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Lesion Mapping and Determinants of Surgical Performance after Traumatic Brain Injury at Bouaké University Hospital (Côte d'Ivoire): Analysis of a Consecutive Hospital Series of 772 Patients

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Abstract

Background: In resource-limited settings, access to neurosurgical treatment after traumatic brain injury (TBI) depends on the entire referral chain as much as on the lesion itself. Few studies map lesion subtypes while simultaneously analysing, within a single series, the pathway linking the recorded surgical indication to the operation actually performed. **Objective:** To identify factors independently associated with the absence of documented surgery among patients with a recorded surgical indication and, secondarily, to map six focal-lesion subtypes and analyse admission delays. **Patients and Methods:** Analytical observational study of a consecutive hospital series of 772 patients with TBI admitted to the neurosurgery department of Bouaké University Hospital between 2025 and 2026, reported in accordance with STROBE. All admitted patients with a usable record were included. The primary endpoint was the documented performance of an operation, defined as the entry of at least one trauma-related neurosurgical procedure in the operating register of the index admission, expressed relative to all recorded indications. All multivariable models used Firth penalised logistic regression with profile-likelihood confidence intervals. **Results:** Patients were young (median age 30 years), predominantly male (83.8%) and mostly injured in road-traffic crashes (89.4%); 389 (50.4%) were referred from another facility. Focal subtypes showed a marked age gradient, from 23 years for depressed skull fracture to 56 years for chronic subdural haematoma, confirmed among patients with a single isolated lesion

(Kruskal-Wallis $p < 0.001$); the median admission delay remained uniformly 2 days across all subtypes, with no independent determinant of a prolonged delay. Surgery was documented for 65.5% of the 563 indications (369/563; 95% CI 61.5 - 69.5), ranging from 63.2% for contusion to 96.9% for chronic subdural haematoma. Lesion subtype was the dominant determinant of non-performance (adjusted odds ratios relative to contusion, from 0.03 for chronic subdural haematoma to 0.31 for acute subdural haematoma). Independently of the lesion, interhospital referral was associated with non-performance, modestly and at the margin of significance (adjusted OR 1.50; 95% CI 1.01 - 2.25; $p = 0.04$), as was a higher Glasgow Coma Scale score (OR 1.13 per point). In-hospital mortality did not differ across pathway stages (4.8%, 4.1% and 4.9%; $p = 0.92$). **Conclusion:** Lesion subtype governed both the surgical indication and its documented performance. Beyond the lesion, referral from another facility was associated with a lower probability that an indicated operation would be performed, pointing to the referral chain, rather than lesion severity, as the modifiable target.

Keywords

Health Services Accessibility, Referral and Consultation, Neurosurgical Procedures, Craniocerebral Trauma

1. Introduction

Traumatic brain injury (TBI) remains one of the leading causes of premature death and acquired disability in young adults in low- and middle-income countries [1] [2]. In sub-Saharan Africa, its rising incidence is driven mainly by road-traffic crashes, which disproportionately affect working-age men [3]-[5], while the scientific output devoted to this condition remains low relative to the burden it represents [6].

Many series have described individual lesion subtypes in isolation—extradural haematoma, acute subdural haematoma, depressed skull fracture—but few offer an integrated view of the full range of neurosurgical lesions within a single cohort, and fewer still link this mapping to the care pathway leading from the surgical decision to the operation itself [7] [8]. Yet, in resource-limited settings, patient outcome depends as much on the performance of the care chain—referral delays, imaging availability, access to the operating theatre and to blood products—as on the nature of the lesion [9]-[12].

The available West African series most often describe epidemiology and mortality, or focus on a single subtype, without quantifying the proportion of surgical indications actually followed by an operation or identifying the factors that keep them from it [13]-[15]. Work on delays addresses the intrahospital continuum but rarely the interplay between lesion type, mode of admission and surgical performance [7] [9].

We therefore analysed a consecutive series of 772 patients. The primary objec-

tive was to identify factors independently associated with the absence of documented surgery among patients with a recorded surgical indication. The secondary objectives were to describe the distribution of the six main focal-lesion subtypes and to analyse admission delays according to lesion profile.

2. Methods

2.1. Design and Setting

This single-centre, descriptive and analytical observational study is based on the retrospective analysis of the institutional TBI database of the neurosurgery department of Bouaké University Hospital, populated from the consecutive-admissions register and the operating register. Only the recent series (2025-2026; n = 772), for which pathway variables were collected in a standardised manner, was included. The manuscript follows the STROBE recommendations for observational studies [16].

The department provides neurosurgical care for both directly admitted patients and those referred from peripheral facilities. Management relied on an initial clinical assessment, brain computed tomography, the formulation of a surgical indication and, where appropriate, performance of the operation. Intracranial-pressure monitoring was unavailable and decompressive craniectomy was not performed under a standardised protocol, unlike the settings in which these strategies have been evaluated [17] [18].

The same series is the subject of a separate manuscript devoted to epidemiology, determinants of mortality and prognostic models, which constitutes the index report of the cohort (manuscript not yet published). Two further works derived from the same cohort are in progress, one devoted to the prehospital pathway and admission delays, the other to the paediatric subgroup (manuscripts not yet published). The present work addresses a question and an endpoint of its own and shares with them only the general descriptive characteristics of the cohort. It overlaps with the work devoted to the pathway solely on the description of admission delays, reported here as a secondary objective and without analysis of their relationship to outcome. This population overlap is declared here and in the cover letter, in accordance with the recommendations of the International Committee of Medical Journal Editors.

2.2. Study Population

Over the period, 826 admissions were recorded for suspected TBI and 54 records were excluded: 23 records that could not be located or lacked essential data, 14 with unavailable or unusable computed tomography, 9 duplicates or readmissions, 5 with a final non-traumatic diagnosis and 3 transferred before complete assessment. The analysis therefore concerns 772 patients.

2.3. Variables and Definitions

A surgical indication was defined as the therapeutic decision made by the attend-

ing neurosurgeon after clinical examination, interpretation of the computed tomography scan and discussion of the therapeutic strategy, and recorded in the medical file before any operation.

Documented surgery was defined as the entry, in the operating register of the index admission, of at least one neurosurgical procedure intended to treat the injury: craniectomy, craniotomy with bone flap, evacuation-drainage, external ventricular drainage, laminectomy or arthrodesis, débridement of a penetrating craniocerebral wound, elevation of a depressed fracture, revision of an open depressed fracture with dural breach, or cranioplasty. The term "documented" is preferred to "performed" because the completeness of this register could not be verified against source documents, and the absence of an entry does not prove the absence of an operation.

Six focal-lesion subtypes were recorded, not mutually exclusive: extradural haematoma (EDH), acute subdural haematoma (ASDH), chronic subdural haematoma (CSDH), contusion or intraparenchymal haematoma, depressed skull fracture, and open depressed fracture with dural breach (ODFDB). For the multivariable analyses, each patient was assigned to a single lesion category corresponding to the principal lesion, with contusion as the reference and patients presenting none of the six subtypes forming a distinct category. When several focal subtypes coexisted, the principal lesion was defined as the intracranial lesion with the greatest mass effect and clinical significance on the admission computed tomography, a fixed rank order (chronic then acute subdural haematoma, extradural haematoma, open depressed fracture with dural breach, depressed skull fracture, then contusion or intraparenchymal haematoma) being applied to break ties. This category was assigned by the attending neurosurgeon from the imaging and clinical data recorded at admission, and thus before and independently of the operating-register outcome that defines the primary endpoint. The coexistence of at least two subtypes was coded as a separate binary variable.

The admission delay was the number of whole days elapsed between the injury and admission to the neurosurgery department. The date of injury was taken from the clinical history recorded at admission (from the patient, relatives, or the referral documents) and the date of admission from the consecutive-admissions register; a patient presenting on the day of injury was coded as a zero-day delay, and for referred patients the interval spanned the whole prehospital and interfacility pathway, transfers included. Records for which the date of injury could not be established (fewer than 2%) were treated as missing for this variable. The threshold for a prolonged delay was set at 3 days, the first value strictly above the observed median. Because this measure has day-level resolution, it cannot distinguish clinically important delays of a few hours, which are decisive for evacuable lesions, and the delay analysis is therefore interpreted with caution.

2.4. Endpoints

The primary endpoint was the documented performance of surgery among patients with a recorded surgical indication. The secondary endpoints were in-hos-

pital mortality, admission delay and the distribution of lesion subtypes.

2.5. Statistical Analysis

Quantitative variables are described by the median and interquartile range (IQR), qualitative variables by the count and percentage, together with exact 95% confidence intervals (Clopper-Pearson) where they carry the principal message. Because the six lesion subtypes are not mutually exclusive and a given patient contributes to several groups, differences between subtypes in the full series are presented descriptively only, with no test statistic or p-value. Every inferential statement about between-subtype differences is drawn from the subgroup of patients with a single isolated focal lesion, where the categories are mutually exclusive and the independence assumption holds; in that subgroup the comparison used the Kruskal-Wallis test.

Several subtypes show markedly imbalanced counts with respect to the endpoint—only 2 of the 65 patients with an indicated chronic subdural haematoma had no documented surgery—exposing the analysis to separation bias. All multivariable models were therefore estimated by Firth penalised likelihood [19], with confidence intervals obtained by profiled penalised likelihood and p-values from the penalised likelihood-ratio test. The primary model addressed the absence of documented surgery among the 563 indications and comprised age, sex, the Glasgow Coma Scale (GCS) score, an admission delay of at least 3 days, interhospital referral, the coexistence of multiple lesions and the principal lesion category. A sensitivity analysis replaced the single category with six non-exclusive indicator variables. Two secondary models addressed a prolonged admission delay and in-hospital mortality.

An exploratory predictive model, distinct from the explanatory model, was built on the same variables; its discrimination was estimated out of sample by ten-fold cross-validation, and optimism was corrected by 2000 bootstrap resamples. No confidence interval is reported for the cross-validated area under the curve: because the out-of-sample predictions are pooled across overlapping training folds they are not independent, so a standard DeLong interval is not valid; a valid interval would require resampling of the entire cross-validation procedure. Calibration was assessed by the calibration slope and the Hosmer-Lemeshow test applied to the out-of-sample predictions. A classification tree (Gini criterion, maximum depth 3, minimum leaf size 20) was used to represent the hierarchy of determinants. These exploratory analyses do not constitute a validated clinical tool.

No imputation was performed; data were complete for all model variables and missingness was below 2% for all analysed variables. The significance threshold was $p < 0.05$, with no correction for multiple comparisons given the descriptive and exploratory aim. Analyses were performed with Python 3.12 and a fixed random seed.

2.6. Ethics Approval

The study was conducted in accordance with the principles of the Declaration of

Helsinki. The protocol was reviewed and approved by the Institutional Ethics Committee of Bouaké University Hospital (approval no. CEI/CHU-BKE/107/2026), which granted a waiver of individual informed consent. The waiver was justified by the retrospective design and the exclusive use of anonymised routine-care records, from which no individual patient could be identified.

3. Results

3.1. Cohort Characteristics

The median age was 30 years (IQR 20 - 44) and 647 patients (83.8%) were men, a sex ratio of 5.2. Road-traffic crashes were the main mechanism (89.4%), predominantly among users of two- or three-wheeled motorised vehicles (77.1%). Overall, 389 patients (50.4%) had been referred from another facility. The median Glasgow Coma Scale score on admission was 13 (IQR 11 - 14), corresponding mostly to mild injuries (56.2%). Overall in-hospital mortality was 4.7% (36 deaths) (Table 1).

Table 1. Characteristics of the series (n = 772).

Characteristic	n	%
Age, median (IQR), years	30 (20 - 44)	-
Male sex	647	83.8
Male/female sex ratio	5.2	-
Mechanism: road-traffic crash	690	89.4
of whom users of two- or three-wheeled motorised vehicles	532/690	77.1
Referred from another facility	389	50.4
Glasgow Coma Scale on admission, median (IQR)	13 (11 - 14)	-
Mild injury (13 - 15)	434	56.2
Moderate injury (9 - 12)	277	35.9
Severe injury (≤8)	61	7.9
Polytrauma	63	8.2
Admission delay, median (IQR), days	2 (1 - 3)	-
Delay ≥ 3 days	285	36.9
At least one of the six focal lesions studied	568	73.6
Isolated focal lesion	371	48.1
At least two concomitant focal lesions	197	25.5
Diffuse involvement or lesion outside the six categories	204	26.4
Recorded surgical indication	563	72.9
Documented surgery	369	47.8
In-hospital death	36	4.7

IQR, interquartile range. Percentages are expressed relative to the total of 772 patients unless otherwise stated; the proportion of users of two- or three-wheeled motorised vehicles is expressed relative to the 690 road-traffic crashes. The proportion of documented surgery is 65.5% when expressed relative to the 563 recorded indications.

3.2. Lesion Mapping

Overall, 568 patients (73.6%) had at least one of the six focal lesions studied: 371 an isolated lesion and 197 at least two concomitant lesions, for 808 lesion occurrences in total. The remaining 204 patients (26.4%) had diffuse involvement or a lesion outside these six categories, the penetrating craniocerebral wound being the most frequent lesion identified in this group.

Contusion or intraparenchymal haematoma was the most frequent subtype (43.5% of the series), ahead of ODFDB (14.8%), ASDH (14.2%), EDH (13.0%), depressed skull fracture (10.6%) and CSDH (8.5%). Surgical-indication rates ranged from 74.4% for contusion to 98.5% for CSDH (Table 2).

Table 2. Distribution of the six focal-lesion subtypes, surgical indication and documented surgery.

Lesion subtype	n (% of 772)	Age, median (IQR), years	Indication, n (%)	Documented surgery, n (%)
Contusion or intraparenchymal haematoma	336 (43.5)	33 (24 - 46)	250 (74.4)	158 (63.2)
ODFDB	114 (14.8)	29 (22 - 38)	97 (85.1)	75 (77.3)
ASDH	110 (14.2)	44 (36 - 58)	97 (88.2)	71 (73.2)
EDH	100 (13.0)	25 (19 - 34)	76 (76.0)	56 (73.7)
Depressed skull fracture	82 (10.6)	23 (17 - 31)	69 (84.1)	52 (75.4)
CSDH	66 (8.5)	56 (48 - 67)	65 (98.5)	63 (96.9)
All lesion occurrences	808	-	-	-

ASDH, acute subdural haematoma; CSDH, chronic subdural haematoma; EDH, extradural haematoma; ODFDB, open depressed fracture with dural breach. The subtypes are not mutually exclusive: 568 patients carry at least one of these lesions, for 808 occurrences in total, and a given patient may contribute to several rows. The indication percentage is expressed relative to the subtype count; that of documented surgery, relative to the recorded indications of that subtype. The age gradient across the full series is shown descriptively, without a test; in the subgroup of isolated lesions, where the categories are mutually exclusive, it is significant (Kruskal-Wallis $p < 0.001$).

The subtypes showed clearly distinct demographic profiles, dominated by an age gradient: a median of 23 years for depressed skull fracture and 25 years for EDH, versus 56 years for CSDH (Figure 1). This gradient was confirmed in the subgroup of isolated lesions, where the categories are mutually exclusive (Kruskal-Wallis $p < 0.001$).

3.3. Admission Delays

The median admission delay was 2 days (IQR 1 - 3) and this value was identical for each of the six subtypes, including those calling for urgent surgery such as EDH and depressed skull fracture. No independent determinant of a delay of at

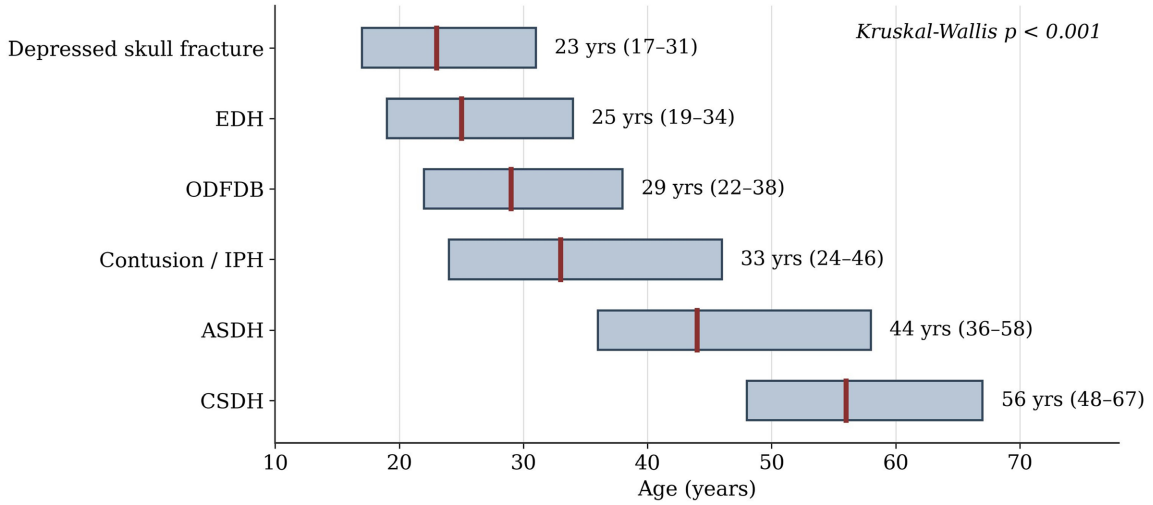

Figure 1. Age by focal-lesion subtype, shown as quartile boxes (first quartile, median, third quartile) ordered by increasing median. Because the subtypes are not mutually exclusive, the comparison is descriptive.

least 3 days was identified: neither age, nor sex, nor the Glasgow Coma Scale score, nor interhospital referral (OR 1.10; 95% CI 0.81 - 1.48), nor lesion type was associated with it. Access delay thus appears indifferent to the degree of neurosurgical urgency.

3.4. Surgical Performance

Of the 772 patients, 563 (72.9%) had a recorded surgical indication and 369 a documented operation, that is 65.5% of the indications (95% CI 61.5 - 69.5) (**Figure 2**). This proportion varied by subtype, from 63.2% for contusion to 96.9% for CSDH; apart from these two extremes, the four other subtypes lay within a narrow band of 73% to 77% (**Figure 3**).

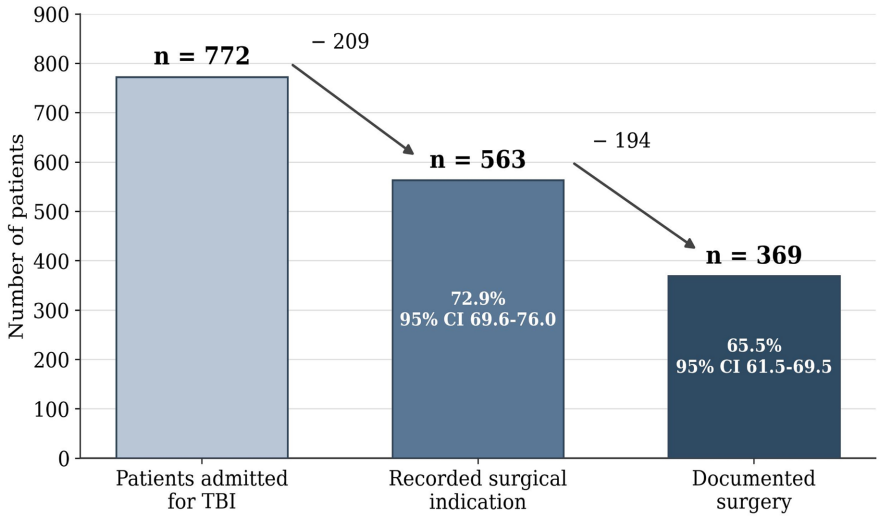

Figure 2. Care-pathway cascade of the series studied (N = 772), from admission to the recorded surgical indication and then to documented surgery, with exact 95% confidence intervals.

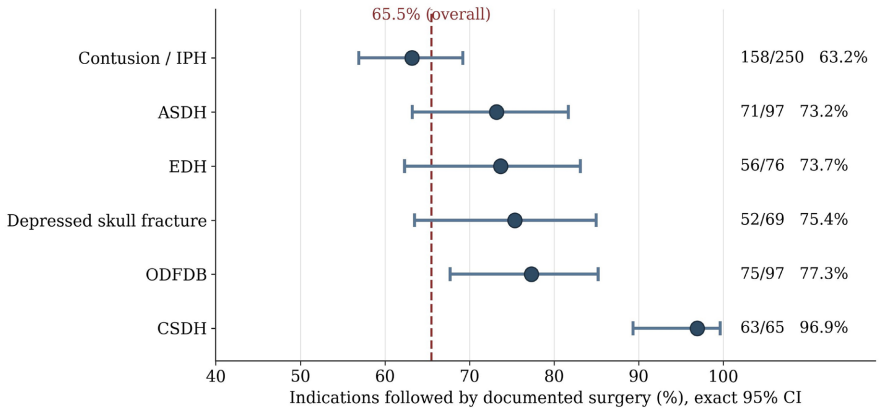

Figure 3. Proportion of surgical indications followed by documented surgery, by focal-lesion subtype, with exact 95% confidence intervals. The vertical dashed line indicates the overall value of 65.5%.

On univariate analysis, patients with and without documented surgery differed by age (median 34 versus 28 years; p = 0.007), interhospital referral (50.1% versus 59.8%; p = 0.03) and lesion profile, but not by the Glasgow Coma Scale score (p = 0.21) or by sex (p = 0.33). Multiple focal lesions were more frequent among operated patients (30.6% versus 16.5%; p < 0.001), as was the absence of any of the six subtypes among non-operated patients (26.3% versus 8.1%; p < 0.001).

3.5. Independent Determinants of Non-Performance

Lesion subtype was the dominant determinant. Relative to contusion, all evacuable focal lesions were associated with a markedly lower probability of non-performance: CSDH (OR 0.03; 95% CI 0.01 - 0.11), ODFDB (0.20; 0.10 - 0.39), depressed skull fracture (0.22; 0.10 - 0.43), EDH (0.23; 0.11 - 0.45) and ASDH (0.31; 0.16 - 0.59), all with p ≤ 0.001. Patients presenting none of the six subtypes did not differ significantly from those with a contusion (OR 1.28; 95% CI 0.70 - 2.38).

Two non-lesional variables stood out. Referral from another facility was associated with a 50% higher risk of non-performance (OR 1.50; 95% CI 1.01 - 2.25; p = 0.04), at comparable lesion profile, age, sex, severity and delay. A higher Glasgow Coma Scale score was also associated with it (OR 1.13 per point; 95% CI 1.04 - 1.24; p = 0.005). Age, male sex, a prolonged delay and the coexistence of multiple lesions did not reach the significance threshold (Table 3 and Figure 4).

Table 3. Independent determinants of the absence of documented surgery among the 563 recorded surgical indications.

Variable	Adjusted OR	95% CI	p
***Principal lesion category* (*ref.*: *contusion*)**			
CSDH	0.03	0.01 - 0.11	<0.001
ODFDB	0.20	0.10 - 0.39	<0.001
Depressed skull fracture	0.22	0.10 - 0.43	<0.001

Continued

EDH	0.23	0.11 - 0.45	<0.001
ASDH	0.31	0.16 - 0.59	0.001
None of the six subtypes	1.28	0.70 - 2.38	0.42
Referral from another facility	1.50	1.01 - 2.25	0.04
Glasgow Coma Scale (per additional point)	1.13	1.04 - 1.24	0.005
Male sex	1.14	0.74 - 1.75	0.55
Age (per year)	1.01	0.99 - 1.02	0.26
Admission delay ≥ 3 days	1.18	0.82 - 1.69	0.37
Multiple focal lesions	0.79	0.51 - 1.22	0.29

OR, odds ratio; CI, confidence interval. Firth penalised logistic regression, intervals obtained by profiled penalised likelihood, p-values from the penalised likelihood-ratio test. An OR below 1 corresponds to a lower probability of non-performance, hence a higher probability that the indication is followed by an operation. The sensitivity analysis substituting six non-exclusive indicator variables for the single category yields the same directions and very similar magnitudes.

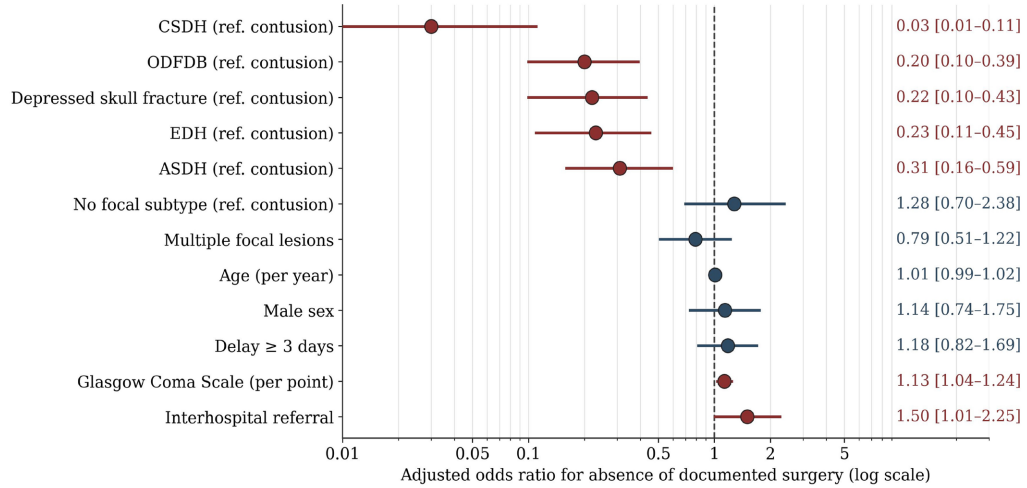

Figure 4. Adjusted odds ratios for the absence of documented surgery among the 563 recorded surgical indications, estimated by Firth penalised logistic regression with profile-likelihood confidence intervals, shown on a logarithmic scale. Estimates whose interval excludes 1 are shown in red. Lesion categories are compared with contusion.

The sensitivity analysis substituting six non-exclusive indicator variables for the single lesion category gave the same directions and very similar magnitudes (CSDH 0.03; depressed skull fracture 0.19; ODFDB 0.19; EDH 0.21; ASDH 0.34; interhospital referral 1.48; GCS 1.14 per point). The choice of specification does not alter the conclusions.

Among the 371 patients with an isolated focal lesion, 337 (90.8%) had a surgical indication and 226 a documented operation, that is 67.1% (95% CI 61.8 - 72.1). The gradient across subtypes was even more marked here, from 42.9% for isolated contusion to 100% for isolated CSDH.

3.6. Exploratory Predictive Model

A predictive model built on the same variables achieved modest discrimination: apparent area under the curve (AUC) 0.753, out-of-sample AUC 0.731 (point estimate; no valid confidence interval, see Methods), bootstrap optimism 0.021 and optimism-corrected AUC 0.732. Calibration was imperfect, with a slope of 0.87 and a significant Hosmer-Lemeshow test ($p < 0.001$) on the out-of-sample predictions. The model is therefore not usable in practice and is presented only to situate the share of variation explained by the available variables. The classification tree reproduced the same hierarchy: the first split isolated patients with none of the six focal subtypes, then CSDH and interhospital referral, with terminal leaves ranging from 2.2% to 90.9% non-performance.

3.7. In-Hospital Mortality

Mortality did not differ across pathway stages: 4.8% (10/209) in patients without a surgical indication, 4.1% (8/194) in those whose indication was not followed by documented surgery and 4.9% (18/369) in operated patients ($p = 0.92$). On penalised multivariable analysis, the Glasgow Coma Scale score was its only independent determinant (OR 0.60 per point; 95% CI 0.51 - 0.70; $p < 0.001$); neither documented surgery (OR 0.69; 95% CI 0.31 - 1.47), nor delay, nor interhospital referral, nor multiple lesions was associated with it (Table 4). The documented-surgery estimate is presented for descriptive completeness only: because surgery is a time-dependent event conditional on survival to the operating theatre, its association with in-hospital mortality cannot be estimated by this time-fixed model without immortal-time bias and is not interpreted causally.

Table 4. Determinants of in-hospital mortality (n = 772, 36 deaths).

Variable	Adjusted OR	95% CI	p
Glasgow Coma Scale (per additional point)	0.60	0.51 - 0.70	<0.001
Documented surgery	0.69	0.31 - 1.47	0.33
Multiple focal lesions	1.32	0.61 - 2.83	0.43
Admission delay ≥ 3 days	1.27	0.60 - 2.61	0.48
Male sex	1.21	0.56 - 2.59	0.63
Referral from another facility	1.09	0.53 - 2.21	0.82
Age (per year)	1.02	0.99 - 1.05	0.18

OR, odds ratio; CI, confidence interval. Firth penalised logistic regression on seven variables for 36 deaths; penalisation limits estimation bias but not the lack of power, and the absences of association reported do not constitute proof of absence of effect. Because surgery is time-dependent and patients must survive to reach the operating theatre, the association between documented surgery and in-hospital mortality cannot be estimated by a time-fixed model of this kind without immortal-time (survival-to-operation) bias; the documented-surgery term is descriptive and carries no causal interpretation. Crude mortality does not differ across pathway stages: 4.8% (10/209) without a surgical indication, 4.1% (8/194) when an indication was not followed by documented surgery, 4.9% (18/369) in operated patients ($p = 0.92$).

4. Discussion

This study offers an integrated view of traumatic lesions and the neurosurgical pathway in a resource-limited African setting. It shows that lesion type governs both the surgical decision and its translation into a recorded operation, and identifies a non-lesional determinant of non-performance: referral from another facility.

4.1. Main Findings

Three lessons emerge. First, each subtype shows a demographic profile consistent with its pathophysiology, with a clear age gradient that withstands restriction to isolated lesions. Second, the admission delay is remarkably homogeneous—a median of 2 days for each subtype—and no available variable explains its prolongation: the pathway handles a depressed skull fracture and a chronic subdural haematoma in the same way, reflecting an absence of upstream triage rather than a difficulty specific to certain lesions. Third, surgery is documented for only two-thirds of indications, and this proportion depends first on the lesion but also on the mode of admission.

4.2. Mode of Admission as a Determinant of the Pathway

The most actionable finding is that, at comparable lesion, severity, age and delay, a patient referred from another facility is one and a half times more likely to have no documented surgery than a directly admitted patient. The effect is modest and its interval borders unity, but it is consistent with the univariate analysis and with the structure of the classification tree, where referral appears as the most discriminating splitting variable after lesion type.

This finding points to a modifiable target. Unlike the nature of the lesion or the initial severity, the referral chain is a matter of organisation: content of the transfer, transmission of images, anticipation of surgical availability, information to families about cost and delays. Studies from Uganda and other low- and middle-income settings have documented similar breakdowns along the referral continuum [7]-[9] [14], and recommendations on the organisation of trauma care make it a priority point of intervention [11] [12].

The association of the Glasgow Coma Scale score should be read with caution: it is absent on univariate analysis and appears only after adjustment, reflecting a suppression effect by lesion type. The most severe patients are also those who most often carry an evacuable lesion, almost always operated; at comparable lesion, it is the most alert patients who have no documented surgery, a configuration compatible with deliberate surgical abstention as much as with an access barrier.

4.3. How to Interpret the Gap between Indications and Operations

The shortfall of 194 operations out of 563 indications admits at least three explanations that this work cannot disentangle. A clinical explanation: the profile of

patients without documented surgery—contusion, absence of an evacuable lesion, higher Glasgow Coma Scale score—corresponds to situations in which an initially recorded indication may be withdrawn in the face of a favourable course or lesion regression. A documentary explanation: the variable comes from the operating register, whose completeness could not be verified against source documents, and under-documentation would mechanically inflate the apparent shortfall. An organisational explanation: unavailability of the theatre or of blood products, cost to the patient, discharge against medical advice; this is the only one for which we have an indication, through the effect of interhospital referral.

The absence of an association between documented surgery and mortality deserves emphasis in this context: if one-third of indications corresponded to genuinely unmet surgical needs, one would expect excess mortality in this group, yet mortality there was 4.1% versus 4.9% in operated patients. This comparison nonetheless calls for a caveat: the group without documented surgery includes patients who died before the operation, which raises its mortality, whereas the operated group by construction comprises only patients who survived to theatre, which lowers its own. The two biases act in opposite directions and their net effect cannot be quantified from the available data. Disentangling the three hypotheses would require, for each indication not followed by an operation, the recorded reason—medical decision, death before the operation, material constraint, refusal or departure of the patient. This information was not available and constitutes the first priority for prospective data collection.

4.4. Comparison with the Literature

The epidemiological profile—young subjects, male predominance, the preponderance of crashes involving two- or three-wheeled motorised vehicles—agrees with the main African series of the past decade [3] [4] [13]. Prolonged prehospital delays have been reported across low- and middle-income settings, where transport and referral networks are major determinants of access to neurosurgical care [9] [14] [20], the identified causes being the absence of structured prehospital systems, transport difficulties, the cost of care and limited access to computed tomography [10] [15] [21].

A gap between documented lesion and operation performed also exists in high-resource systems: in the European CENTER-TBI cohort, 99 of 461 patients with an extradural haematoma (21%) were operated on in the acute phase, with substantial between-centre variability [22]. There, this gap primarily reflects differences in decision threshold [23] [24], which counsels caution before interpreting an incomplete conversion as the signature of a pathway failure. The Global Neurotrauma Outcomes Study, covering 1635 patients operated on in 159 hospitals across 57 countries, showed that the case-mix and mortality of emergency neurosurgery vary strongly with the level of resources [25] [26], making the standardisation of pathway data all the more necessary [27]-[30].

Unlike classical TBI prognostic models, which predict patient outcome from

admission characteristics [31] [32], the exploratory model presented here predicts access to treatment rather than its result. Its modest discrimination and imperfect calibration show that a substantial part of the decision escapes the variables recorded in routine—which is itself informative: the pathway is not determined by clinical and radiological data alone.

4.5. Strengths and Limitations

The main strengths lie in the simultaneous analysis of six subtypes within a large consecutive series, the systematic use of penalised estimation in the face of markedly imbalanced counts, and a complete internal validation of the exploratory model.

The limitations are substantial. The single-centre nature limits generalisation. The surgical-performance variable comes from the operating register, whose completeness was not established against source documents: under-documentation of operations would mechanically inflate the proportion of indications not followed by an operation, which is the primary endpoint of this work. The absence of information on individual reasons for non-performance prevents distinguishing medical decisions from logistical or financial constraints, and prevents identifying patients who died before the operation, mechanically classified among those without documented surgery. The six subtypes are not mutually exclusive, which invalidates the inferential use of between-group comparisons; the analysis restricted to isolated lesions, where this difficulty disappears, nonetheless confirms all the gradients. Several odds ratios rest on markedly imbalanced counts and, despite penalisation, should be read as a direction rather than a magnitude. Because delay is measured in days, it does not capture the first hours, decisive for evacuable lesions. The mortality model rests on 36 deaths for seven variables: penalisation limits estimation bias but not the lack of power, and the absences of association it reports do not constitute proof of absence of effect. In particular, documented surgery is a time-dependent exposure conditional on survival to the operating theatre; its association with in-hospital mortality cannot be estimated by a time-fixed logistic model without immortal-time bias, so that estimate is descriptive and is not interpreted as a causal effect of surgery. Finally, the absence of longer-term functional assessment precludes studying the impact of the pathway on long-term neurological outcome [33].

5. Conclusion

In patients with TBI managed at a neurosurgical referral centre, lesion characteristics determined the surgical need and governed the probability that an indication would be followed by a recorded operation. Beyond the lesion, referral from another facility was associated with a lower probability that an indication would be followed by an operation—an association of modest magnitude and borderline significance that nonetheless points to the referral chain as an accessible target for improvement. The uniform admission delay of 2 days, whatever the lesion ur-

gency, constitutes a second such target. The share of the gap between indications and operations attributable to an unmet need, a legitimate clinical reassessment or incomplete recording cannot be established from routine data and calls for prospective collection of the reason for each unperformed indication.

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Author Contributions

All authors made a substantial contribution to the conception of the study, the collection of data, the analysis and interpretation of results, or the drafting and critical revision of the manuscript. All read and approved the submitted version and collectively assume responsibility for it.

Conflicts of Interest

The authors declare that they have no conflicts of interest concerning the publication of this article.

Availability of Data and Materials

The anonymised individual data and the analysis code are available from the corresponding author on reasonable request, in compliance with the applicable ethics regulations.

Consent to Publish

Not applicable. The manuscript contains no individual data allowing a patient to be identified; the analysis concerned anonymised routine-care data.

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List of Abbreviations

ASDH, acute subdural haematoma; AUC, area under the curve; CI, confidence interval; CSDH, chronic subdural haematoma; EDH, extradural haematoma; GCS, Glasgow Coma Scale; IQR, interquartile range; ODFDB, open depressed fracture with dural breach; OR, odds ratio; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology; TBI, traumatic brain injury.