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Pediatric Intracranial Infections Requiring Neurosurgery: A German Multicenter Analysis of 10-Year Trends Pre–COVID-19 and Post–COVID-19

Daniel Dubinski, MD, MSc[*], Sae-Yeon Won, MD[*], Artem Rafaelian, MD [*], Ulrich Sure, MD[‡], Phillipp Dammann, MD[‡], Laurèl Rauschenbach, MD[‡], Christian Senft, MD[§], Nazife Dinc, MD[§], Nazeer Aboud, MD[§], Florian Ringel, MD[||], Malte Ottenhausen, MD[||], Daniel Scurtu, MD[||], Wolfgang Deinsberger, MD[¶], Stefanie Kästner, MD[¶#], Joe Jun Qiao Chen, MD[¶#], Veit Rohde, MD[**], Friederike Knerlich-Lukoschus, MD[**], Hans Bock, MD[**], Silvia Hernandez, MD[**], Dorothee Mielke, MD[††], Peter Baumgarten, MD[††], Paulina Guenzerodt, MD[††], Hartmut Vatter, MD[‡‡], Sevgi Sarikaya-Seiwert, MD[‡‡], Matthias Schneider, MD[‡‡], Thomas Beez, MD[§§], Hendrik-Jan Mijderwijk, MD, MSc, PhD[§§], Linda Wierich Altamirano, MD[§§], Robert Mlynski, MD[||||], Eva Herrmann, PhD[¶¶], Thomas Freiman, MD[*], Florian Gessler, MD, PhD[*]

[*]Department of Neurosurgery, Rostock University Medical Center, Rostock, Germany; [‡]Department of Neurosurgery and Spine Surgery, University Hospital Essen, University of Duisburg-Essen, Essen, Germany; [§]Department of Neurosurgery, Jena University Hospital, Friedrich Schiller University Jena, Jena, Germany; [||]Department of Neurosurgery, University Medical Center Mainz, Mainz, Germany; [¶]Neurosurgical Department, Klinikum Kassel, Kassel, Germany; [#]Kassel School of Medicine, University of Southampton, Southampton, UK; [**]Department of Neurosurgery, University Medical Center Göttingen, Göttingen, Germany; [††]Department of Neurosurgery, University Hospital Augsburg, Augsburg, Germany; [‡‡]Department of Neurosurgery, University Hospital Bonn, Bonn, Germany; [§§]Department of Neurosurgery, Medical Faculty, Heinrich-Heine-University, Düsseldorf, Germany; [||||]Department of Otorhinolaryngology, Head and Neck Surgery "Otto Körner", Rostock University Medical Center, Rostock, Germany; [¶¶]Department of Medicine, Institute of Biostatistics and Mathematical Modelling, Goethe University Frankfurt, University Hospital, Frankfurt, Germany

Correspondence: Daniel Dubinski, MD, MSc, Department of Neurosurgery, Rostock University Medical Center, Schillingallee 35, Rostock 18057, Germany.
Email: Daniel.dubinski@med.uni-rostock.de

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BACKGROUND AND OBJECTIVES: Intracranial infection in children is a rare but life-threatening condition that requires immediate neurosurgical care. The impact of the COVID-19 pandemic on incidence and outcome is unclear.

METHODS: This study is a multicenter retrospective analysis of children who underwent neurosurgical treatment of intracranial infections (epidural abscess, subdural empyema, cerebral abscess, ventriculitis, and meningitis) between January 2014 and October 2024. Comparison of children with intracranial infections and neurosurgical intervention stratified by pre and postpandemic.

RESULTS: The annual incidence of pediatric intracranial infections requiring neurosurgery increased significantly from 5.6 cases (95% CI: 4.0-7.5) prepandemic to 14.4 cases (95% CI: 11.2-18.0) postpandemic, with an incidence risk ratio (IRR) of 2.6 (95% CI: 1.8-3.8; $P < .0001$). Causative were the observed sinusitis-associated cases, with absolute numbers rising from 13 prepandemic to 31 postpandemic. The annual incidence increased from 1.81 cases (95% CI: 0.99-2.97) to 6.45 cases (95% CI: 4.44-9.00), yielding an IRR of 3.6 (95% CI: 1.9-7.1; $P = .0001$). For otitis-related cases, absolute counts surged from 6 to 19, accompanied by an incidence increase from 0.83 (95% CI: 0.33-1.69) to 3.95 (95% CI: 2.43-6.01), with an IRR of 4.7 (95% CI: 2.0-13.0; $P = .0009$). However, functional outcomes assessed by the pediatric modified Rankin Scale showed no statistically significant differences between pre- and postpandemic cohorts in the Wilcoxon-Mann-Whitney test, both at discharge ($P = .388$) and at 3-month follow-up ($P = .927$).

CONCLUSION: Our study demonstrates a significant increase in the incidence of intracranial infections requiring neurosurgical treatment in children after the pandemic, with a 2.4-fold higher IRR compared with the prepandemic period. The postpandemic group had a significantly higher incidence of underlying complicated otitis and sinusitis.

KEY WORDS: Pediatric neurosurgery, Intracranial empyema, Sinusitis, Otitis, COVID

ABBREVIATIONS: CRP, C-reactive protein; **ENT,** ear, nose, and throat; **IRR,** incidence risk ratio; **PCT,** procalcitonin.

Key Points:

Question: Did the COVID-19 pandemic affect the case numbers and treatment outcomes of children with intracranial infections requiring neurosurgery in Germany?

Findings: Among 109 pediatric patients who underwent 178 neurosurgical interventions for intracranial infections between 2014 and 2024, the annual incidence increased significantly in the postpandemic period (2021-2024). This rise was primarily driven by a surge in sinusitis- and otitis-associated infections. However, infection localization (eg, cerebral abscess, subdural empyema), neurosurgical management, and functional outcome (assessed via the pediatric modified Rankin Scale (mRS)) showed no statistically significant differences between prepandemic and postpandemic cohorts.

Meaning: The rise in incidence of severe pediatric intracranial infections, requiring neurosurgery in the postpandemic period, highlights the pandemic's indirect effects on pediatric health and underscores the need for strategies to mitigate delayed care in future crises.

The pandemic declared by the WHO in 2020 has posed unprecedented challenges to healthcare services worldwide, including pediatric neurosurgery and otolaryngology. During the pandemic multiple centers observed an increase in intracranial infections in children, leading the Centers for Disease Control and Prevention to issue a health alert in May 2022.[1] In the further course, single center studies (with a small number of cases) and epidemiological studies (lacking patient-level data) confirmed the registered increased incidence in pediatric intracranial infection requiring neurosurgery.[2-5]

Owing to the strict isolation measures with consecutively reduced infection rate, otorhinolaryngologists initially recorded a rapid decrease of severe forms of otitis and sinusitis.[6] Hence, for otolaryngology, elective surgical procedures, such as grommets or adenoid- and tonsillectomies were significantly reduced.[6-9] In rare cases, otitis and sinusitis can lead to severe complications in the form of otogenic and sinogenic intracranial spread.[4,6,9,10] The intricate anatomy of the lateral skull base increases the risk of inflammation progression up to epidural abscess, subdural empyema, cerebral abscess, ventriculitis, and/or meningitis.[1,11-13]

The complex and varied symptomatology of intracranial abscesses in children—including neurological deficits, headaches, altered mental status, seizures, and gastrointestinal disturbances—makes prompt diagnosis and management difficult. If suspected, however, effective management necessitates a comprehensive, multidisciplinary team, comprising neuroradiologists, otorhinolaryngologists, pediatric neurologists, infectious disease specialists, and pediatric neurosurgeons.

In this multicenter analysis, we examined the frequency and clinical characteristics of intracranial infections in children requiring neurosurgery postpandemic and compared them with those before the pandemic.

METHODS

Data Source

This multicenter study was approved by the Institutional Review Board, with a waiver of informed consent granted because of the use of anonymized data (identification number 2024-0163). The study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guideline. The data encompass detailed records on patient age; sex; preoperative symptoms; preoperative antibiotics; laboratory examination; preoperative MRI findings; type of neurosurgery; postoperative complications; intraoperative intracranial swabs; prior ear, nose, and throat (ENT) treatment and ENT surgery; postoperative antibiotic management; and outcome measured by pediatric mRS at discharge and at 3 months. The pediatric mRS assesses functional outcomes (0 = no symptoms, 6 = death) in children after neurological injury, adapted to account for developmental milestones. We choose scores 0-2 as a "good outcome," reflecting preserved independence and age-appropriate functioning.[14-16]

Study Population

Patients younger than 18 years with a diagnosis of intracranial infection (International Statistical Classification of Diseases-10-GM-2025 code: G06.0-G06.2) were included. We chose an eleven-year observational period from March 2013 to March 2024. We choose the terms "prepandemic" and "postpandemic" for clarity and standardization, anchoring the cutoff to March 11, 2020, the date the WHO declared COVID-19 a pandemic. Patients admitted before this date were assigned to the prepandemic cohort, ensuring consistency across analyses, even though regional pandemic impacts may have varied.[17] The Current Procedural Terminology (CPT®) for neurosurgical intervention included 61522, 61320, 61321, 61514, and 61323. Exclusion criteria included previous neurosurgical intervention within 6 months before admission to exclude the etiology of postoperative infection and all cases of ventriculoperitoneal shunt infections because it has a different etiology and would also distort the research question.

Statistical Analysis

Yearly rates of incidence and incidence risk ratios (IRRs) as well as 95% CIs and *P*-values were derived from a Poisson regression model. Calculation was performed with R version 4.4 (R Foundation for Statistical Computing). Univariate and multivariate analyses were performed using a Cox proportional regression model. Hazard ratios and 95% CIs were calculated. Multivariate analysis was performed on variates with *P* values <0.2, and *P* values <0.05 were considered to indicate statistical significance. All statistical analyses were conducted using the GraphPad Prism 10 (GraphPad Software).

Declaration of Generative Artificial Intelligence and Artificial Intelligence-Assisted Technologies in the Writing Process

During the preparation of this work, the author used LLaMA, a language model from Meta AI, version 1.0 to improve writing quality and efficiency. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

TABLE 1. Cohort Description

Variable	Cohort
Number of patients	109
Sex at birth	
Female	34 (31)
Male	75 (69)
Age, median (IQR)	7 (2-11)
Preoperative state	
Headache, n (%)	69 (63)
Fever, n (%)	76 (70)
Facial swelling, n (%)	26 (24)
Neck stiffness, n (%)	32 (29)
Sinusitis, n (%)	44 (40)
Otitis, n (%)	25 (23)
Seizures, n (%)	32 (29)
Preoperative antibiotics, n (%)	66 (61)
Neurological deficit, n (%)	
GCS, median, (IQR)	14 (11-15)
Aphasia, n (%)	11 (10)
Paresis, n (%)	24 (22)
Seizure, n (%)	32 (2)
Systemic signs of infection	
Tmax, °C median (IQR)	39.5 (38.5-39.6)
CRP, mg/L, median (IQR)	78.95 (18-196)
WBC count, $\times 10^9$/L median (IQR)	11.5 (10-19)
PCT, ng/mL, median (IQR)	1.57 (0.09-2.97)
Preoperative MRI, n	
Contrast enhancing, n (%)	96 (88)
DWI/ADC positive, n (%)	90 (85)
Epidural abscess, n (%)	29 (27)
Subdural empyema, n (%)	40 (37)
Cerebral abscess, n (%)	31 (28)
Meningitis, n (%)	30 (26)
Ventricular extension, n (%)	15 (14)
Midline shift, n (%)	36 (33)
Neurosurgical intervention	
Burr hole, n (%)	43 (39)
Craniotomy, n (%)	27 (25)
Craniectomy, n (%)	28 (26)
EVD, n (%)	11 (10)

TABLE 1. Continued.

Variable	Cohort
ICP probe, n (%)	10 (9)
Postoperative complication, n (%)	19 (17)
Intraoperative intracranial swabs, n (%)	97 (88)
Total number of operations, median (IQR)	1 (1-2)
VP Shunt implantation, n (%)	14 (13)
Intraoperative intracranial germs	n = 97
Streptococcus intermedius, n (%)	33 (34)
Staphylococcus aureus, n (%)	8 (8)
Streptococcus pneumoniae, n (%)	6 (6)
Haemophilus influenzae, n (%)	6 (6)
Others, n (%)	44 (46)
Prior ENT treatment, n (%)	
Prior ENT surgery, n (%)	55 (50)
Positive sinus cultures, n (%)	44 (40)
Postoperative antibiotic management	
Duration of antibiotic treatment, median (IQR)	4 (4-8)
Antibiotic administration oral, n (%)	16 (15)
Pediatric mRS at discharge	
0, n (%)	16 (15)
1, n (%)	30 (28)
2, n (%)	35 (31)
3, n (%)	11 (10)
4, n (%)	5 (5)
5, n (%)	5 (5)
6, n (%)	7 (6)
Pediatric mRS at 3 mo	n = 96
0, n (%)	42 (44)
1, n (%)	32 (33)
2, n (%)	9 (9)
3, n (%)	4 (4)
4, n (%)	1 (1)
5, n (%)	0 (0)
6, n (%)	8 (8)

CRP, C-reactive protein (mg/L); DWI/ADC, diffusion-weighted imaging/apparent diffusion coefficient; ENT, ear, nose, and throat surgery; EVD, external ventricular drain; GCS, Glasgow Coma Scale; ICP, intracranial pressure; mRS, pediatric modified Rankin Scale; OR, odds ratio; PCT, procalcitonin (ng/mL); Tmax: maximum temperature (°C); VP, ventriculoperitoneal; WBC, White blood cell count ($\times 10^9$/L).
Baseline demographical, clinical, and laboratory characteristics of pediatric intracranial infection before and after the pandemic. Data are presented as median (IQR) for continuous variables and number (%) for categorical variables.

RESULTS

In our study, the pre- and postpandemic cohorts showed good comparability with no significant difference in the distribution of age (median of 7 years for both groups (95% CI: −2.05 to 2.05; $P = 1$) and sex 10 vs 24 females odds ratio (OR) 0.6 (95% CI: 0.22-1.26; $P = .204$). Table 1.

Interestingly, aphasia was more frequent in the postpandemic cohort OR 0.1 (95% CI: 0.01-1.08; $P = .026$), whereas paresis was more common in the prepandemic cohort OR 2.1 (95% CI: 0.86-5.42; $P = .076$). Other clinical symptoms at hospitalization were not significantly different between children in the pre- and postpandemic cohorts: headache OR 0.6 (95% CI: 0.31-1.53; $P = .241$), fever OR 0.5 (95% CI: 0.25-1.34; $P = .145$), facial swelling OR 0.7 (95% CI: 0.30-1.91; $P = .367$), neck stiffness OR 0.9 (95% CI: 0.38-2.07; $P = .481$), seizures OR 1.0 (95% CI: 0.46-2.48; $P = .518$), and Glasgow Coma Scale (95% CI: −1.45-1.45; $P = 1$); Table 2.

Laboratory results at admission showed a statistically significant increase of white blood cell count in the prepandemic cohort with a median of 13.7×10^9/L vs 9.09×10^9/L in the postpandemic cohort (95% CI: 1.19-6.62; $P = .005$) in the univariate analysis but not in the multivariate analysis. However, the median highest measured temperature in °C was 39.5 for both cohorts and therefore not significant (95% CI: −5.05 to 5.05; $P = 1$). The initially measured C-reactive protein (CRP) and procalcitonin (PCT) values were also statistically insignificant: 95% CI: −98.81 to 94.01; $P = .960$ and −9.82 to 9.90; $P = .993$.

The annual incidence of pediatric intracranial infections requiring neurosurgery increased significantly from 5.6 cases (95% CI: 4.0-7.5) prepandemic to 14.4 cases (95% CI: 11.2-18.0) postpandemic, with an IRR of 2.6 (95% CI: 1.8-3.8; $P < .0001$) (Figure 1). A similar trend was observed for sinusitis-associated cases, with absolute numbers rising from 13 prepandemic to 31 postpandemic. The annual incidence increased from 1.81 cases (95% CI: 0.99-2.97) to 6.45 cases (95% CI: 4.44-9.00), yielding an IRR of 3.6 (95% CI: 1.9-7.1; $P = .0001$). For otitis-related cases, absolute counts surged from 6 to 19, accompanied by an incidence increase from 0.83 (95% CI: 0.33-1.69) to 3.95 (95% CI: 2.43-6.01), with an IRR of 4.7 (95% CI: 2.0-13.0; $P = .0009$). Figure 1.

The univariate analysis of the intracranial manifestations of infection and preoperative MRI findings shows that contrast enhancement OR: 0.8 (95% CI: 0.31.3.44; $P = .594$), positive diffusion-weighted imaging/apparent diffusion coefficient OR: 0.6 (95% CI: 0.24-1.82; $P = .299$), epidural abscess OR: 0.4 (95% CI: 0.19-1.23; $P = .094$), subdural empyema OR: 0.6 (95% CI: 0.27-1.41; $P = .177$), meningitis OR: 1.2 (95% CI: 0.53-2.93; $P = .382$), ventricular extension OR: 0.7 (95% CI: 0.23-2.32; $P = .412$), and midline shift OR: 1.6 (95% CI: 0.71-3.63; $P = .169$) showed no significant differences between the 2 groups. Cerebral abscess OR: 2.4 (95% CI: 1.03-5.68; $P = .032$) was statistically significantly higher in the prepandemic cohort. Intracranial swabs were positive in 97 cases without a statistically significant change in the bacterial spectrum between the pre- and postpandemic cohorts with *Streptococcus intermedius* as the pathogen in most cases OR: 1.3 (95% CI 0.47-2.75; $P = .473$). Figure 2.

Regarding the surgical procedures performed, there was no significant difference in the comparison of the pre- and postpandemic cohorts with burr hole OR for burr hole: 1.0 (95% CI: 0.45-2.20; $P = .572$); OR craniotomy: 0.8 (95% CI: 0.35-2.14; $P = .475$); OR for craniectomy: 1.7 (95% CI: 0.75-4.24; $P = .135$); OR for external ventricular drain placement: 0.3 (95% CI: 0.06-1.50; $P = .113$); and OR for intracranial pressure probe: 0.3 (95% CI: 0.07-4.27; $P = .163$). The OR for the occurrence of postoperative complication was 1.1 (95% CI: 0.41-3.12; $P = .494$). Positive intracranial swabs were statistically more significant in the prepandemic cohort OR: 3.9 (95% CI: 1.06-14.48; $P = .234$). However, the total number of surgical intervention and the necessity for ventriculoperitoneal shunt placement were nonsignificant: (95% CI: 0.42-0.42; $P = 1$) and OR 0.8 (95% CI: 0.25-2.67; $P = .500$). Prior ENT surgery was significantly more present in the postpandemic cohort with an OR of 0.4 (95% CI: 0.18-0.90; $P = .002$) but nonsignificant in the multivariate analysis. A trend was recorded for positive sinus cultures with OR 0.4 (95% CI: 0.21-1.10; $P = .060$) but nonsignificant in the multivariate analysis. Table 2.

The duration of antibiotic treatment and the route of postoperative antibiotic administration (oral) was not different between the pre- and postpandemic cohorts, 95% CI: −1.06 to 1.06; $P = 1$ and .7 (95% CI: 0.33-1.87; $P = .378$, respectively.

Functional outcomes assessed by the pediatric mRS showed no statistically significant differences between pre- and postpandemic cohorts in the Wilcoxon-Mann-Whitney test, both at discharge ($P = .388$) and at 3-month follow-up ($P = .927$) (Figures 3 and 4 and Table 2).

DISCUSSION

This multicenter observational study of 109 pediatric patients revealed a notable surge in pediatric intracranial infections necessitating neurosurgical intervention during the postpandemic era compared with prepandemic levels. The postpandemic cohort also exhibited a significant rise in the prevalence of complicated sinusitis or otitis highlighting a distinct epidemiological shift in underlying etiologies.

During data collection, we did not account for regional variations or differences in social and economic status. However, we intentionally limited our study to major hospitals within Germany, rather than expanding to neighboring European countries. This decision was made to ensure objectivity and consistency within a single healthcare system, where pediatric care follows specific national clinical guidelines—particularly in areas such as prehospital antibiotic administration. This approach allowed us to maintain homogeneity and reduce variability related to differing healthcare infrastructures.

TABLE 2. Univariate and Multivariate Analysis Stratified by Pre- and Postpandemic Cohorts

Variable	Prepandemic	Postpandemic	Univariate		Multivariate	
			OR 95% CI	*P*-value	OR 95% CI	*P*-value
Number of patients	43	66				
Sex at birth						
Female	10	24	0.6 (0.22 to 1.26)	.204	—	—
Male	33	42	0.6 (0.22 to 1.26)	.204	—	—
Age, median (IQR)	7 (2-11)	7 (2-11)	(−2.05 to 2.05)	1	—	—
Preoperative state						
Headache, n (%)	25 (58)	44 (67)	0.6 (0.31 to 1.53)	.241	—	—
Fever, n (%)	27 (56)	49 (74)	0.5 (0.25 to 1.34)	.145	—	—
Facial swelling, n (%)	9 (21)	17 (26)	0.7 (0.30 to 1.91)	.367	—	—
Neck stiffness, n (%)	12 (28)	20 (30)	0.9 (0.38 to 2.07)	.481	—	—
Sinusitis, n (%)	13 (30)	29 (46)	3.6 (1.93 to 7.12)	.0001	3.8 (0.04-1.04)	.005
Otitis, n (%)	6 (14)	19 (29)	4.7 (2.01 to 13.02)	.0009	4.1 (1.34-6.23)	.001
Preoperative antibiotics, n (%)	29 (67)	37 (56)	1.6 (0.72 to 3.60)	.161		
Neurological deficit, n (%)						
GCS, median, (IQR)	14 (12-15)	14 (11.5-15)	−1.45 to 1.45	1		
Aphasia, n (%)	1 (2)	10 (15)	0.1 (0.01 to 1.08)	.026	3.8 (0.21-2.13)	.012
Paresis, n (%)	13 (30)	11 (17)	2.1 (0.86 to 5.42)	.076	5.2 (0.08-0.69)	.023
Seizure, n (%)	13 (30)	19 (29)	1.0 (0.46 to 2.48)	.518		
Systemic signs of infection						
Tmax, °C median (IQR)	39.5 (38.5-39.6)	39.5 (38.5-39.6)	(−5.05 to 5.05)	1	—	—
CRP, mg/L, median (IQR)	77.65 (18-196)	80 (18-196)	(−98.81 to 94.01)	.960	—	—
WBC count, × 10^9/L median (IQR)	13.7 (10-19)	9.09 (10-19)	(1.19 to 6.62)	.005	—	—
PCT, ng/mL, median (IQR)	0.29 (0.09-2.97)	2.71 (0.09-2.80)	(−9.82 to 9.90)	.993	—	—
Preoperative MRI, n						
Contrast enhancing, n (%)	38 (88)	58 (88)	0.8 (0.31 to 3.44)	.594	—	—
DWI/ADC positive, n (%)	34 (79)	56 (85)	0.6 (0.24 to 1.82)	.299	—	—
Epidural abscess, n (%)	8 (19)	21 (32)	0.4 (0.19 to 1.23)	.094	—	—
Subdural empyema, n (%)	13 (30)	27 (41)	0.6 (0.27-1.41)	.177	—	—
Cerebral abscess, n (%)	17 (40)	14 (21)	2.4 (1.03 to 5.68)	.032	—	—
Meningitis, n (%)	13 (30)	17 (26)	1.2 (0.53 to 2.93)	.382	—	—
Ventricular extension, n (%)	5 (12)	10 (15)	0.7 (0.23 to 2.32)	.412	—	—
Midline shift, n (%)	17 (40)	19 (29)	1.6 (0.71 to 3.63)	.169	—	—

TABLE 2. Continued.

Variable	Prepandemic	Postpandemic	Univariate		Multivariate	
			OR 95% CI	*P*-value	OR 95% CI	*P*-value
Neurosurgical intervention						
Burr hole, n (%)	17 (39)	26 (39)	1.0 (0.45 to 2.20)	.572	—	—
Craniotomy, n (%)	10 (23)	17 (26)	0.8 (0.35 to 2.14)	.475	—	—
Craniectomy, n (%)	14 (32)	14 (21)	1.7 (0.75 to 4.27)	.135	—	—
EVD, n (%)	2 (5)	9 (14)	0.3 (0.06 to 1.50)	.113	—	—
ICP probe, n (%)	2 (5)	8 (12)	0.3 (0.07 to 1.75)	.163	—	—
Postoperative complication, n (%)	8 (19)	11 (17)	1.1 (0.41 to 3.12)	.494	—	—
Intraoperative intracranial swabs, n (%)	41 (93)	56 (85)	3.9 (1.06 to 14.48)	.234	—	—
Total number of operations, median (IQR)	1 (1-2)	1 (1-2)	(0.42 to 0.42)	1	—	—
VP shunt implantation, n (%)	5 (12)	9 (14)	0.8 (0.25 to 2.67)	.500	—	—
Intraoperative intracranial germs	n = 41	n = 56				
Streptococcus intermedius, n (%)	12 (28)	21 (38)	1.3 (0.47 to 2.75)	.473	—	—
Staphylococcus aureus, n (%)	4 (12)	4 (7)	0.4 (0.12 to 1.94)	.246	—	—
Streptococcus pneumoniae, n (%)	4 (12)	2 (4)	0.2 (0.04 to 1.28)	.083	—	—
Haemophilus influenzae, n (%)	1 (1)	5 (9)	3.4 (0.38 to 30.53)	.234	—	—
Others, n (%)	20 (45)	24 (42)	—	—	—	—
Prior ENT treatment, n (%)						
Prior ENT surgery, n (%)	16 (37)	39 (59)	0.4 (0.18 to 0.90)	.020	—	—
Positive sinus cultures, n (%)	13 (30)	31 (47)	0.4 (0.21 to 1.10)	.060	—	—
Postoperative antibiotic management						
Duration of antibiotic treatment, median (IQR)	4 (4-8)	4 (4-8)	−1.06 to 1.06	1.0	—	—
Antibiotic administration oral, n (%)	11 (26)	20 (30)	0.7 (0.33 to 1.87)	.378	—	—
Pediatric mRS at discharge						
0, n (%)	3 (7)	13 (20)	0.3 (0.08 to 1.14)	.056	—	—
1, n (%)	14 (32)	16 (26)	1.3 (0.59 to 3.23)	.289	—	—
2, n (%)	15 (35)	20 (32)	1.2 (0.54 to 2.79)	.383	—	—
3, n (%)	3 (7)	8 (14)	0.4 (0.12 to 1.86)	.222	—	—
4, n (%)	3 (7)	2 (3)	1.57 (0.30 to 8.19)	.443	—	—
5, n (%)	0 (0)	5 (7)	—	.058	—	—
6, n (%)	5 (12)	2 (3)	2.7 (0.62 to 12.27)	.156	—	—
Pediatric mRS at 3 months	n = 38	n = 58				
0, n (%)	18 (47)	24 (41)	1.5 (0.67 to 3.73)	.385	—	—
1, n (%)	11 (29)	21 (36)	0.8 (0.34 to 2.06)	.443	–	—
2, n (%)	4 (10)	5 (8)	1.4 (0.35 to 5.66)	.439	—	—

TABLE 2. Continued.

Variable	Prepandemic	Postpandemic	Univariate		Multivariate	
			OR 95% CI	*P*-value	OR 95% CI	*P*-value
3, n (%)	0 (0)	4 (7)	—	.151	—	—
4, n (%)	0 (0)	1 (2)	—	.630	—	—
5, n (%)	0 (0)	0 (0)	—	—	—	—
6, n (%)	5 (14)	3 (5)	0.5 (0.05 to 5.56)	.527	—	—

CRP, C-reactive protein (mg/L); DWI/ADC, diffusion-weighted imaging/apparent diffusion coefficient; ENT, ear, nose, and throat surgery; EVD, external ventricular drain; GCS, Glasgow Coma Scale; ICP, intracranial pressure; mRS, pediatric modified Rankin Scale; OR, odds ratio; PCT, procalcitonin (ng/mL); Tmax, maximum temperature (°C); VP, ventriculoperitoneal; WBC, white blood cell count (×10^9/L).

Comparison of clinical, laboratory, and surgical parameters between prepandemic (2014-2020) and postpandemic (2020-2024) cohorts using univariate and multivariate logistic regression.

The dramatic rise in severe pediatric intracranial infections observed in our multicenter analysis is unlikely to be unifactorial. One of the factors contributing to our finding could include systemic healthcare disruptions eg delayed diagnoses and reduced preventive care in particular those from the specialist field of ENT. During the peak of the pandemic (2020-2021), an initial decline was reported for sinusitis and otitis cases, likely due to widespread public health measures such as masking, social distancing, and reduced traveling.[18,19] This observations was also reflected in our analysis in the reduced number of intracranial infections for this period. However, these public health interventions not only curtailed COVID-19 transmission but also suppressed the spread of other respiratory pathogens, including those responsible for sinus infections.[5,20,21] As restrictions eased and population mobility resumed, a rebound effect occurred. In the postpandemic era, emerging data and clinical observations suggest a notable rise in both the frequency and severity of acute sinusitis cases compared with prepandemic levels.[19] The resurgence of sinusitis cases may reflect heightened exposure to viral and bacterial pathogens after the relaxation of precautions, coupled with potential immune system vulnerabilities stemming from reduced exposure to common pathogens during lockdowns—a phenomenon sometimes termed "immunity debt."[20,22] The increase in the postpandemic incidence of intracranial infections which originate for the significantly largest part as a complication of sinusitis and otitis is therefore consistent with this.

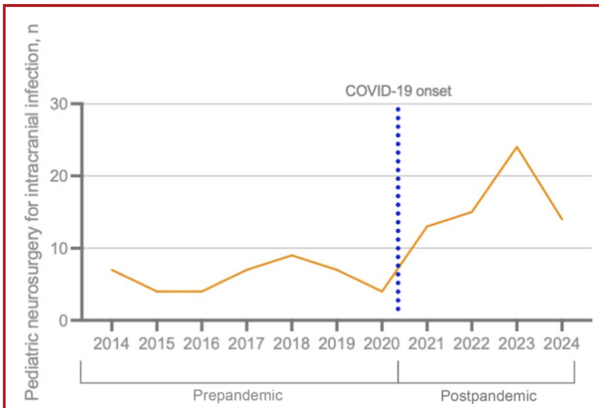

FIGURE 1. *Pre- and postpandemic trends in pediatric intracranial infection rates in Germany (2014-2024). This line graph illustrates the annual total number of pediatric intracranial infection cases requiring neurosurgery reported between 2014 and 2024, stratified into prepandemic (2014-2019) and postpandemic (2020-2024) periods. A vertical dashed line marks the onset of the COVID-19 pandemic (March 2020). OR, odds ratio.*

Another pertinent factor could be the unique immunological profile of children—marked by a robust yet balanced interplay of innate and adaptive responses—explains both their relative protection from severe acute COVID-19 and their vulnerability to postinfectious inflammatory syndromes such as multisystem inflammatory syndrome in children or sinusitis and otitis with progression to intracranial infection.[23] During acute SARS-CoV-2 infection, children exhibit a rapid, effective innate immune response characterized by early type I interferon production, which limits viral replication and spread.[24,25] This is complemented by a dynamic adaptive immune response, including the generation of neutralizing antibodies, which collectively curb progression to severe disease.[26,27] In addition, the pediatric immune system's abundance of naive T cells and regulatory T cells (Tregs) helps temper excessive inflammation, preventing the cytokine storms often seen in adults. However, these same protective mechanisms may paradoxically contribute to postinfectious complications when dysregulated, as seen in multisystem inflammatory syndrome in children or sinusitis and otitis with progression to intracranial infection requiring neurosurgery.

Our study identified a notable shift in the predominant neurological deficits among children with intracranial infections: Aphasia was more frequent in the postpandemic cohort, whereas paresis was more common in the prepandemic cohort. A possible explanation for this finding could be discussed in the widespread

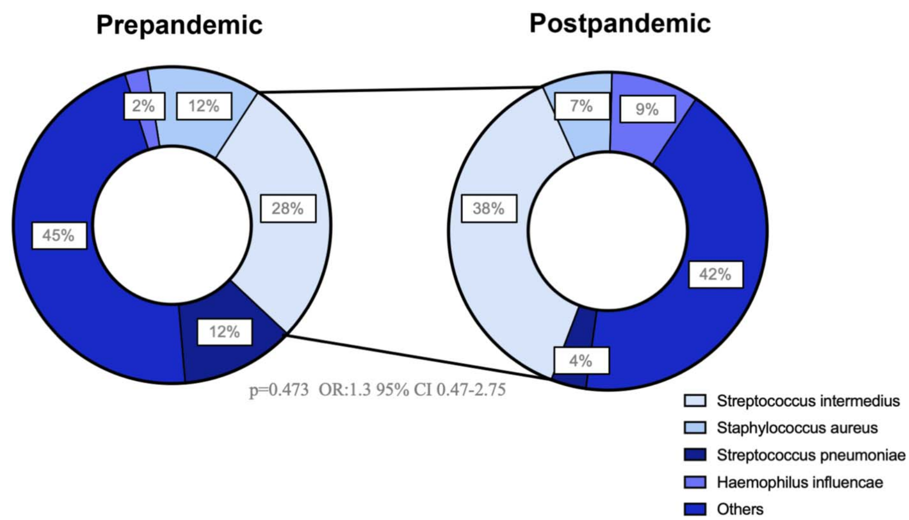

FIGURE 2. *Pathogen distribution in intracranial swabs (n = 97) Pie chart illustrating the relative frequencies of pathogens identified in intraoperative intracranial swabs from pediatric patients with intracranial infections. The predominant pathogen was Streptococcus intermedius (highlighted in pale blue), accounting for 28% of pre- and 38% postpandemic cases. OR, odds ratio.*

healthcare disruptions (eg, fear of hospital visits, lockdowns, and triage protocols), which may have delayed care-seeking for subtle or early symptoms. Early-stage intracranial infections (eg, abscesses, meningitis) often present with nonspecific signs (eg, headache, irritability), which caregivers might have overlooked or managed at home. By the time children reached clinical attention, infections may have progressed to involve broader cortical regions, including language centers (eg, temporal or frontal lobes), manifesting as aphasia. By contrast, prepandemic cohorts may have been diagnosed earlier, when focal motor deficits (eg, paresis from frontal/parietal lobe lesions) were the primary signs. While our observation of increased aphasia in the postpandemic cohort and higher paresis rates in the prepandemic group provides intriguing insights, several limitations warrant consideration. The retrospective design of the

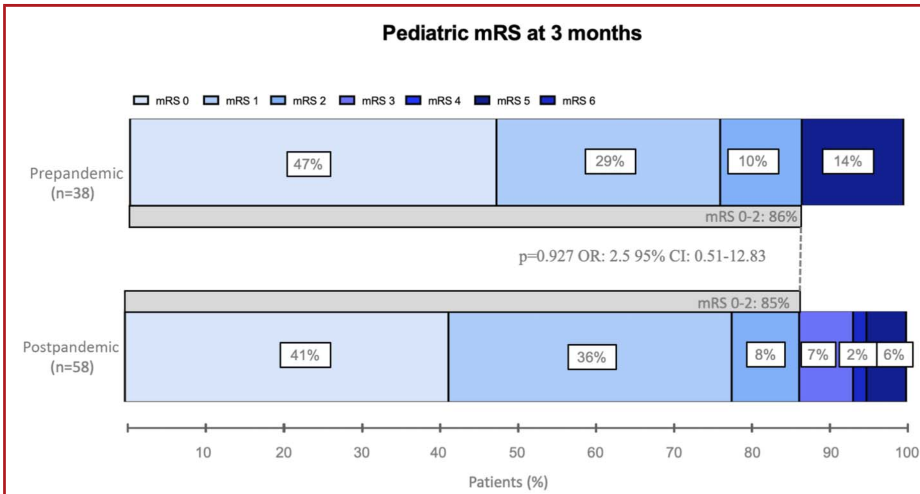

FIGURE 3. *Distribution of pediatric mRS scores at discharge in 109 children with neurosurgical intervention for intracranial infection. Comparison of the functional outcomes of 109 pediatric patients at hospital discharge, as assessed by the pediatric mRS. Scores range from 0 (no symptoms) to 6 (death) with no statistical significance in good clinical outcome as defined of mRS 0-2 (dashed line). mRS, modified Rankin Scale; OR, odds ratio.*

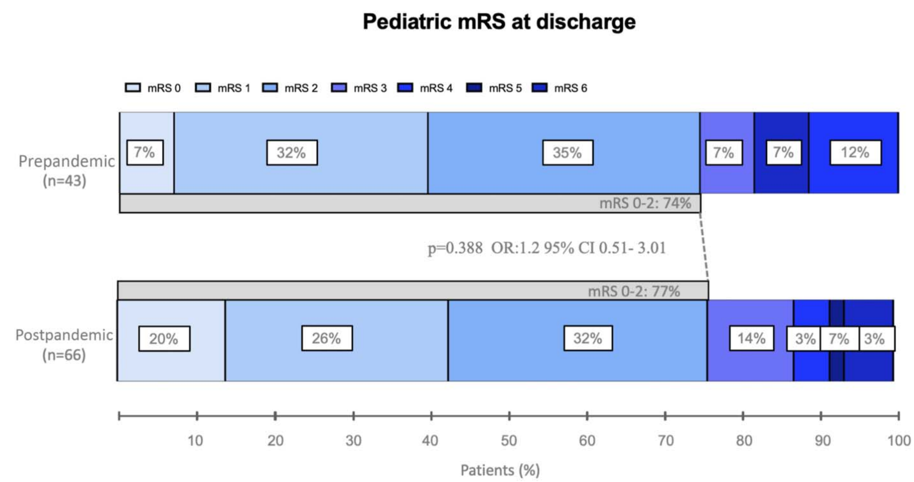

FIGURE 4. *Distribution of pediatric mRS scores at 3 months in 96 children with neurosurgical intervention for intracranial infection. 17 patients were lost to follow-up. Comparison of the functional outcomes of 96 pediatric patients at hospital discharge, as assessed by the pediatric mRS. Scores range from 0 (no symptoms) to 6 (death). No statistical significance in good clinical outcome as defined of mRS 0-2 (dashed line). mRS, modified Rankin Scale; OR, odds ratio.*

study introduces the possibility of selection bias, as differences in health care–seeking behavior, diagnostic intensity, or hospital admission criteria. Furthermore, residual confounding from unmeasured variables, such as differences in socioeconomic status, access to early intervention services, or preexisting neurodevelopmental conditions, might all have influenced both the risk of specific deficits and the likelihood of hospitalization.

Our analysis revealed no statistically significant differences in inflammatory markers—maximum temperature, CRP, white blood cell count (in univariate but nonsignificant in the multivariate analysis), and PCT—between the prepandemic and postpandemic cohorts. This lack of significance may reflect several factors. Systemic inflammation parameters such as CRP and PCT are nonspecific indicators of inflammation and may not correlate directly with localized neurological injury. For example, a brain abscess or focal meningitis can cause significant cortical damage (eg, aphasia) without markedly elevating systemic inflammatory markers, particularly if the infection is contained or treated empirically before laboratory results. These results underscore that neurological deficits in intracranial infections are not solely dictated by systemic inflammation but may instead reflect localized neuroanatomical damage, pathogen-specific virulence mechanisms, or care-seeking delays.[28] The dissociation between clinical presentation and laboratory findings highlights the need for comprehensive neuroimaging and targeted microbiological testing to guide management, even in cases with "unremarkable" inflammatory markers.

The lack of significance in imaging parameters may reflect several underlying factors. First, pathogen-driven pathophysiological processes (eg, abscess formation, meningeal inflammation) likely remained stable over time, as the microbiological profile (eg, *Streptococcus intermedius* predominance) did not differ markedly between cohorts. These results reinforce that neurological deficits are not solely dictated by gross structural findings on imaging. Instead, they may arise from subtle differences in lesion localization, timing of intervention, or host neuroplasticity—factors not fully captured by conventional radiological categories.[22,25] For instance, a small abscess in Broca area could cause profound aphasia without midline shift or ventriculitis, whereas a larger lesion in a noneloquent region might present with paresis due to mass effect.

Although our study found no significant differences in neurosurgical management or outcomes for pediatric intracranial infections between pre- and postpandemic cohorts, broader literature reports a significant decline in elective and nonurgent pediatric neurosurgeries during the pandemic, including shunt revisions, epilepsy procedures, and trauma surgeries.[29-31] Unlike shunt revisions or epilepsy surgeries—which are often scheduled electively—intracranial infections (eg, abscesses, empyema) demand immediate neurosurgical intervention to prevent mortality or irreversible neurological damage.

In our analysis *Streptococcus intermedius* was identified as the predominant pathogen in pediatric intracranial abscesses similar to Hoyer et al,[3] who emphasized the critical role of the *Streptococcus anginosus* group, particularly *S. intermedius*, in brain abscess formation. This pathogen is known for its pyogenic potential and association with deep-seated infections, often originating from dental, sinus, or gastrointestinal sources. The virulence of *S. intermedius* is attributed to its ability to produce biofilms and tissue-degrading enzymes such as hyaluronidase and collagenase, which facilitate invasion and abscess formation.[1,32,33] Our analysis therefore reinforce the clinical importance of considering *Streptococcus anginosus* group pathogens in cases of pediatric intracranial infection.

Despite the existing literature, the current understanding of intracranial infections in pediatric population remains inadequate, primarily due to the rarity of cases and the absence of robust clinical trials. While early pandemic data confirmed the rarity of severe acute SARS-CoV-2 infection in children who exhibited rapid recovery and no reported fatalities—this study addresses a critical gap in understanding delayed, multifactorial complications that could not be assessed in initial observational studies. The mild acute phase of pediatric SARS-CoV-2 infection contrasts starkly with emerging evidence of postinfectious sequelae, such as intracranial infections linked to sinusitis and otitis.

Limitations

This study has several limitations. Due to its retrospective and multicenter design, variations in clinical documentation, follow-up routines, and imaging protocols between centers may have influenced data consistency. Moreover, pandemic-related changes in healthcare structures were not fully accounted for and may have impacted the observed incidence trends. Despite these limitations, the study provides important national-level insights into the evolving burden of pediatric intracranial infections requiring neurosurgical treatment.

CONCLUSION

Pediatric intracranial infections are rare, and pediatric studies are often underpowered because of low case numbers. Our study provides robust comparative data, demonstrating that systemic inflammatory markers, imaging profiles, and surgical management remained consistent between pre- and postpandemic cohorts, despite broader declines in elective pediatric neurosurgical volumes. These findings underscore the resilience of emergency neurosurgical care during the pandemic and the stability of pathogen behavior in these time-sensitive infections.

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