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THORACOLUMBAR DEFORMITIES SECONDARY TO SPINAL TUMORS AND THEIR TREATMENTS: IS IT POSSIBLE TO PREDICT AND PREVENT THEM?

DEFORMIDADES TORACOLOMBARES SECUNDÁRIAS A TUMORES ESPINHAIS E SEUS TRATAMENTOS: SERÁ POSSÍVEL PREVER E PREVENIR?

DEFORMIDADES TORACOLUMBARES SECUNDARIAS A TUMORES ESPINALES Y SUS TRATAMIENTOS: ¿ES POSIBLE PREVERLAS Y PREVENIRLAS?

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ABSTRACT

Thoracolumbar deformities related to spinal tumors or their treatments have emerged as a significant clinical challenge, primarily due to their impact on spinal stability, function, and patients' quality of life. Structural changes may occur following tumor resection, radiotherapy, or chemotherapy, particularly in vulnerable populations such as children and adolescents. To analyze the risk factors, pathophysiological mechanisms, and preventive strategies associated with the development of thoracolumbar deformities during or after the treatment of spinal tumors. This narrative review is based on literature from the past three decades retrieved from the PubMed database. It includes original articles, systematic reviews, meta-analyses, and clinical guidelines addressing spinal instability, the biomechanical consequences of oncologic treatments, and preventive and therapeutic approaches. The development of spinal deformities is multifactorial, involving anatomical factors, patient age, extent of surgical resection, tumor location, and the adverse effects of radiotherapy and chemotherapy. Potential preventive strategies include laminoplasty, selective use of orthotic bracing, regular radiographic monitoring, and prophylactic spinal fusion, particularly in pediatric populations. The management of spinal tumors should extend beyond tumor resection to include measures aimed at preserving spinal biomechanics. Early identification of high-risk patients and the implementation of preventive strategies are essential to reducing the incidence of post-treatment deformities and improving functional outcomes. ***Level of Evidence IV; Case Series.***

Keywords: Scoliosis; Kyphosis; Laminectomy; Laminoplasty; Radiotherapy.

RESUMO

Deformidades toracolombares relacionadas a tumores vertebrais ou a seus tratamentos tornaram-se um desafio clínico relevante, principalmente pelo impacto na estabilidade da coluna, funcionalidade e qualidade de vida dos pacientes. As alterações estruturais podem ocorrer após ressecções tumorais, radioterapia ou quimioterapia, especialmente em populações vulneráveis, como crianças e adolescentes. Este trabalho tem como objetivo analisar os fatores de risco, mecanismos fisiopatológicos e estratégias preventivas associados ao desenvolvimento de deformidades da coluna toracolombar durante ou após o tratamento de tumores espinhais. Revisão narrativa, baseada em literatura publicada nas últimas três décadas extraídas da base de dados PubMed. Foram incluídos artigos originais, revisões sistemáticas, metanálises e diretrizes clínicas abordando a instabilidade vertebral, impacto dos tratamentos oncológicos na biomecânica da coluna e abordagens preventivas e terapêuticas. O desenvolvimento de deformidades da coluna é multifatorial, envolvendo fatores anatômicos, idade do paciente, localização tumoral, extensão da ressecção cirúrgica e efeitos adversos da radioterapia e quimioterapia. Estratégias preventivas potenciais incluem laminoplastias, uso criterioso de órteses, acompanhamento radiográfico e fusões profiláticas, especialmente em pacientes pediátricos. A abordagem dos tumores espinhais deve ir além da ressecção da lesão, incorporando medidas voltadas à preservação da biomecânica da coluna. A identificação precoce de pacientes de maior risco e a adoção de estratégias preventivas são cruciais para reduzir a incidência de deformidades pós-tratamento e melhorar o prognóstico funcional dos pacientes. ***Nível de Evidência: IV; Série de Casos.***

Descritores: *Escoliose; Cifose; Laminectomia; Laminoplastia; Radioterapia.*

RESUMEN

Las deformidades toracolumbares relacionadas con tumores espinales o sus tratamientos han surgido como un desafío clínico significativo, principalmente debido a su impacto en la estabilidad de la columna, la funcionalidad, y la calidad de vida de los pacientes. Los cambios estructurales pueden ocurrir tras la resección tumoral, la radioterapia o la quimioterapia, particularmente en poblaciones vulnerables como niños y adolescentes. Este trabajo tiene como objetivo analizar los factores de riesgo, los mecanismos fisiopatológicos y las estrategias preventivas asociadas con el desarrollo de deformidades toracolumbares durante o después del tratamiento de tumores espinales. Revisión narrativa basada en literatura publicada en las últimas tres décadas, y recuperada de la base de datos PubMed. Se incluyeron artículos originales, revisiones sistemáticas, metaanálisis y guías clínicas que abordan la inestabilidad vertebral, las consecuencias biomecánicas

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de los tratamientos oncológicos y los enfoques preventivos y terapéuticos. El desarrollo de deformidades espinales es multifactorial, involucrando factores anatómicos, edad del paciente, localización del tumor, extensión de la resección quirúrgica y efectos adversos de la radioterapia y quimioterapia. Las estrategias preventivas potenciales incluyen la laminoplastia, el uso selectivo de órtesis, el monitoreo radiográfico periódico y la fusión profiláctica, especialmente en pacientes pediátricos. El manejo de los tumores espinales debe ir más allá de la resección tumoral, incorporando medidas dirigidas a preservar la biomecánica de la columna. La identificación temprana de pacientes de alto riesgo y la implementación de estrategias preventivas son esenciales para reducir la incidencia de deformidades posoperatorias y mejorar los resultados funcionales. ***Nivel de Evidencia IV; Serie de Casos.***

Descriptores: *Escoliosis; Cifosis; Laminectomía; Laminoplastia; Radioterapia.*

INTRODUCTION

Thoracolumbar spinal deformities (SD) directly related to tumors in this region or secondary to the specific treatment methods for each tumor have become an increasingly relevant topic in neurosurgery and orthopedics, due to their significant impact on patient function and quality of life, especially in individuals already weakened by treatment of the underlying disease.[1,2]

These deformities may arise following various therapeutic interventions, such as surgical resection of para-axial thoracic tumors, vertebral tumors or metastases, and both intramedullary and extramedullary tumors. In such cases, the resection of mechanical structures essential for spinal stability, combined with adjuvant treatments like radiotherapy and chemotherapy, contributes to biomechanical compromise.[1,3-5]

The management of spinal tumors presents a series of technical and clinical challenges. Lesions located within the vertebral canal may cause neurological compression, resulting in pain, motor impairment, and deformity, making surgical intervention the only viable option.[6,7] Laminectomy, a widely adopted technique, involves dissection of the extensor musculature and removal of the laminae and posterior ligaments. This disrupts the posterior tension band of the spine, leading to redistribution of axial loads and, ultimately, loss of the spine's physiological curvature.[3,7,8] While effective for tumor removal and relief of neurological symptoms, laminectomy may compromise spinal stability and predispose patients, particularly children and young adults with growing spines, to postoperative deformities such as kyphosis, scoliosis, or kyphoscoliosis, with incidence rates ranging from 16% to 100%.[1-3,6, 9-12]

In pediatric patients, who may live for many decades after tumor treatment, secondary deformities may occur at an early or late stage and require continuous observation and rehabilitation, and in some cases, new surgical interventions for correction.[4,5,7]

This article aims to explore in detail the risk factors, pathophysiological mechanisms, and preventive and therapeutic approaches for thoracolumbar deformities related to vertebral tumors.

MATERIALS AND METHODS

This is a case series study with a narrative review approved by the institutional research ethics committee, CAAE 71146723.6.0000.5273, aimed at analyzing risk factors, pathophysiological mechanisms, and preventive strategies associated with SD occurring during or after the treatment of thoracolumbar tumors. The study followed methodological guidelines recommended for non-systematic reviews, allowing for a broad and critical examination of the topic.

Data Sources and Selection Criteria

The bibliographic search was conducted using the PubMed database, covering publications from the past 30 years. The review included original articles, systematic reviews, meta-analyses, and clinical guidelines that addressed the impact of surgical techniques (such as laminectomy, laminoplasty, and spinal fusion) on spinal stability; vertebral instability caused by tumors; the effects of radiotherapy and chemotherapy on bone integrity and spinal biomechanics; major risk factors for post-treatment deformities; and both preventive and therapeutic strategies aimed at minimizing the risk of structural and functional complications.

Inclusion and Exclusion Criteria

Included articles presented clinical and/or biomechanical data on spinal deformities caused by the tumor itself or resulting from oncologic treatment; reported retrospective or prospective studies involving patient cohorts who underwent spinal tumor resection and/or adjuvant therapy; or provided relevant information regarding risk factors, preventive strategies, and long-term prognosis. Studies were excluded if full-text access was unavailable or if they were opinion articles, letters to the editor, or isolated case reports lacking comparative analysis.

Data Analysis

The selected studies were critically analyzed by comparing findings related to the incidence of deformities, their functional impact, and the effectiveness of preventive interventions. Information was organized into thematic categories, including: Biomechanical Impact of Surgical Approaches; Effects of Radiotherapy and Chemotherapy; Individual Factors and Specific Anatomy; and Intraoperative and Rehabilitative Preventive Strategies.

Evidence synthesis was conducted through comparison of study outcomes, with attention to recurring findings and knowledge gaps in the management of post-treatment spinal deformities.

DISCUSSION

The development of deformities secondary to vertebral tumors is multifactorial[9] and involves a complex interplay of anatomical and biomechanical alterations, tumor aggressiveness, and treatment-related effects. A comprehensive understanding of these deformities requires an integrated analysis of vertebral stability, oncologic principles, and the specific characteristics of both the patient and the tumor. In this context, it is essential to outline the main mechanisms contributing to these outcomes:

Specificity of Vertebral Tumor Types

A significant subset of spinal deformities is associated with both benign and malignant primary bone tumors, as well as metastatic lesions that directly compromise the structural integrity of the vertebrae.[13] Benign primary spinal tumors may cause structural alterations in approximately 25% of cases and nonspecific pain in up to 95%.[13] Osteoid osteomas and osteoblastomas, although non-infiltrative in nature, are frequent sources of intense nocturnal pain and typically respond well to nonsteroidal anti-inflammatory drugs.[13] In pediatric and adolescent patients, the asymmetric localization of these tumors – whether in the vertebral body or posterior elements – is the most significant factor contributing to the development of thoracic or lumbar scoliosis. This is thought to result from localized inflammation of the paravertebral musculature, leading to asymmetric muscle contractures. In a study by Saifuddin et al., 465 children with osteoid osteoma (n=191) or osteoblastoma (n=274) were evaluated, and 63% presented with scoliosis (14). This deformity is generally reversible following definitive tumor treatment, either through surgical resection or radiofrequency ablation. However, delays in diagnosis may result in more persistent structural deformities.[13,14]

In contrast, tumors with aggressive behavior and high osteolytic potential, such as multiple myeloma, are a frequent cause of multilevel vertebral collapse. This hematologic malignancy primarily affects the axial skeleton, especially the thoracic and lumbar regions, where red bone marrow is predominant. The trabecular bone destruction caused

by clonal plasma cell proliferation leads to pathological fractures, which often progress to kyphotic deformity, vertebral height loss, and chronic pain. Moreover, long-term corticosteroid use and generalized osteopenia in these patients further exacerbate bone fragility.[15]

Vertebral metastases represent the most common form of osseous dissemination of malignant tumors.[16] Neoplastic infiltration may present as lytic, blastic, or mixed lesions, with lytic lesions being the most prone to compromise vertebral integrity due to the greater bone fragility they induce.[17]

When findings such as vertebral body collapse, cortical destruction, subluxation, deformity, or involvement of the posterior elements are present, spinal mechanical stability may be significantly impaired, potentially indicating the need for surgical intervention.[16,17]

To standardize the evaluation of tumor-related spinal instability, the Spine Oncology Study Group developed the Spinal Instability Neoplastic Score (SINS), a scoring system based on evidence and expert consensus. It aims to guide clinical decision-making in an objective and reproducible manner. According to this classification, patients with a score ≥7 should be referred to a spine surgeon for evaluation of surgical stabilization, particularly in the presence of significant mechanical pain or risk of progressive deformity.[17]

Accessing tumors located within the spinal canal, whether intramedullary or extramedullary, often necessitates the removal of bony and ligamentous structures, significantly compromising spinal stability (2,6,8). Neural-origin tumors, such as neuroblastomas and ganglioneuromas (NB/GN), may involve multiple segments of the paravertebral region, with potential invasion of the spinal canal. Surgical resection with wide margins is frequently required, occasionally involving disarticulation of multiple ribs and, in some cases, direct access to the spinal canal for adequate decompression, often resulting in spinal instability.[4] (Figure 1)

Barrena et al. reported that all NB/GN cases requiring spinal fusion due to deformity involved dumbbell-shaped tumors, which also required laminectomy for removal.[4] In a cohort of 954 neuroblastoma survivors predominantly treated with surgical approaches, the cumulative 20-year incidence of scoliosis requiring corrective surgery was 5.8%. The study identified laminectomy, radiotherapy, and thoracotomy as independent risk factors for the development of severe scoliosis.[18] Furthermore, among 98 neuroblastoma patients with symptomatic epidural compression, those treated with a combination of chemotherapy, radiotherapy, and surgery had a spinal deformity rate of 62.5%.[1]

Procedures such as laminectomy involve the removal of the lamina, spinous processes, and, in many cases, additional resection of portions of the facet joints. This removal directly affects the posterior ligamentous complex, which includes the interspinous ligaments, supraspinous ligament, ligamentum flavum, and paravertebral muscles. These structures are responsible for maintaining normal spinal curvature and ensuring the balanced distribution of mechanical forces along the spine by redirecting axial loads to the anterior column, particularly the vertebral bodies.[3,7] This shift in biomechanical balance may result in progressive compression, vertebral wedging, and the development of postoperative kyphosis.[3,10,20]

Research indicates that the extent of the laminectomy is directly related to the risk of instability and deformity.[1,9,10] Procedures involving multiple spinal levels, especially those exceeding four segments, are more strongly associated with significant changes in spinal alignment.[1,5,9,20]

Facetectomy, whether partial or total, is often performed during tumor resection to improve visualization and access; however, it may compromise segmental stability, as the facet joints are fundamental in limiting excessive motion and preventing abnormal displacement.[12]

In a biomechanical study, Zdeblick et al. demonstrated that resection of more than 50% of the cervical facet joint complex, comprising the joint surfaces and the articular capsule, resulted in segmental hypermobility and indicated the need for immediate stabilization.[21] In this context, the resection of extradural and intradural extramedullary tumors carries a higher risk of post-treatment spinal deformity compared to intradural intramedullary tumors, as the former require broader exposure to achieve complete visualization and resection.[6]

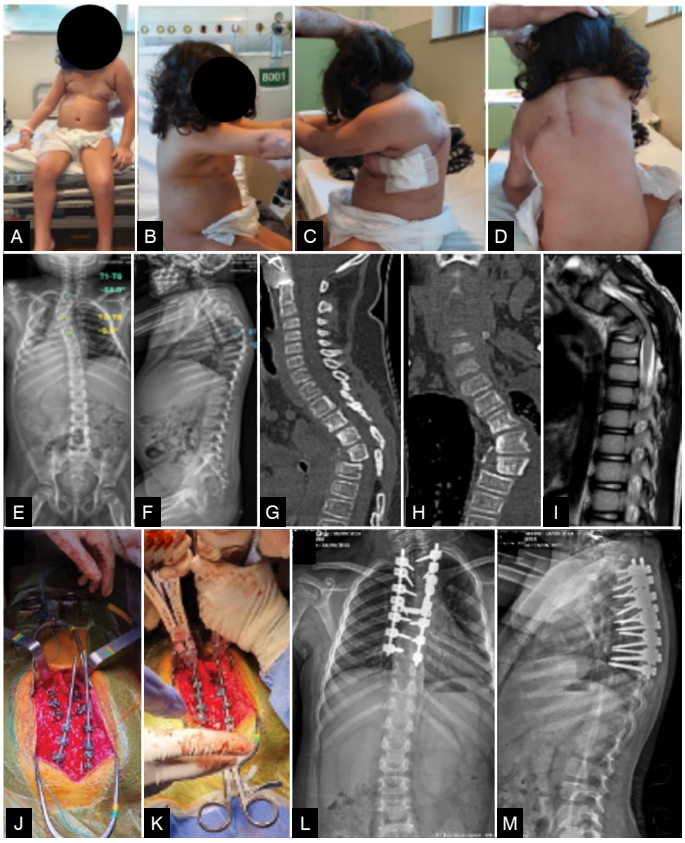

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Figure 1. A–D: Six-year-old patient referred with paraplegia (ASIA B) two months after resection of a ganglioneuroma, with a postoperative history of cerebrospinal fluid fistula and meningitis; E and F: Panoramic anteroposterior and lateral radiographs of the spine showing resultant deformity; G and H: Computed Tomography scan of the spine showing T5–T6 subluxation; I: Sagittal T2-weighted magnetic resonance imaging showing spinal cord compression at the T5–T6 level; J and K: T2–T8 spinal fusion performed with deformity reduction and indirect decompression via cantilever technique; L and M: Postoperative radiographs showing deformity correction and complete recovery of neurological status (ASIA E). This case highlights the importance of mechanical stabilization. The neurological deficit could likely have been prevented if spinal instrumentation had been performed at the time of tumor resection.

Laminoplasty has been investigated as an alternative approach to preserve part of the bony and ligamentous structures, allowing for reconstruction of the neural arch after tumor removal. Although it appears to reduce the risk of deformity,[9, 20,22] its effectiveness varies depending on the technique used and the extent of posterior ligament complex preservation, which plays a key role in maintaining the biomechanical integrity of the spine.[8] In pediatric patients with intramedullary tumors, the incidence of SD after laminoplasty is 5%, compared to 30% in patients who undergo laminectomy.[20] It is worth noting that despite the rationale of anatomical preservation for enhanced stability, statistically significant differences between the two techniques are not consistently observed, suggesting that the isolated efficacy of laminoplasty in preventing deformity remains controversial.[2,3,22]

Effects of Radiotherapy and Chemotherapy

Adjuvant treatments such as radiotherapy and chemotherapy, although essential for controlling certain vertebral tumors and metastases, introduce changes that may increase susceptibility to SD.[1,23,24]

In pediatric populations, vertebral exposure to ionizing radiation can impair normal growth by directly affecting the growth plates and cartilaginous endplates. This leads to inhibition of endochondral ossification, potentially resulting in asymmetric growth and future deformity.[1,23] The disruption of normal development produces smaller vertebral bodies

and an uneven distribution of mechanical forces, which may contribute to vertebral wedging and progression to deformities such as kyphosis and scoliosis.[25] In their review, Gawade et al. reported a prevalence of post-radiotherapy scoliosis ranging from 10% to 80% and kyphosis from 2% to 48%. They noted that the risk of radiation-induced spinal misalignment is influenced by age under six years, radiation doses ≥20 Gy, and asymmetric irradiation of the spine.[25]

In skeletally mature patients, the main adverse effect of radiotherapy is trabecular bone weakening due to osteoradionecrosis, which may lead to compression fractures, resulting in pain, muscular fatigue, sagittal imbalance, and significant impairment in quality of life.[24,26] Another contributing factor is radiation-induced inflammation of the paravertebral muscles in the irradiated area, which can result in muscle atrophy or tissue fibrosis.[25]

Chemotherapy, whether combined with radiotherapy or used as monotherapy, reduces bone turnover and bone mineral density. Certain chemotherapeutic agents, such as ifosfamide, may also cause proximal tubular injury, leading to loss of protein, phosphate, and bicarbonate. These effects can contribute to the development of secondary deformities and rickets.[25,27] (Figure 2)

Individual Factors and Specific Anatomy

In addition to the direct effects of surgical procedures and adjuvant therapies, individual patient factors play a crucial role in the pathogenesis of post-treatment deformities.

Several studies have identified age as an independent predictor of deformity, with significantly higher risks observed in pediatric populations due to a greater proportion of cartilage, ligamentous hyperlaxity, and the more horizontal orientation of the facet joints.[1,2,20,28] In younger patients, particularly those under 13 years of age, the loss of structural support may lead to progressive deformities during growth.[3,28]

The presence of any preoperative deformity, even if mild, suggests that the spine is already subject to biomechanical imbalance and has been identified as a statistically significant predictor of postoperative spinal deformity.[1-3,20,28] Surgical intervention may further disrupt this balance, accelerating the progression of deformity. These cases require a more cautious operative strategy and close postoperative monitoring.

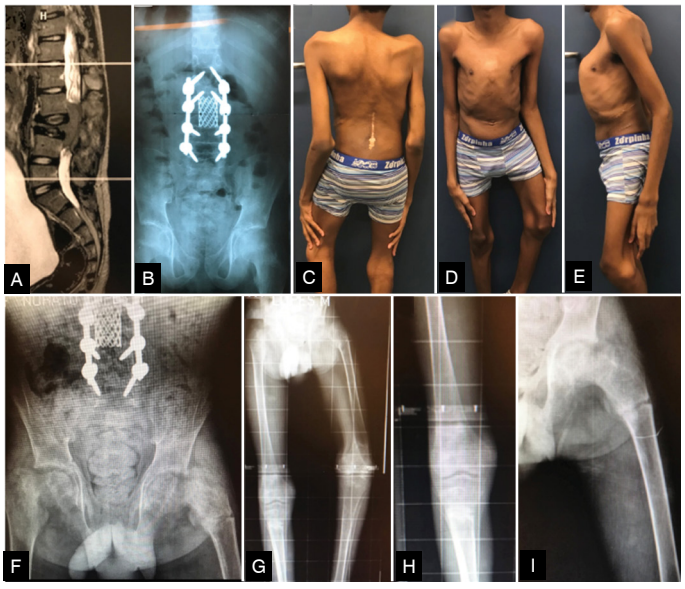

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Figure 2. A: Sagittal T2-weighted lumbar spine magnetic resonance imaging of an 11-year-old male patient showing Ewing's sarcoma; B: Immediate postoperative image following tumor resection and spinal instrumentation from L1 to L5; C-E: Clinical photographs taken six years after surgery, showing rickets secondary to Fanconi syndrome induced by ifosfamide treatment; F-I: Radiographs obtained at six-year follow-up, revealing bone abnormalities in the hip, femur, and knee.

Tumors located in transitional regions such as the thoracolumbar or cervicothoracic junctions are associated with an increased risk of deformity[3,28] due to the elevated mechanical load and anatomical complexity of these segments. Resection of stabilizing elements in these areas may result in more pronounced imbalance compared to other spinal levels.[29] Yao et al. reported that syringomyelia was an independent factor associated with the development of spinal deformity requiring fusion. Expansion of the cavity led to anterior horn compression in the spinal cord, resulting in asymmetric muscle weakness.[28]

Preventive Strategies

Given the complex interplay of contributing factors, the development of preventive strategies is essential to reduce both the incidence and progression of post-treatment deformities. These strategies can be broadly categorized into two main groups: intraoperative techniques and perioperative or rehabilitative strategies.

Intraoperative Strategies

The choice of surgical technique plays a critical role in determining postoperative spinal stability, especially when the approach prioritizes the preservation of bony and adjacent soft tissue structures. Opting for laminoplasty instead of conventional laminectomy favors preservation of the neural arch and support elements such as the posterior ligamentous complex (PLC), thereby reducing the risk of progressive instability.[9,10] In a study by De Jonge et al. involving 76 patients treated for malignant spinal tumors, 67 developed deformity. Among the nine patients who maintained spinal stability after treatment, eight had undergone laminoplasty.[11]

In patients requiring multilevel decompression, extensive facetectomy for improved tumor visualization, or those with pre-existing spinal deformity, prophylactic spinal fusion may be indicated.[1,9] This decision must carefully balance the need for segmental spinal stability to preserve mobility. (Figure 3)

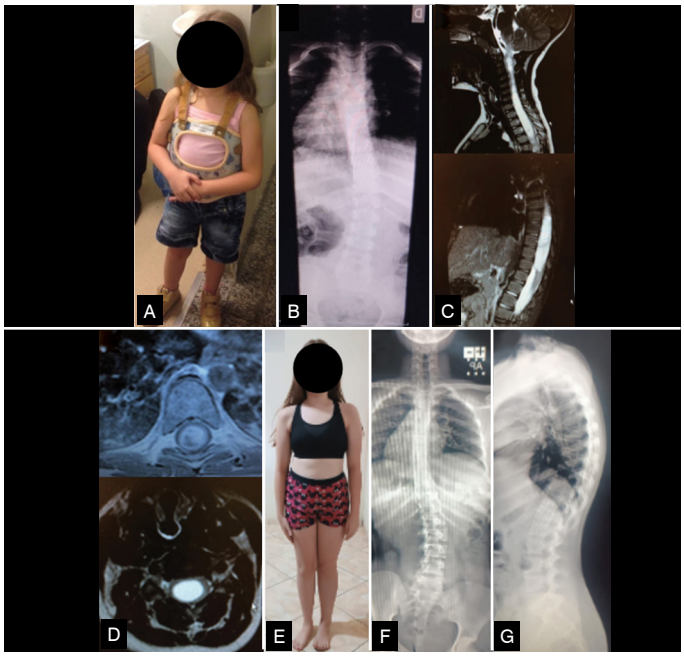

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Figure 3. A: Six-year-old patient undergoing brace treatment for a diagnosis of idiopathic scoliosis at another institution. B: Panoramic anteroposterior radiograph. C and D: Cervical and thoracic spine magnetic resonance imaging showing an intramedullary expansive lesion. E: Same patient ten years after surgery, following T2 to T11 laminoplasty and T3 to T11 myelotomy for tumor resection, with histopathological diagnosis of astrocytoma. F and G: Panoramic anteroposterior and lateral radiographs after ten years of follow-up. In this case, despite the need for extensive laminoplasty in a young patient, no significant spinal deformity was observed. The use of laminoplasty is believed to have played a key role in preserving spinal alignment.

Perioperative and Rehabilitative Strategies

During the postoperative period, the use of orthoses may assist in trunk stabilization by limiting movements that could exacerbate instability. However, the criteria for their indication remain unclear in the literature.[1,20] When combined with rigorous pain management, these orthoses may help delay the progression of deformity during the recovery phase, allowing tissues to adapt to the new structural configuration. Periodic radiographic monitoring plays a critical role in the early detection of changes in spinal alignment.[1] This strategy enables timely interventions, whether through adjustments in rehabilitation or, in more severe cases, the implementation of additional surgical procedures to prevent irreversible progression of deformities.

CONCLUSION

Spinal deformities related to thoracolumbar tumors represent a significant clinical challenge, compromising vertebral stability, spinal function, and overall quality of life. Factors such as the extent of laminectomy, patient age, pre-existing deformities, and the adverse effects of radiotherapy and chemotherapy play a key role in the progression of these structural alterations. In this context, management should extend beyond tumor resection to include strategies that minimize risk and preserve spinal biomechanics, to reduce the need for future interventions and improve long-term outcomes.

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