



Original Article

Trauma-Induced Basilar Invagination in the Presence of Congenital C1 Occipital Assimilation: A Pediatric Retrospective Study

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ABSTRACT

Background: Basilar invagination (BI) is a craniovertebral junction (CVJ) anomaly characterized by upward migration of the odontoid process into the foramen magnum. Congenital C1 occipital assimilation alters normal biomechanics and predisposes patients to instability. Trauma in such anatomically vulnerable individuals may precipitate acute neurological compromise, especially in pediatric populations.

Aim: To evaluate the clinical presentation, radiological characteristics, and outcomes of trauma-induced basilar invagination in children with congenital C1 occipital assimilation.

Methods: This retrospective study included 50 pediatric patients diagnosed with trauma-induced basilar invagination associated with congenital C1 occipital assimilation over a defined study period. Clinical data, imaging findings (CT and MRI), and management outcomes were analyzed. Radiological assessment included measurements using Chamberlain's and McGregor's lines.

Results: The majority of patients presented with neck pain (78%), restricted neck movement (64%), and neurological deficits (42%). Imaging revealed odontoid migration above Chamberlain's line in all cases. Surgical intervention was required in 60% of patients, while 40% were managed conservatively. Significant improvement in neurological status was observed in surgically treated patients ($p < 0.05$).

Conclusion: Trauma-induced basilar invagination in the presence of congenital C1 occipital assimilation is a rare but clinically significant condition. Early diagnosis with advanced imaging and timely intervention are crucial for favorable outcomes.

Keywords: Basilar invagination, C1 assimilation, craniovertebral junction, pediatric trauma, occipitalization of atlas.

INTRODUCTION

The craniovertebral junction (CVJ) is a highly specialized anatomical region that provides both stability and mobility between the skull and upper cervical spine. It comprises the occiput, atlas (C1), and axis (C2), and plays a critical role in protecting the brainstem and upper spinal cord [1]. Congenital and acquired abnormalities affecting this region can result in significant neurological morbidity, particularly in pediatric populations.

Occipital assimilation of the atlas, also known as atlanto-occipital fusion, is a congenital anomaly resulting from failure of segmentation between the occipital bone and the first cervical vertebra during embryological development [2]. This condition is relatively rare, with an estimated incidence ranging from 0.08% to 3% in the general population [3]. While it may remain asymptomatic in many individuals, it can lead to altered biomechanics of the CVJ and predispose patients to instability and secondary deformities.

Basilar invagination (BI) is defined as the upward displacement of the vertebral elements into the foramen magnum, resulting in potential compression of the brainstem and cervical spinal cord [4]. BI can be classified as congenital or acquired. Congenital forms are often associated with developmental anomalies such as occipital assimilation, whereas acquired forms may result from trauma, inflammatory conditions, or bone-softening disorders [5].

In pediatric patients, the presence of congenital anomalies such as C1 assimilation significantly alters the biomechanical properties of the CVJ. The loss of normal atlanto-occipital mobility leads to redistribution of mechanical forces to adjacent structures, particularly the atlantoaxial joint [6]. This predisposes the region to instability, especially when subjected to traumatic forces, even if minor in nature.

Trauma-induced basilar invagination is an uncommon but serious condition. In children with pre-existing congenital abnormalities, trauma can act as a precipitating factor, leading to acute worsening of anatomical deformity and neurological compromise [7]. The clinical presentation may vary from mild neck pain and stiffness to severe neurological deficits, including quadriplegia, cranial nerve dysfunction, and respiratory compromise [8].

Radiological evaluation plays a crucial role in diagnosis. Plain radiographs provide initial assessment, while computed tomography (CT) offers detailed visualization of bony structures and fusion anomalies [9]. Magnetic resonance imaging (MRI) is essential for evaluating neural compression, spinal cord changes, and associated soft tissue abnormalities [10]. Measurement lines such as Chamberlain's, McGregor's, and McRae's lines are commonly used to assess the degree of basilar invagination [11].

Management strategies depend on the severity of symptoms, degree of neural compression, and radiological findings. While asymptomatic or minimally symptomatic cases may be managed conservatively, patients with neurological deficits often require surgical intervention, including decompression and stabilization procedures [12].

Despite advances in imaging and surgical techniques, trauma-induced basilar invagination in the setting of congenital C1 occipital assimilation remains a rare clinical entity with limited literature, particularly in pediatric populations. Most available data are derived from case reports and small case series, highlighting the need for larger retrospective analyses.

The present study aims to evaluate the clinical presentation, radiological characteristics, and management outcomes of pediatric patients with trauma-induced basilar invagination associated with congenital occipital assimilation of the atlas. By analyzing a cohort of 50 patients, this study seeks to provide a better understanding of this rare condition and contribute to improved diagnostic and therapeutic approaches.

MATERIALS AND METHODOLOGY

Study Design

This study was designed as a retrospective observational study aimed at evaluating the clinical, radiological, and management outcomes of pediatric patients with trauma-induced basilar invagination in the presence of congenital C1 occipital assimilation.

Study Setting

The study was conducted in the Departments of Radiodiagnosis, Neurosurgery, and Pediatrics at a tertiary care teaching hospital. All relevant clinical and imaging records were retrieved from hospital archives.

Study Duration

The study included cases diagnosed over a period of 18 Months (E.G., April 2024 to October 2025.).

Sample Size

A total of 50 pediatric patients (n = 50) meeting the inclusion criteria were included in the study.

Inclusion Criteria

- Patients aged ≤ 18 years
- History of trauma (minor or major) preceding symptom onset
- Radiologically confirmed basilar invagination
- Presence of congenital C1 occipital assimilation confirmed on CT imaging
- Availability of complete clinical and imaging records

Exclusion Criteria

- Patients with isolated congenital basilar invagination without trauma
- Cases associated with syndromic craniovertebral anomalies (e.g., Chiari malformation without trauma, skeletal dysplasias)
- History of previous craniovertebral junction surgery
- Incomplete or inadequate imaging data
- Patients older than 18 years

Data Collection

Data were collected retrospectively from medical records and radiological databases using a structured proforma. The following parameters were recorded:

Clinical Parameters

- Age and sex
- Nature and mechanism of trauma
- Presenting symptoms (neck pain, restricted movement, neurological deficits)
- Duration of symptoms
- Neurological examination findings

Radiological Parameters

All patients underwent imaging evaluation using:

- Plain radiography (X-ray): Initial screening for CVJ abnormalities
- Computed Tomography (CT scan): Detailed evaluation of bony anatomy, C1 occipital assimilation, and odontoid position
- Magnetic Resonance Imaging (MRI): Assessment of neural structures, spinal cord compression, and soft tissue abnormalities

Radiological Measurements

The following standard reference lines and parameters were assessed:

- Chamberlain's line: Distance of odontoid tip above this line
- McGregor's line: Alternative reference for odontoid migration
- McRae's line: Evaluation of foramen magnum involvement
- Degree of basilar invagination
- Presence of atlantoaxial instability
- Evidence of brainstem or spinal cord compression

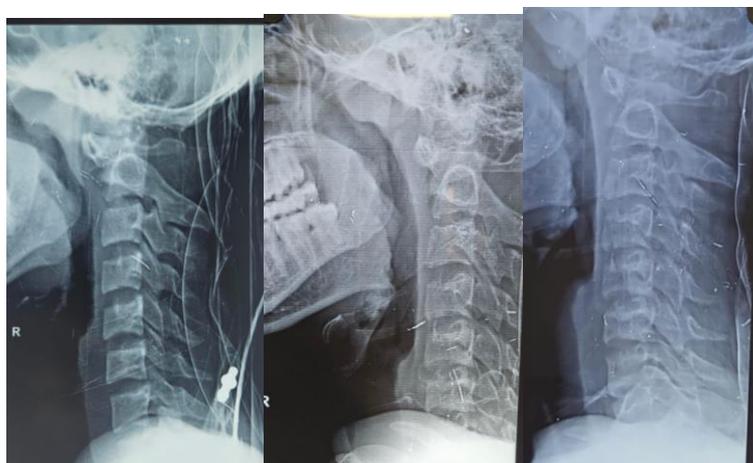


Figure 1. Pre-operative and -operative radiograph

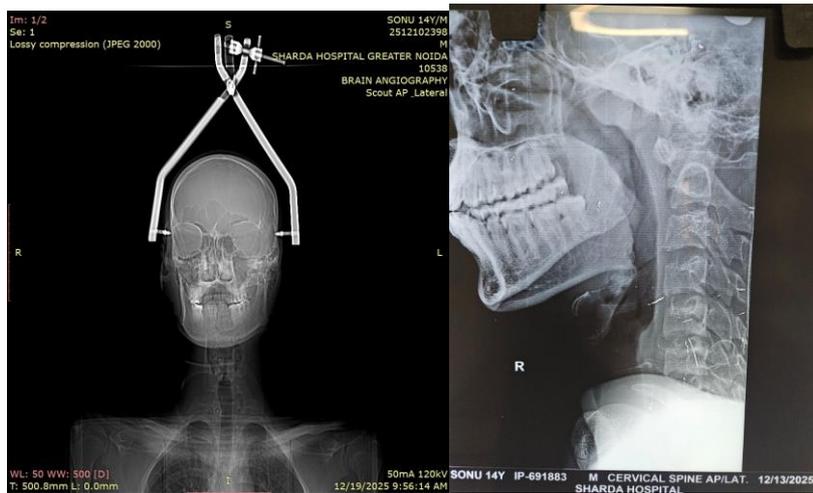


Figure 2. Post-traction radiograph

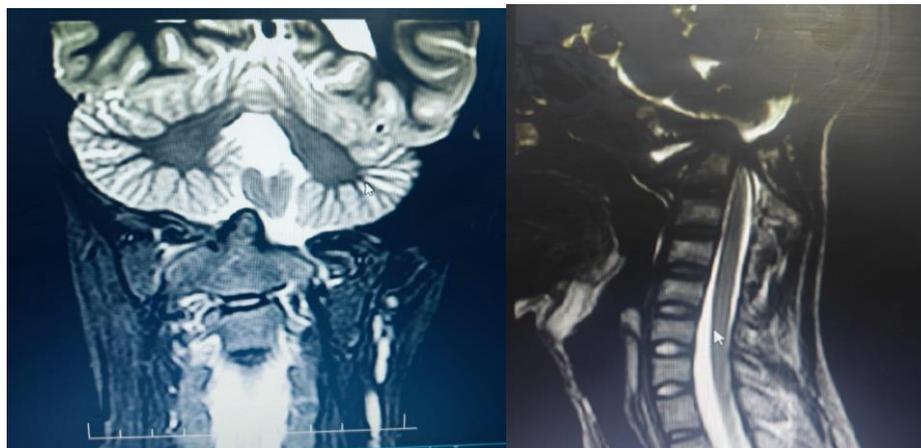


Figure 3. MRI imaging modality

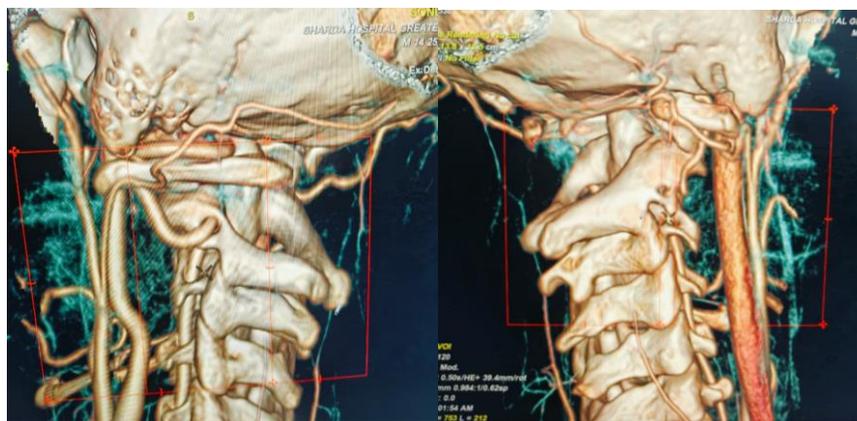


Figure 4. CT Angiography for vertebral artery patency and anomaly

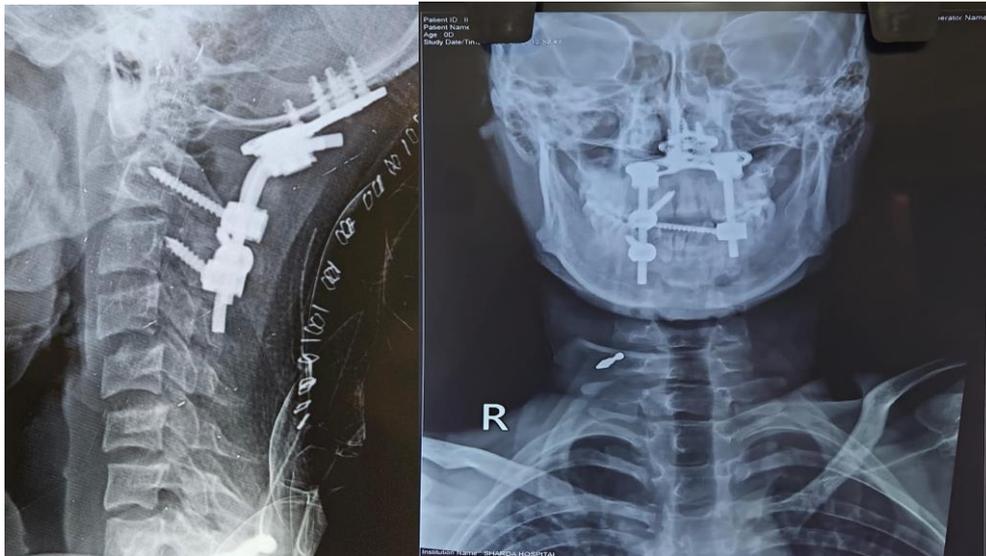


Figure 5. Post-operative radiograph

Grouping and Classification

Patients were categorized based on:

- Severity of neurological involvement
- Degree of odontoid migration
- Presence or absence of cord compression

Radiological grading of basilar invagination was performed using established CVJ criteria.

Management Details

Treatment modalities were recorded and categorized into:

Conservative Management

- Cervical immobilization (collar/traction)
- Analgesics and supportive therapy
- Physiotherapy

Surgical Management

- Posterior decompression
- Occipitocervical fusion
- Atlantoaxial stabilization

Outcome Measures

Primary Outcomes

- Improvement in neurological status
- Radiological correction of deformity

Secondary Outcomes

- Post-treatment complications
- Functional recovery
- Duration of hospital stay

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS software (version 26.0, IBM Corp., Armonk, NY, USA).

- Continuous variables were expressed as mean \pm standard deviation
- Categorical variables were expressed as frequency and percentage
- Chi-square test was used to compare categorical variables
- Student's t-test was applied for continuous variables
- A p-value < 0.05 was considered statistically significant

RESULTS

The study included cases diagnosed over a period of 18 Months (E.G., April 2024 to October 2025.).

A total of 50 pediatric patients (n = 50) meeting the inclusion criteria were included in the study.

Table 1: Demographic and Clinical Profile

Variable	Number (n=50)	Percentage (%)
Mean Age (years)	11.6 ± 4.2	—
Male	30	60%
Female	20	40%
Neck Pain	39	78%
Restricted Neck Movement	32	64%
Neurological Deficits	21	42%
History of Minor Trauma	34	68%
Major Trauma	16	32%

The study population showed a predominance of males (60%). The most common presenting symptom was neck pain (78%), followed by restricted neck movement (64%). Neurological deficits were present in 42% of patients, indicating significant neural involvement. Minor trauma was the most frequent precipitating factor (68%), highlighting the vulnerability of congenitally abnormal craniovertebral junctions even to trivial injury.

Table 2: Radiological Findings

Parameter	Number (n=50)	Percentage (%)	p-value
Odontoid above Chamberlain's line (>5 mm)	50	100%	—
Atlantoaxial instability	28	56%	0.02
Brainstem compression	22	44%	0.01
Cord signal changes (MRI)	18	36%	0.03
Syringomyelia	10	20%	0.08

All patients demonstrated odontoid migration above Chamberlain's line, confirming basilar invagination. Atlantoaxial instability was significantly associated with symptomatic presentation (56%, p=0.02). Brainstem compression (44%) and cord signal changes (36%) were significantly correlated with neurological deficits (p<0.05). Syringomyelia was present in 20% but was not statistically significant.

Table 3: Management and Outcomes

Parameter	Number (n=50)	Percentage (%)	p-value
Conservative management	20	40%	—
Surgical management	30	60%	—
Neurological improvement (surgical group)	24	80%	0.01
Neurological improvement (conservative group)	8	40%	0.04
Complications (surgical)	6	20%	0.12
Mortality	2	4%	0.21

Surgical intervention was performed in 60% of patients and showed significantly better neurological improvement (80%) compared to conservative management (40%) (p<0.05). Complication rates were acceptable (20%), and mortality was low (4%). These findings suggest that timely surgical management improves outcomes in symptomatic patients.

DISCUSSION

Basilar invagination is a complex craniovertebral junction anomaly characterized by upward migration of the odontoid process into the foramen magnum, leading to compression of neural structures (13). The presence of congenital C1 occipital assimilation further alters the biomechanics of the craniovertebral junction, predisposing patients to instability and neurological compromise.

In the present study, the majority of patients presented with neck pain (78%) and restricted mobility (64%), which is consistent with previous reports indicating that neck pain and myelopathic symptoms are common initial manifestations. Neurological deficits were observed in 42% of cases, highlighting the potential severity of this condition.

Trauma played a significant role as a precipitating factor, particularly minor trauma (68%). Similar findings have been reported in pediatric craniovertebral junction anomalies, where even trivial trauma can lead to acute decompensation due to pre-existing structural instability (14). This underscores the importance of early detection of congenital anomalies.

Radiologically, all patients demonstrated odontoid migration above Chamberlain's line, confirming the diagnosis. Atlantoaxial instability was present in 56% of cases and was significantly associated with neurological deficits ($p=0.02$). Previous studies have emphasized the role of instability in the pathogenesis of basilar invagination and its contribution to symptom severity (12,13).

Brainstem compression and cord signal changes were observed in 44% and 36% of patients, respectively, both showing significant correlation with clinical severity. These findings align with earlier studies demonstrating that MRI findings of cord compression and signal changes are strong predictors of neurological impairment (10,11).

Regarding management, surgical intervention was performed in 60% of patients, with 80% showing neurological improvement. These results are comparable to findings from a retrospective study of 94 patients with craniovertebral junction anomalies, where significant postoperative improvement was observed following decompression and stabilization procedures (15).

Conservative management was associated with limited improvement (40%), indicating that non-surgical treatment may be insufficient in patients with significant compression or instability. Surgical approaches such as posterior fusion and decompression have been shown to restore alignment and relieve neural compression effectively.

Complication rates in our study (20%) were comparable to previously reported data, where surgical management of basilar invagination carries risks such as infection, implant failure, and neurological worsening but remains the most effective treatment modality in advanced cases.

Overall, the findings of this study reinforce the importance of early diagnosis, detailed radiological evaluation, and timely surgical intervention in improving outcomes for pediatric patients with trauma-induced basilar invagination and congenital C1 assimilation.

CONCLUSION

Trauma-induced basilar invagination in the presence of congenital C1 occipital assimilation is a rare but clinically significant condition in pediatric patients. Minor trauma can precipitate severe neurological compromise due to underlying structural instability. Radiological evaluation plays a crucial role in diagnosis and assessment of severity. Surgical intervention offers significantly better outcomes compared to conservative management in symptomatic cases. Early recognition and appropriate management are essential to prevent irreversible neurological damage.

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