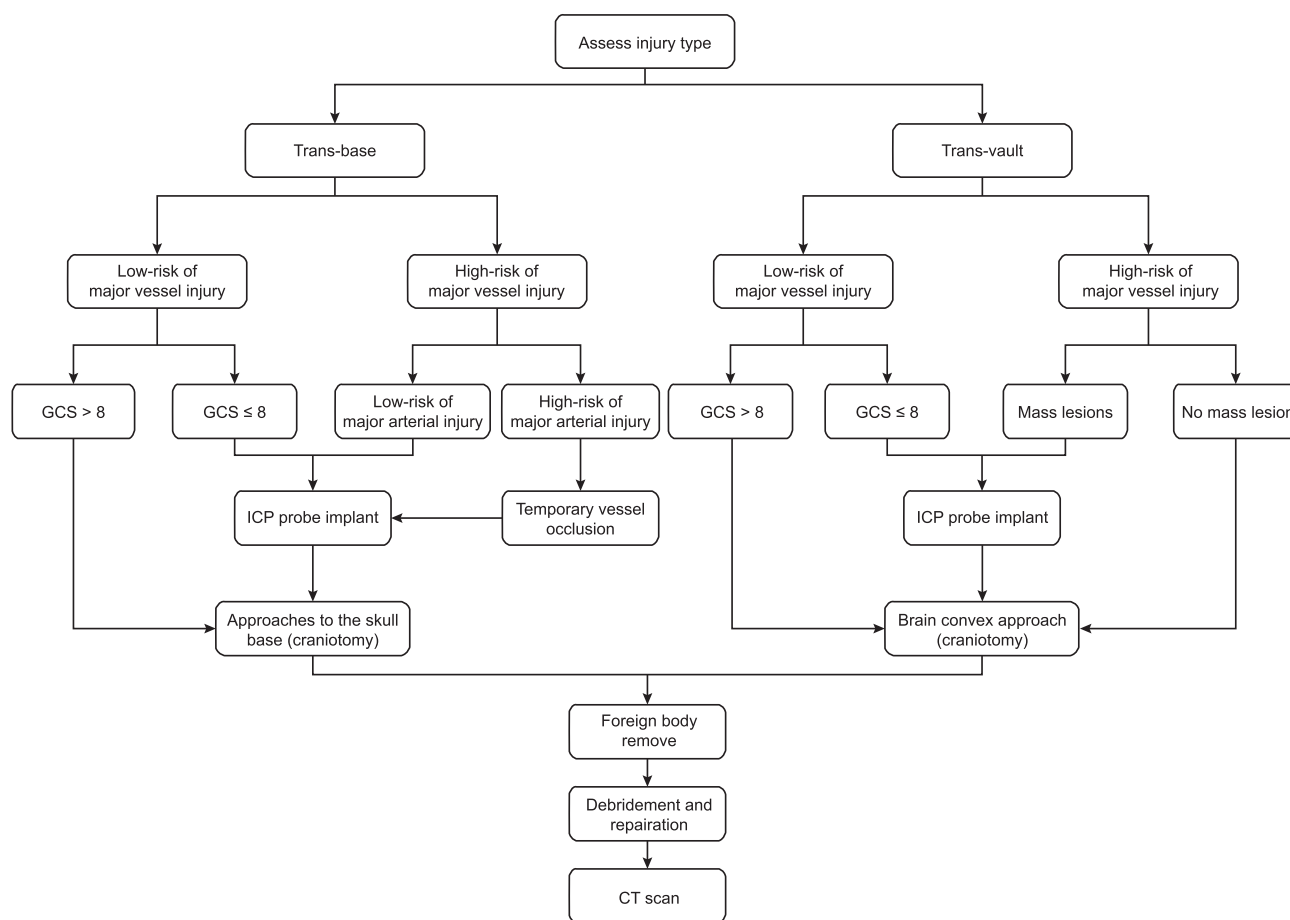


Fig. 2. Surgical management modality for trans-base and trans-vault low-velocity penetrating brain injury.

Treatment protocols

Emergency surgeries were performed, and intracranial FBs were removed in all cases. Different strategies were used for the trans-base and trans-vault cases. The surgical approaches in the trans-base group included subfrontal ($n = 5, 38.5\%$), subtemporal ($n = 5, 38.5\%$), lateral fissure ($n = 2, 15.4\%$), and distal lateral ($n = 1, 7.7\%$). In patient No. 3, the FB pierced from the posterior pharyngeal wall to the cerebellum, in close proximity to the basilar artery (BA). Therefore, we adopted a far lateral approach to expose the FB and intracranial segment of the BA. In all trans-vault cases, the brain convex approach centering on the FB was the preferred option. By sufficiently considering the vascular supply of the flap, we made a C-shape incision centered on the wound tract while incorporating the area that needed debridement.

For patients No. 2 and 4, the integrity of the internal carotid artery (ICA) was suspected to be compromised; therefore, temporary common carotid artery occlusion was adopted. Additionally, ICP probe placement was performed in 10 patients, 7 of whom were in the trans-base group and 3 in the trans-vault group, with no significant difference between two groups ($\chi^2 = 1.784, p = 0.173$). Based on the clinical findings, a standardized management mode of LVPBI for determining the surgical approach was generated (Fig. 2). Corresponding methods were adopted according to the evaluation of various factors, such as injury types, risk stratification of vessel injury, GCS score, and presence of intracranial mass lesions. After removing the FBs, debridement around the lesions was performed, followed by cranial reconstruction. The leaks were repaired using bone wax, artificial dura, and temporal fascia and muscle flaps.

Complications and outcomes

As shown in Table 2, CN injuries occurred in 6 patients (46.2%) of the trans-base group. Patients with trans-base LVPBI were more likely to sustain CN injury ($\chi^2 = 8.308, p = 0.006$). Moreover, all of them were trans-orbital LVPBI cases, involving the CN II in 5 cases, CN III in 4 cases, and CN IV and VI coexisted in 1 case. In patients No. 2, 5, and 9, the FBs involved only the cisterns, including prepontine cistern or pontocerebellar trigone, which led to simple CN injuries with no damage of brain tissue. For patient No. 4, who was an infant, the condition of the CN II and V (ocular branch of the trigeminal nerve) was uncertain, as the patient could not cooperate with a test. In the trans-vault group, no patient was diagnosed with CN injury.

High risk of major vessel injury occurred in 5 (38.5%) patients in the trans-base group, involving the ICA, cavernous sinus (CS), BA, and transverse sinus in respectively 4, 4, 1 and 1 case. In comparison, there was only 1 (7.1%) patient in the trans-vault group who was at a high risk of anterior cerebral artery (ACA) injury. Trans-base LVPBI was more likely to sustain high-risk vessel injuries ($\chi^2 = 5.342, p = 0.029$). High risk of both ICA and CS injury occurred in three trans-orbital LVPBI cases (patient No. 4, 5, 9), accounting for 50% of all trans-orbital cases. Intracranial hemorrhage (ICH) following trans-base and trans-vault LVPBI was present in 5 (38.5%) and 10 (71.4%) patients, respectively. No difference was observed in the possibility of ICH between the trans-vault group and trans-base group ($\chi^2 = 2.967, p = 0.091$).

Post-discharge follow-up was performed for all the 27 patients. The follow-up period was 3–75 months (median, 46 months; IQR,

Table 2
Significance of injury characteristics, treatment, complications and outcomes according to phenotype groups.

Events	Trans-base (n = 13)	Trans-vault (n = 14)	χ^2 value or U value	p value
Injury characteristics				
Patients <18 years	9 (69.2)	7 (50.0)	1.033	0.267
Metal foreign bodies	4 (30.8)	13 (92.9)	11.143	0.001
Depth of stab (cm)	4.5 (3.9–7.7)	2.4 (2.0–5.9)	46.000	0.029
Glasgow Coma Scale	15 (8–15)	15 (13.5–15)	73.500	0.327
Treatment				
Intracranial pressure probe placement	7 (53.8)	4 (28.6)	1.784	0.173
Length of stay (day)	19 (11.0–24.5)	12.5 (8.5–20.0)	64.500	0.198
Complications and outcomes				
Early complications				
Cranial nerve injury	6 (46.2)	0 (0)	8.308	0.006
Vessel injury (high-risk)	6 (46.2)	1 (7.1)	5.342	0.029
Intracranial hemorrhage	5 (38.5)	10 (71.4)	2.967	0.091
Late complications				
Intracranial infection	6 (46.2)	2 (14.3)	3.283	0.082
Cerebrospinal fluid leak	2 (15.4)	1 (7.1)	0.464	0.471
Post-traumatic epilepsy	1 (7.7)	0 (0)	1.118	0.481
Outcomes index				
Length of stay > 14 days	8 (61.5)	5 (35.7)	1.801	0.170
Performance status score < 70	3 (23.1)	6 (42.9)	1.187	0.249

Data are expressed as n (%) or media (Q₁–Q₃).

28–59.5 months) in the trans-base group, and 2–77 months (median, 48 months; IQR, 14.25–61 months) in the trans-vault group. There was one death in each group (patient No. 11 and 27), both of whom died of intracranial infection. No statistical difference was observed in the risk for intracranial infection ($\chi^2 = 3.283$, $p = 0.082$), CSF leak ($\chi^2 = 0.464$, $p = 0.471$) or epilepsy ($\chi^2 = 1.118$, $p = 0.481$) between the two groups.

The LOS of the trans-base LVPBI patients ranged from 3 to 43 days (median, 19 days; IQR, 11–24 days); the LOS of trans-vault LVPBI patients ranged from 6 to 35 days (median, 12.5 days; IQR, 8.5–20 days). The PSS ranged from 0 to 90 (median, 80; IQR, 60–80) in the trans-base group and from 0 to 90 (median, 80; IQR, 47.5–90) in the trans-vault group. There was no intergroup difference when LOS ($U = 64.500$, $p = 0.198$) and PSS ($U = 86.000$, $p = 0.804$) were treated as continuous variables, as well as in the number of patients with LOS >14 ($\chi^2 = 1.801$, $p = 0.17$) and PSS <70 ($\chi^2 = 1.187$, $p = 0.249$). However, our analysis revealed that the phenotypes ($p = 0.014$) and intracranial infection ($p = 0.017$) were significant determinants of PSS in generalized linear models, and the trans-vault group scored a lower average PSS than the trans-base group.

Furthermore, our data indicated that the risk factors for intracranial infection included DOS ($p = 0.022$) and admission GCS score ($p = 0.037$). PSS was positively correlated with GCS score ($p = 0.001$). In contrast, LOS was positively correlated with DOS ($p = 0.004$) and negatively correlated with GCS score ($p = 0.041$). Moreover, as shown in Fig. 3, there was a linear negative correlation between DOS and PSS scores ($p = 0.045$).

Discussion

Our study is the first to validate that trans-base and trans-vault LVPBIs have different features regarding demography and injury characteristics, treatment protocols, and complications and outcomes, offering an important first step to the standardized management of LVPBIs or even PBIs.

Demography and injury characteristics

Our results are consistent with those of previous studies showing that males constitute a significantly higher proportion of PBI patients than females.⁵ This may be associated with increased

exposure to risky behavior in male populations. Additionally, minor patients (<18 years old) were especially vulnerable, accounting for 59.2% of all cases, which can be explained by the fact that minors have thinner skulls than those of adults and are more likely to suffer from LVPBI.¹⁰ Another explanation was the inadequate supervision of children, as most of them were involved in accidents sustained by chopsticks, nails, or toys.

Interestingly, the trans-vault group presented less DOS but a higher number of cases with metal FBs. This variance has been associated with different anatomical structures of the cranial base and cranial vault. For the most part, it is difficult for low-energy plastic or wood objects to penetrate the thick bone lamella of the calvaria. In comparison, the holes, cracks, or thin bone areas in the skull base might predispose to low resistance of the trans-base pathway. Additionally, a GCS score of 15 was observed in 18 (66.7%) of the LVPBI cases, possibly because the pathology is more localized, such as limited lacerations of cutting injury and local bleeding along the wound tract.¹⁵

Treatment protocols

The flow chart in Fig. 2 aims to help clinicians make accurate surgical judgments for different patients. A management algorithm for non-missile PBI was proposed, wherein vascular damage and FB residue (in-situ or removed) were taken into consideration.⁹ However, our method focuses on separate strategies between the trans-base and trans-vault types. Our flowchart is not a rigid pattern but a mindset that can be modified on a case-by-case basis. Exceptions include complex injuries involving both cranial vault and base. Although there was no similar case in our series, clinicians can still follow this directional pattern for individual operation design.

We introduced the ICP monitoring and vascular occlusion technique into the systematic algorithm of LVPBI. ICP monitoring can provide guidance for managing delayed hemorrhage, edema, ischemia, or other conditions related to TBI.^{16,17} We strongly recommend implantation of ICP probe in patients with a GCS score ≤ 8 or with mass lesions on CT scan, but do not recommend it if the GCS score is > 8 or no mass lesion exist. Furthermore, we believe that there are exceptions that permit personalized selection of ICP monitoring in patients with GCS scores of 9–12, which requires further research. We followed a vessel-first consideration for each phenotype, as vessel injury always results in poor outcomes.¹⁸ For

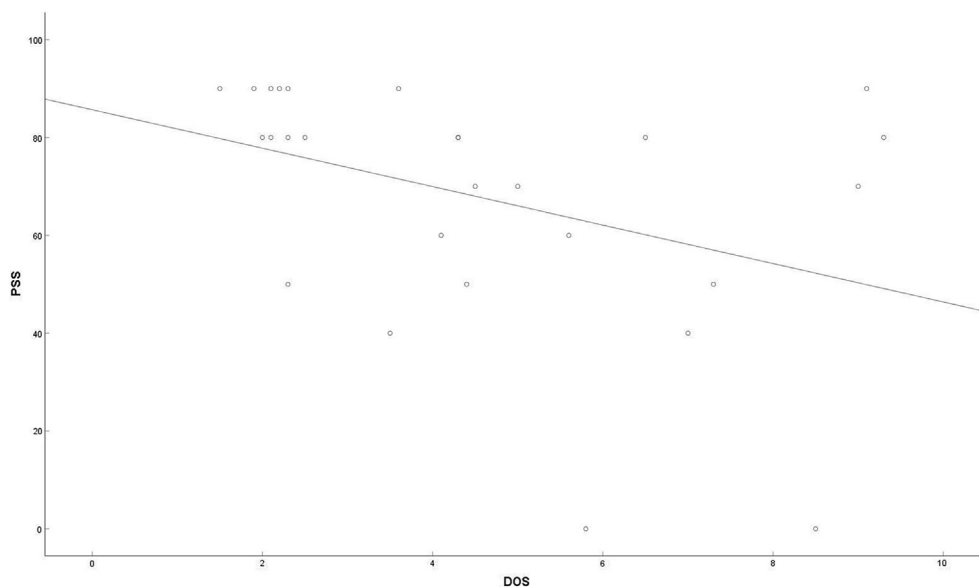


Fig. 3. Statistical linear diagram of depth of stab (DOS) and performance status score (PSS).

example, two patients underwent extravascular common carotid artery occlusion to prevent ICA bleeding. According to different vessel lesions, various endovascular means, such as selective occlusion with balloons or coils and placement of stents or stent-grafts, can be utilized,^{19,20} with the advantages of lowering the rates of procedure-associated morbidity and mortality.²¹ Moreover, endovascular techniques could also be applied in vascular complications, such as arteriovenous fistula and traumatic intracranial aneurysms.^{22–24}

Trans-base and trans-vault phenotypes share common principles of craniotomy, including vessel protection, adequate exposure, debridement, decompression, and prevention of secondary injury.²⁵ The brain convex approach in trans-vault cases causes minimal damage to the brain tissue by making use of the existing wound tract, and it is easy to observe and manipulate during operations. In comparison, trauma to the skull base has the characteristics of a poor visual field and high operational difficulty; therefore, management of trans-base LVPBIs are technically demanding. Common surgical procedures include transfacial, subtemporal, trans-sylvian, subfrontal, transmastoid, far lateral, and posterior approaches.²⁶ It is still debatable whether craniotomy is the best approach in all PBIs¹⁸; however, it was the only option available at our institution. Withdrawing FBs without visual inspection is risky because it can lead to catastrophic hemorrhage and FB residue.²⁷

Complications and outcomes

Complications related to PBIs include cerebral hemorrhage, contusion, edema and ischemia, vessel injury, CN injury, infection, hydrocephalus, CSF leaks, and epilepsy.^{13,28} The higher incidences of CN and major vessel injuries in the trans-base group can be explained by the fact that the skull base is where the CN passes out of the cranial cavity, the arteries bifurcate, and the veins intersect, while the sub-calvaria areas of the brain are mainly distributed by small arteriovenous branches and venous sinuses.²⁹

The incidence of intracranial infections in PBI ranges from 5% to 23%, with risk factors including CSF leak, transventricular and bihemispheric injuries, air sinus wounds, and contaminated tissue or retained fragments.¹³ It is highly recommended for all PBI patients to start antibiotic prophylaxis as soon as possible and

continue treatment for at least 7–14 days.¹⁸ We further analyzed the risk factors influencing intracranial infection, and the DOS and GCS score were observed to be meaningful. A greater DOS results in more contamination, and GCS score is closely related to the severity of LVPBI. CSF leaks and epilepsy are common complications of PBI.^{18,30} From our experience, careful intraoperative repair and postoperative anti-epilepsy treatment are helpful in preventing such complications.

For the first time, we found that the trans-base and trans-vault phenotypes were influencing factors of long-term PSS. Lower PSS in the trans-vault group might be related to the tendency of functional area damage. It is worth noting that the KPSS cannot be applied directly to children. Therefore, we adopted the LPSS in patients under 16 years of age, which is an equally concise measure of performance developed by Lansky.¹⁴

Limitations

The small sample size is the main limitation of this study, which could have an adverse effect on meaningful comparisons between the subsets. The study's retrospective nature is also a limiting factor as there was no control over patients' management. Finally, we might have not precisely assessed some neurological deficits and chronic-phase complications of discharged patients by telephonic interviews, which may result in underreported complications.

Conclusion

LVPBIs pose management challenges based on the nature of penetrating trauma, the complexity of craniocerebral anatomy, the limited surgical options, and the wide range of complications. Our study addresses considerations based on anatomy, in that demography and injury characteristics, treatment protocols, complications, and outcomes were differentiated between trans-base and trans-vault LVPBIs. Despite limitations, we put forward this classification and present instructive data and analyses, which can contribute to the further understanding and standardized management of these injuries. Nevertheless, a future retrospective study of a larger sample size will be invaluable to further assess the benefit of this approach.

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Ethical statement

This study was approved by the Ethical Research Committee of Xiangya Hospital, Central South University (No.202010135).

Declaration of competing interest

The authors have no competing interests or personal financial interests to declare. They have no personal relations with organizations, publishers or any individual that may jeopardize the integrity of this work.

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