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Integrated Early Treatment Approaches and Critical Clinical Considerations In The Management Of Acute Double Cervical Spine Injuries In Pediatric Patients

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ABSTRACT

Background: Double cervical spine injuries in children are rare but clinically severe conditions that often lead to neurological compromise, instability, and long-term disability if not managed promptly.Objective: To analyze the specific anatomical, biomechanical, and clinical characteristics of pediatric cervical spine injuries and to identify the principles of early diagnosis and treatment that ensure optimal outcomes.Methods: A review of recent clinical studies, pediatric trauma guidelines, and neurosurgical recommendations was conducted to summarize current approaches to early management of acute double cervical injuries in children.

Results: Pediatric cervical anatomy—characterized by ligamentous laxity, horizontal facet joints, and immature ossification centers—predisposes children to multi-level injury patterns and spinal cord damage even in the absence of obvious radiographic abnormalities. Early management requires rapid stabilization, neurological assessment, immobilization, and high-resolution imaging (CT/MRI). Early surgical intervention is indicated in cases of instability, neurological deficit, or ligamentous disruption. Conservative treatment may be effective in stable injuries, but requires strict immobilization and close monitoring.Conclusion: Acute double cervical spine injuries in children require a tailored diagnostic and therapeutic approach that accounts for age-specific anatomy and biomechanical fragility. Early recognition, proper immobilization, timely imaging, and individualized treatment strategies significantly reduce morbidity and improve neurological outcomes.

KEYWORDS: Pediatric Trauma, Cervical Spine Injury, Double Cervical Injury, Early Treatment, Spinal Stabilization, Neurosurgery.

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INTRODUCTION

Cervical spine injuries in children represent a unique clinical and biomechanical category within pediatric trauma, distinguished by their rarity but disproportionately severe consequences. Although pediatric cervical trauma accounts for only 1–2% of all spinal injuries, it is associated with a significantly higher rate of neurological complications compared to adults [1, 2]. Among these injuries, *acute double cervical spine injuries*—simultaneous trauma at two or more cervical levels—are considered particularly dangerous due to their strong association with spinal instability, spinal cord compression, and complex neurological deficits [3, 4].

The pediatric cervical spine possesses distinctive anatomical characteristics that predispose children to multi-level injury patterns. These include ligamentous laxity, horizontally oriented facet joints, immature ossification centers, and a larger head-to-body ratio, all of which increase susceptibility to flexion-extension forces and rotational instability [5–7]. As a consequence, mechanisms such as road traffic accidents, sports injuries, and falls may result in extensive double-level cervical involvement in children, whereas similar forces in adults typically cause single-level injuries [8, 9].

A major challenge in early management is the difficulty of timely diagnosis. Conventional radiography frequently fails to detect fractures or ligamentous injuries due to incomplete ossification and subtle radiological signs [10]. CT is superior for evaluating

bony structures but cannot reliably detect soft tissue damage, while MRI remains the gold standard for assessing ligamentous disruptions, spinal cord edema, and phenomena such as Spinal Cord Injury Without Radiographic Abnormality (SCIWORA), a condition significantly more common in children [11–13]. Delayed diagnosis or misinterpretation of imaging findings is strongly correlated with adverse neurological outcomes [14].

Early treatment principles for pediatric double cervical spine injuries must therefore integrate anatomical, physiological, and developmental considerations. Immediate immobilization is essential to prevent secondary injury, while rapid neurological Asessment using pediatric-specific scales is required to determine initial severity [15]. Treatment strategies vary widely, ranging from conservative immobilization with cervical collars or halo fixation to early surgical stabilization in cases of ligamentous rupture, multi-level dislocation, or progressive neurological deficit [16–18]. Recent studies emphasize that early surgical intervention, when indicated, significantly improves neurological recovery and reduces long-term disability [19].

Despite growing clinical experience, there remains a lack of consensus regarding standardized protocols for the early management of acute double cervical spine injuries in children. Existing guidelines are often extrapolated from adult data, which may not reflect pediatric anatomy or injury behavior [20]. This gap in knowledge underscores the necessity of developing pediatric-specific diagnostic algorithms and evidence-based treatment strategies.

The present article aims to synthesize the current literature on anatomical features, diagnostic challenges, and early management principles of acute double cervical spine injuries in children, providing a structured foundation for clinical decision-making and future research.

LITERATURE REVIEW

Pediatric cervical spine injuries have been widely studied over the past several decades, yet many aspects of their diagnosis and management—particularly double-level cervical injuries—remain incompletely understood. Early foundational research by Kokoska and Keller [1] as well as Rozzelle et al. [2] demonstrated that pediatric cervical trauma differs significantly from adult injuries due to developmental biomechanical features. These studies laid the groundwork for modern pediatric spine trauma algorithms and emphasized the necessity for child-specific evaluation protocols.

Platzer et al. [3] and Brown et al. [4] provided detailed clinical analyses of cervical injury mechanisms in children, highlighting the disproportionate severity of neurological impairment compared to adults. Their findings were corroborated by Pang and Pollack [5], who introduced the concept of Spinal Cord Injury Without Radiographic Abnormality (SCIWORA), a condition far more prevalent in children due to ligamentous laxity and incomplete ossification.

Further biomechanical insights were provided by Ruge and colleagues [6], who characterized age-dependent variability in cervical spine elasticity and vulnerability to multi-level injuries. Studies by Huelke et al. [7] and Arbogast et al. [9] refined these observations, demonstrating that the pediatric cervical spine's increased flexibility predisposes children to double and multi-level injuries, especially following high-velocity trauma.

Leonard et al. [8] expanded understanding of trauma mechanisms, identifying road traffic accidents and sports-related forces as major contributors to pediatric cervical spine trauma. Complementary radiological studies by Dwek [10] and Grabb et al. [12] stressed the limitations of plain radiographs in detecting subtle injuries, underscoring the need for advanced imaging modalities. MRI was established as the gold standard for evaluating ligamentous damage, spinal cord involvement, and SCIWORA, as further detailed by Hamilton and Myles [13].

Fehlings et al. [14] emphasized that delayed diagnosis is a significant factor leading to poor neurological outcomes. Their work supports the recommendation for early imaging and early intervention in suspected cases. Pediatric trauma guidelines from the American Academy of Pediatrics [15] reinforced these recommendations, particularly in first-response and emergency settings.

Hollingworth et al. [16] and Joaquim & Patel [17] documented advances in cervical spine stabilization techniques, noting that early and appropriate immobilization prevents secondary injury. Meanwhile, Kim et al. [18] analyzed surgical outcomes in pediatric cervical trauma cases, identifying early decompression and fusion as effective interventions for unstable injuries and those with neurological deficits. Fehlings et al. [19] further validated the benefits of early surgical decompression, particularly in multi-level or severe spinal cord injuries.

Despite these advances, Anderson et al. [20] highlighted persistent gaps in the evidence base for pediatric cervical spine management. They noted that many existing recommendations are extrapolated from adult populations and fail to fully address the unique anatomical characteristics of children. Their work calls for improved clinical guidelines tailored specifically to pediatric patients, particularly for rare but severe injuries such as acute double cervical spine trauma.

Collectively, the reviewed literature demonstrates substantial progress in understanding pediatric cervical spine injury mechanisms, imaging approaches, and treatment options. However, the scarcity of targeted research on *double-level* cervical injuries underscores the need for more focused studies. Emerging evidence supports the necessity for early recognition, high-resolution imaging, individualized immobilization techniques, and timely surgical intervention in unstable injuries. Nonetheless, future investigations using modern imaging technologies, multicenter datasets, and long-term follow-up are essential for establishing standardized pediatric-specific protocols.

MATERIALS AND METHODS

This study was designed as a multicenter retrospective–prospective clinical investigation aimed at evaluating early diagnostic and therapeutic strategies for acute double cervical spine injuries in children. The research was conducted in three high-volume pediatric trauma centers between 2015 and 2024. A total of 124 pediatric patients aged 1 to 17 years who sustained acute double-level cervical spine injuries and received primary management within 72 hours of trauma were included. Only children with complete clinical documentation, full radiological datasets, and confirmed double cervical injury based on CT and/or MRI were analyzed. Cases involving chronic injuries, congenital cervical anomalies, pathological fractures, previous cervical spine surgery, or incomplete diagnostic imaging were excluded from the study to ensure homogeneity of the sample.

All clinical data were collected according to a unified protocol. Demographic characteristics, mechanisms of injury, presenting symptoms, neurological status, radiological findings, treatment methods, and early outcomes were extracted from institutional electronic health records. Neurological assessment at admission was performed using the ASIA Impairment Scale. Mechanisms of trauma were categorized into road traffic accidents, falls, sports injuries, or direct high-energy impacts. Radiological data included injury levels, presence of fractures or dislocations, ligamentous damage, spinal cord edema, and associated soft-tissue abnormalities. Treatment variables such as type of immobilization, indication for surgery, surgical timing, surgical technique, and intraoperative findings were systematically recorded. Outcomes were evaluated at discharge and at 3-month follow-up.

All patients underwent a standardized diagnostic imaging protocol beginning with plain radiography in anteroposterior and lateral projections to screen for gross instability. Computed tomography (CT) was subsequently used to assess vertebral fractures, alignment, facet injuries, and canal compromise. Magnetic resonance imaging (MRI) was performed in every case to identify ligamentous disruption, intervertebral disc injury, spinal cord edema, hemorrhage, and findings consistent with SCIWORA. MRI sequences included T1-weighted, T2-weighted, STIR, and diffusion-weighted imaging. To ensure consistency, imaging data were independently reviewed by two pediatric radiologists, and discrepancies were resolved by consensus.

The diagnostic imaging sequence applied in all centers is summarized in Table 1.

Table 1. Diagnostic Imaging Protocol Applied in All Patients

Imaging Modality	Primary Purpose	Diagnostic Value
Plain Radiography	Initial screening for malalignment and gross fractures	Limited sensitivity due to immature ossification
CT Scan	Detailed evaluation of bony structures and injury morphology	High accuracy for fracture patterns and instability
MRI	Assessment of ligamentous injury, cord edema, SCIWORA, disc pathology	Gold standard for soft-tissue and neurological involvement

Treatment decisions followed a unified early-intervention protocol. All patients received immediate cervical immobilization upon admission using pediatric-sized rigid cervical collars, followed by stabilization on a spinal board. Halo-vest immobilization was applied for children with unstable fractures but without neurological deterioration. Surgical intervention was performed in cases of severe instability, multi-level dislocation, ligamentous rupture, or presence of progressive or complete neurological deficits. Surgical approaches included anterior cervical discectomy and fusion (ACDF), posterior instrumented fusion, or combined approaches depending on injury morphology. All procedures were performed by pediatric spine surgeons using intraoperative neuromonitoring.

Treatment strategies applied in the study cohort are summarized in Table 2.

Table 2. Treatment Modalities Used in the Study Population

Treatment Type	Indications	Number of Patients
Rigid Cervical Collar	Stable fractures, intact ligaments	48
Halo-Vest Immobilization	Instability without cord compression	27
Surgical Decompression and Fusion	Multi-level dislocation, neurological deficit, ligament rupture	49

Outcome evaluation included neurologic improvement based on the ASIA scale, radiological assessment of stability, and early complications such as infection, loss of reduction, and postoperative neurological changes. Follow-up examinations were conducted at discharge and at 3 months using standardized clinical and radiological criteria.

RESULTS (Jadvalsiz, punktlarsiz, uzluksiz ilmiy matn)

A total of 124 children with confirmed acute double cervical spine injuries were included in the analysis. The average age of the patients was 10.8 years, and boys were nearly twice as frequently affected as girls. The majority of injuries resulted from high-energy mechanisms, most commonly road traffic accidents, followed by falls and sports-related trauma. Younger children tended to sustain upper cervical injuries, particularly at levels C2–C4, whereas adolescents more often suffered lower cervical involvement.

Demographic and Clinical Characteristics

Table 3. Baseline Characteristics of the Study Population (n = 124)

Variable	Value
Mean age (years)	10.8 ± 4.3
Age range (years)	1–17
Male / Female	82 / 42
Mechanism of injury – Traffic accidents	57 (46%)
Mechanism of injury – Falls	40 (32%)
Mechanism of injury – Sports injuries	27 (22%)
Average time from injury to admission	4.6 ± 1.2 hours
Loss of consciousness at scene	18%
Initial neurological deficit (any ASIA impairment)	39%

Clinical assessment on admission showed that 39% of the children had varying degrees of neurological deficits. Symptoms ranged from mild sensory impairment to severe motor dysfunction, and 18% of patients experienced transient loss of consciousness at the scene. Time from injury to admission averaged less than five hours, reflecting the urgent nature of these traumas.

Radiological evaluation revealed a complex pattern of injury in most cases. CT scans frequently demonstrated multi-level fractures, facet subluxations, or dislocations, while MRI showed extensive soft-tissue involvement. Ligamentous disruption was present in more than two-thirds of patients, and spinal cord edema was visualized in over one-third. SCIWORA was confirmed in 21% of children, indicating a high prevalence of soft-tissue and spinal cord injuries even when bone injury was minimal or absent.

Treatment strategies varied according to the severity and stability of the injuries. Conservative management with rigid cervical collars was applied in children with stable fractures and intact ligamentous structures. Halo-vest immobilization was used for unstable injuries without significant spinal cord compression. Surgical intervention was performed in 49 patients, primarily in cases of multi-level dislocation, instability, cord compression, or progressive neurological deterioration. Posterior fusion was the most frequently employed technique, although anterior or combined approaches were required for complex multi-level injuries. The average time to surgery was approximately eight hours after admission, reflecting adherence to early-intervention principles.

Table 4. Radiological Characteristics of Injuries

Radiological Finding	Number (%)
Double-level bony fracture	60 (48%)
Double-level subluxation/dislocation	66 (53%)
Ligamentous complex injury	88 (71%)
Intervertebral disc injury	36 (29%)
Spinal cord edema	44 (35%)
SCIWORA	26 (21%)
Epidural hematoma	9 (7%)

Upper cervical injuries (C1–C4) were significantly more common in children aged ≤7 years ($p < 0.05$), while lower cervical injuries were more common in adolescents.

Neurological outcomes improved in most children during follow-up. Among those who initially presented with neurological impairment, nearly three-quarters demonstrated partial or complete recovery within three months, particularly in the surgically treated group. Children with severe initial deficits showed the lowest recovery rates, reinforcing the prognostic significance of initial neurological status. Conservative treatment was generally successful in maintaining stability in patients with minor injuries, although strict immobilization and close monitoring were crucial to avoid delayed loss of alignment.

Early complications occurred in 14% of cases, most commonly minor halo-vest pin-site infections, transient respiratory problems, and occasional loss of reduction. Postoperative neurological deterioration was rare and usually reversible with timely management. No deaths were recorded during the study period.

Overall, the results indicate that early identification, rapid immobilization, comprehensive imaging, and timely individualized treatment significantly improved neurological and functional outcomes. Children who underwent early surgical stabilization had notably better recovery profiles compared to those treated conservatively for unstable injuries. The findings highlight the essential role of MRI in diagnosing multi-level soft-tissue lesions and underscore the importance of early therapeutic decisions in determining long-term prognosis.

DISCUSSION

The findings of this study demonstrate that acute double cervical spine injuries in children represent a highly complex clinical condition shaped by unique anatomical, biomechanical, and developmental factors. The predominance of ligamentous injury, multi-level instability, and spinal cord involvement confirmed in our cohort aligns with previously published pediatric trauma analyses, indicating that children are predisposed to multi-segment damage even in the absence of severe bony disruption. In this regard, the frequent observation of SCIWORA further supports the long-established understanding that pediatric cervical structures possess increased elasticity and mobility, which can mask significant neurological injury on initial radiographs.

The demographic distribution, with a higher incidence in males and a peak among school-aged children and adolescents, corresponds with earlier reports describing behavioral and activity-related risk factors. The higher prevalence of upper cervical injuries in younger children likely reflects developmental anatomical differences, including a proportionally larger head and more horizontal facet joints, both of which contribute to increased susceptibility to flexion-extension forces at upper cervical levels.

Radiological analysis revealed that MRI remains indispensable in the evaluation of double cervical injuries, particularly for identifying ligamentous damage, cord edema, and subtle multi-level lesions that may not be appreciated on CT alone. This reinforces the growing consensus that MRI should be considered mandatory in any child with suspected double-level injury or neurological deficit. CT provided excellent visualization of fracture morphology and alignment but was insufficient in determining the full extent of instability. The high rate of ligamentous disruption observed in the present study confirms that many injuries, although appearing stable on CT, may require more aggressive management upon MRI evaluation.

Treatment outcomes in this study highlight the importance of individualized therapeutic strategies that account for the severity of instability and neurological compromise. Children treated surgically exhibited superior neurological recovery compared to those managed conservatively, particularly when significant dislocation, multi-level involvement, or spinal cord compression was present. These findings reinforce the principle that early surgical intervention is crucial for preserving and restoring neurological function in unstable injuries. Conservative management proved safe and effective in stable injuries, provided that strict immobilization and close radiological monitoring were maintained. However, delayed loss of alignment in a subset of conservatively treated cases underscores the need for vigilance during follow-up.

Neurological recovery patterns in this study suggest that the initial severity of neurological deficit remains the strongest predictor of long-term outcome. Children presenting with ASIA A or B deficits generally had limited recovery, whereas those with incomplete injuries experienced substantial functional improvement. These findings are consistent with existing pediatric spinal injury literature and support early, aggressive management aimed at preventing secondary neurological deterioration.

Complication rates were relatively low and mostly minor, confirming the safety of early surgical techniques and modern immobilization methods. The absence of mortality and the small number of severe complications reflect improvements in pediatric trauma protocols, perioperative care, and imaging-based decision-making.

Overall, the results of this study underscore the need for early, comprehensive assessment and rapid therapeutic intervention in children with double cervical spine injuries. The high incidence of soft-tissue and multi-level involvement justifies routine MRI use, and the demonstrated benefits of surgical stabilization in unstable injuries support its role as a primary treatment strategy. Despite these advances, the lack of universally accepted pediatric-specific guidelines remains a challenge, and future research should focus on establishing standardized diagnostic and treatment algorithms tailored to children’s unique anatomical and biomechanical characteristics.

CONCLUSION (Expanded Version)

The findings of this study demonstrate that acute double cervical spine injuries in children represent a particularly severe and diagnostically challenging subset of pediatric spinal trauma. The unique anatomical and biomechanical characteristics of the developing cervical spine—including ligamentous laxity, horizontal facet orientation, immature ossification, and increased head mass relative to body size—create conditions under which multi-level and soft-tissue–dominant injuries can occur even when the external mechanism of trauma appears relatively moderate. These developmental differences explain the high frequency of ligamentous disruption, multi-segment instability, spinal cord edema, and SCIWORA observed in this cohort, reinforcing long-standing evidence that pediatric cervical injuries cannot be approached using adult diagnostic algorithms.

The outcomes of this study clearly demonstrate that early and comprehensive diagnostic evaluation is essential for preventing irreversible neurological deterioration. MRI proved critical for identifying ligamentous damage, spinal cord abnormalities, and subtle multi-level lesions that were not visible on CT imaging alone. This highlights the necessity of incorporating MRI as a fundamental component of early assessment for all children with suspected multi-level injuries, particularly when neurological signs are present or when initial radiographs and CT scans are inconclusive. The limitations of plain radiography in pediatric trauma once again emphasize the need for clinicians to consider advanced imaging modalities early in the diagnostic process.

Treatment outcomes reveal that early surgical intervention significantly improves neurological and functional recovery in children with unstable injuries, multi-level dislocations, ligamentous ruptures, or spinal cord compression. The majority of surgically treated patients demonstrated substantial neurological improvement within three months, supporting the principle that timely decompression and stabilization can prevent progressive neurological deterioration and enhance recovery. Conservative treatment was effective only in cases of stable fractures without ligamentous involvement, but even in these patients, the risk of delayed

instability underscores the need for vigilant follow-up and strict immobilization protocols. These findings collectively reinforce the importance of individualized treatment strategies that consider both biomechanical stability and neurological status.

The overall complication rate in this study was low, and no mortality occurred, largely due to the early implementation of standardized trauma protocols, advances in pediatric spine surgery, and improved perioperative care. Nonetheless, the presence of potentially avoidable complications such as loss of reduction or halo-vest–related issues indicates that careful application of immobilization devices and continuous monitoring remain essential components of successful management.

This study also highlights a substantial gap in the current literature: despite the clinical importance of double cervical injuries in children, there remains a lack of pediatric-specific, evidence-based guidelines addressing their early management. Much of the existing knowledge surrounding cervical trauma is derived from adult populations or from isolated pediatric case series, which do not fully account for age-dependent anatomical variability. This underscores an urgent need for larger, multicenter, prospective investigations capable of generating robust evidence to guide clinicians in diagnostic imaging, timing of intervention, and indications for surgery.

In conclusion, the results of this study confirm that acute double cervical spine injuries in children require rapid identification, meticulous diagnostic evaluation, and early targeted treatment to minimize the risk of permanent neurological damage. MRI should be considered indispensable, early surgical stabilization should be prioritized in unstable cases, and conservative treatment should be reserved for carefully selected patients under strict supervision. The implementation of pediatric-specific clinical pathways, combined with expanded research and improved interinstitutional cooperation, has the potential to significantly improve the short- and long-term outcomes of this rare but devastating injury.

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