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HIDDEN NEURAXIAL PATHOLOGY IN IDIOPATHIC SCOLIOSIS: ORIGINAL RESEARCH

PATOLOGIA NEUROAXIAL OCULTA NA ESCOLIOSE IDIOPÁTICA: PESQUISA ORIGINAL

PATOLOGÍA NEUROAXIAL OCULTA EN LA ESCOLIOSIS IDIOPÁTICA: INVESTIGACIÓN ORIGINAL

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ABSTRACT

Objective: To evaluate the prevalence of hidden neuraxial pathology (NAP) revealed in idiopathic scoliosis (IS) in neurologically normal patients. Methods: We selected 401 patients with IS who visited our clinic. We identified patterns of NAP and its frequency. In addition to the main part of the study, we assessed the reliability of Magnetic Resonance Imaging (MRI) measuring of the pedicles to plan screw width and trajectory. Results: Among the 401 patients, 53 (13%) presented NAP. The proportion of males in this group was higher (42% vs. 21%, p=0.004), the age of onset of the deformity was lower (8.9±3.77 vs. 9.9±3.93 years old, p=0.045), the left-sided thoracic curve was more frequent (21% vs. 8%, p=0.016), thoracic kyphosis was more pronounced (p=0.070), and the percentage of revision surgeries for deformity progression or non-fusion was higher (13% vs. 5%, p=0.147). Conclusions: The spine MRI should be performed in the early stages of IS, as in some cases of NAP (Chiari, tethered spinal cord), there is the possibility of an early neurosurgical operation that will prevent the development of scoliosis. The main signs of hidden NAP in IS are early-onset IS, IS with left-sided thoracic curve, male gender, and thoracic kyphosis > 40°Cobb. ***Level of Evidence II; Retrospective Study.***

Keywords: Scoliosis; Spinal Cord Diseases; Kyphosis; Age of Onset.

RESUMO

Objetivo: Avaliar a prevalência das patologias neuroaxiais ocultas (PNO) reveladas na escoliose idiopática (EI) em pacientes neurologicamente normais. Métodos: Foram selecionados 401 pacientes com EI que visitaram nossa clínica. Identificamos padrões de PNO e sua frequência. Além disso, avaliamos a confiabilidade da medição por ressonância magnética (RM) dos pedículos para planejar a largura e a trajetória do parafuso. Resultados: Entre os 401 pacientes, 53 (13%) apresentaram PNO. A proporção de homens neste grupo foi maior (42% contra 21%, p=0,004), a idade de início da deformidade foi menor (8,9±3,77 contra 9,9±3,93 anos, p=0,045), a curva torácica do lado esquerdo foi mais frequente (21% contra 8%, p=0,016), a cifose torácica foi mais pronunciada (p=0,070) e a porcentagem de cirurgias de revisão para progressão da deformidade ou não fusão foi maior (13% contra 5%, p=0,147). Conclusões: A ressonância magnética da coluna deve ser realizada nos estágios iniciais da EI, pois em alguns casos de PNO (Chiari, medula espinhal amarrada) existe a possibilidade de uma operação neurocirúrgica precoce que impedirá o desenvolvimento de escoliose. Os principais sinais de PNO oculta na EI são: EI de início precoce, EI com curvatura torácica à esquerda, sexo masculino e cifose torácica > 40°Cobb. ***Nível de Evidência II; Estudo Retrospectivo.***

Descritores: *Escoliose; Doenças da Medula Espinal; Cifose; Idade de Início.*

RESUMEN

Objetivo: Evaluar la prevalencia de las patologías neuroaxiales ocultas (PNO) reveladas en la escoliosis idiopática (EI) en pacientes neurológicamente normales. Métodos: Se seleccionaron 401 pacientes con EI que visitaron nuestra clínica. Se identificaron patrones de PNO y su frecuencia. Además, evaluamos la fiabilidad de la medición por resonancia magnética (RM) de los pedículos para planificar la anchura y la trayectoria del tornillo. Resultados: Entre los 401 pacientes, 53 (13%) presentaron PNO. La proporción de hombres en este grupo fue mayor (42% vs 21%, p=0,004), la edad de aparición de la deformidad fue menor (8,9±3,77 vs 9,9±3,93 años edad, p=0,045), la curva torácica del lado izquierdo se encontró con más frecuencia (21 % frente a 8 %, p=0,016), la cifosis torácica fue más pronunciada (p=0,070) y el porcentaje de cirugías de revisión por progresión de la deformidad o falta de fusión fue mayor (13% vs 5%, p=0,147). Conclusiones: La resonancia magnética de la columna debe realizarse en las primeras etapas de la EI, ya que en algunos casos de PNO (Chiari, médula anclada) existe la posibilidad de una operación neuroquirúrgica temprana que prevendrá el desarrollo de la escoliosis. Los principales signos de PNO oculta en EI son: EI de inicio temprano, EI con curvatura torácica izquierda, sexo masculino y cifosis torácica > 40°Cobb. ***Nivel de Evidencia II; Estudio Retrospectivo.***

Descriptores: *Escoliosis; Enfermedades de la Médula Espinal; Cifosis; Edad de Inicio.*

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INTRODUCTION

Idiopathic scoliosis is a complex disease with multiple causes, including genetic and epigenetic factors. Other theories include central and peripheral neural system pathologic growth, functional and structural changes, uncoupled neuro-osseous growth, vestibular system asymmetry, pathology of local spinal muscles, cerebrospinal fluid flow disturbance, and disturbances of vertebral growth.

Some idiopathic scoliosis (IS) cases reveal unexpected, hidden, or asymptomatic neuroaxial pathology (NAP). The most common types of NAP are syringomyelia, Chiari malformation, and occult tethered spinal cord.[1] Spinal cord tumors are rare but can be dangerous. In some cases, they can cause scoliosis without initially visible neurological deficiency.[2-11]

Scoliosis can be caused by spinal cord pathology and can be considered neuromuscular. Scoliosis cannot be considered idiopathic in cases of asymptomatic light cerebellar tonsil ectopia, soft syringomyelia, enlarged central spinal canal, or filum terminal lipoma with a normal conus medullaris position. Syringomyelia might be secondary to severe scoliosis in some cases due to spinal cord compression in the curve's apex.

The feasibility of magnetic resonance imaging (MRI) of the spinal cord in children with idiopathic scoliosis is still being discussed. This paper aims to determine whether MRI should be performed in all patients with idiopathic scoliosis, even in small curves.

MATERIAL AND METHODS

MRI scanners were introduced in our clinic in 2006. Until 2012, tomography was not performed in IS patients as a rule. In 2012, an MRI of the spinal cord was performed only in 14% of patients with a presumptive diagnosis of IS, admitted for surgery in our clinic, first of all, in patients with atypical curves, male gender, and early onset scoliosis. Currently, it is done in approximately 78% of cases. (Table 1)

We conducted a study on patients who had scoliosis in childhood without any neurological symptoms and entered the clinic with presumptive IS. Inclusion criteria were radiographs of the entire spine in two projections before initial surgery and an MRI of two or more parts of the spinal cord. Exclusion criteria were vertebral malformations, fractures, or displacements according to x-rays, neurological deficit, associated anomalies or syndromic/systemic pathology, and cutaneous stigmata.

The study was divided into several parts to maximize the possibilities of MRI of the spinal cord in IS. The first part compared clinical and radiographic data of patients with idiopathic scoliosis and scoliosis with hidden neuroaxial pathology. Patient data was collected retrospectively (up to 2019) and prospectively (2019-2021). We divided all patients into two groups: patients without neuraxial pathology and patients with neuraxial pathology discovered accidentally by MRI. We evaluated and compared various criteria, including gender, age of deformity, chronic pain and its localization, wearing of the corrective corset, the direction of the middle (thoracic) curve, location of apex vertebra/disc of the main curve, Lenke type, lumbar spine modifier, thoracic sagittal profile, and the value of the main curve at the time of MRI. We also explored and compared correction rates, frequency of neurological complications, and dangerous events in intraoperative neuromonitoring.

In the second stage of the study, we compared the results of CT and MRI scans, as well as the vertebral dimensions obtained from CT and MRI. Measurements were performed by different physicians (radiologists and spinal surgeons) in five patients with idiopathic scoliosis from levels Th1 to L5. (Figure 1)

Ethical approval (IRB): Approved by the Institutional Review Board. All procedures performed in studies involving human participants were under the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Table 1. Frequency of MRI performed in patients with suspected idiopathic scoliosis before surgery in MRI – magnet resonance imaging.

	All patient	without MRI	MRI	Neural axis pathology
2012	57	46	8/14%	3
2013	33	27	6/18%	1
2014	53	26	27/51%	1
2015	51	23	28/55%	4
2016	71	28	43/61%	4
2017	63	18	45/71%	9
2018	71	18	53/75%	7
2019	88	19	69/78%	7
2020	75	27	52/69%	5
2021	90	20	70/78%	12
All	652	251	401/61%	53/13%

Statistic

Statistical calculations were performed using Microsoft Excel 2010 software, its integrated data analysis package, Attestat, and SPSS Statistics.

For the signs described by quantitative values (age, deformity, correction percentage, duration of observations), the nature of the statistical distribution of the collected data was checked. The statistical significance of the intergroup differences was assessed using nonparametric Wilcoxon and Mann-Whitney criteria for independent and paired samples at $p<0.05$.

RESULTS

In the 2012-2021 period, 401 mixed-age patients with idiopathic scoliosis underwent an MRI of the spine before surgery at our clinic (61%). Among them, 53 (13%) had different neural axis pathology, most commonly asymptomatic syringomyelia and Chiari I (66%), which did not require additional surgery (Table 2). However, there were potentially dangerous conditions among them, such as tumors of the spinal cord and cerebellum. (Figure 2, Figure 3)

When comparing two groups of patients, we found differences in clinical and radiological characteristics (Table 3). In group 2, the proportion of males was higher (42% vs 21%, $p=0.004$). The mean time to onset of spinal deformity in group 2 was less than in group 1 (8.9 ± 3.77 vs 9.9 ± 3.93 years old, $p=0.045$). Patients with IS without neuroaxial pathology (group 1) were more likely to suffer from back pain (79% vs 59%, $p=0.005$). Left-sided lower thoracic curve or right-sided lumbar were more common in group 2 (21% vs 8%, $p=0.016$). According to Lenke, the distribution by types of deformity was almost the same in both groups; this also applied to the lumbar modifier. The apical vertebra or disc of the main arch in patients in group 2 was more often located in the transitional thoracolumbar zone (Th11-L1), compared to group 1: 21% vs 12% ($p=0.256$) (Figure 4). Thoracic kyphosis was more pronounced in group 2 ($p=0.070$). The magnitude of the main curve at the time of admission to the hospital was approximately the same in both

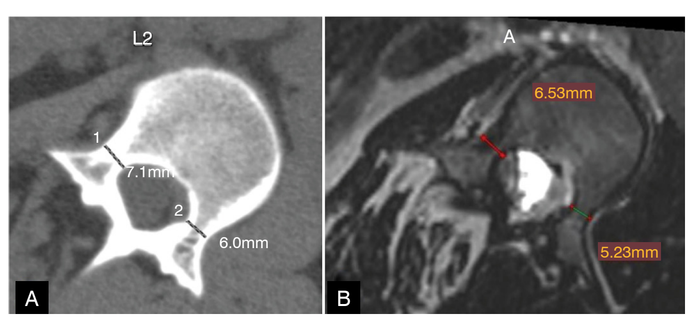

Figure 1. A. Axial CT-slice of L2 vertebrae with pedicle width measurement. B. Axial T2-weighted fast spin-echo images of the L2 vertebrae with pedicle width measurement.

Table 2. Types of accidentally found neuraxial pathology and several neurosurgical and orthopedic surgeries in patients with initially presumed idiopathic scoliosis.

Neuraxial pathology	Number of patients	Number neurosurgical procedures	Number of surgeries for spinal deformity
Chiari	4	0	4
Chiari + syringomyelia	8	6	6
Chiari + BI + syringomyelia	3	4	3
Chiari + FTL + syringomyelia	1	2	1
FTL + syringomyelia	1	0	1
FTL with low-lying conus medullaris	3	2	3
FTL with normal conus medullaris	4	0	2
Syringomyelia	20	0	20
Abnormal mass in SC	3	3	2
Abnormal mass in SC + syringomyelia	2	0	1
Hydrocephalus + syringomyelia	2	3	2
Dandy-Walker + syringomyelia	1	1	0
Tumor of cerebellum + hydrocephalus	1	1	0

BI – basilar invagination, FTL – filum terminalis lipoma, SC – spinal cord.

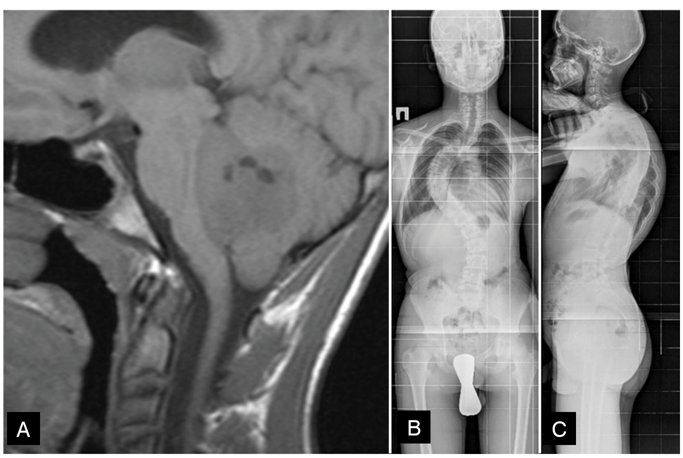

Figure 2. A. MRI of the craniovertebral junction and cerebellum of 17, a 17-year--old male with a hidden tumor of the fourth ventricle, examined for suspected idiopathic scoliosis. B. An anterior-posterior vertical X-ray of the same patient's spine shows a pattern similar to Lenke type 1 typical idiopathic scoliosis. C. Lateral vertical X-ray of the spine of the same patient showing thoracic hyperkyphosis.

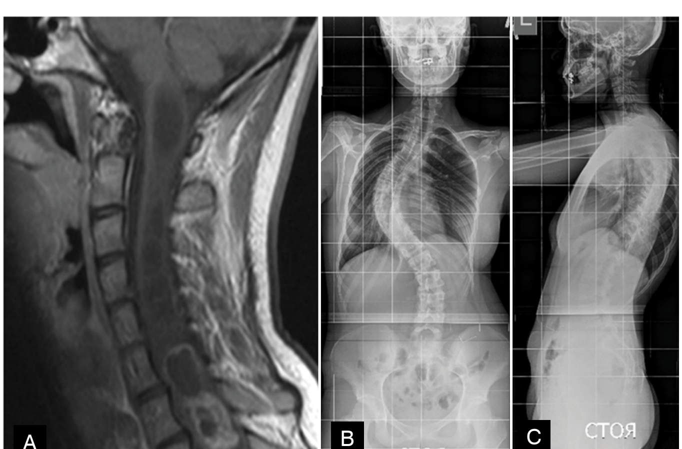

Figure 3. A. MRI of the craniovertebral junction and cervical spine of 18, an 18-year-old female with a hidden tumor of the cervical spine and secondary syringomyelia, examined for suspected idiopathic scoliosis. B. An anterior--posterior vertical X-ray of the spine of the same patient shows a pattern similar to Lenke type 1 typical idiopathic scoliosis. C. Lateral vertical X-ray of the spine of the same patient, showing thoracic normal kyphosis.

groups. No significant difference in the position of the conus medullaris among the groups was found. (Figure 5)

Comparable results were obtained when comparing the measurements of vertebral pedicle width between CT and MRI scans. (Table 4)

DISCUSSION

The incidence of spinal cord pathology in suspected IS and their predictors

In the first half of 2018, three review articles were published on the problem of latent spinal cord pathology in idiopathic scoliosis (IS) and their predictors: Faloon et al.,[12] Heemskerk et al.[1] and Tully et al.[13] Their research on the incidence of neuraxial pathology in idiopathic scoliosis (IS) has shown that the incidence of latent neuraxial pathology ranges from 8 to 16%. The authors concluded that all patients with suspected IS, despite the absence of neurological symptoms, should undergo routine MRI of the entire spinal cord.

Some researchers have pointed out that neuroaxial pathology is detected more often in early-onset scoliosis than adolescent idiopathic scoliosis.[1,5,14-18] There were separate works devoted to severe IS (mixed age, >90°Cobb)[19] and IS with left-sided lower thoracic curve/right-sided lumbar curve (mixed age):[20] incidence of neuroaxial pathology was 37.43% and 40.21%, curves respectively. Several studies also confirm these patterns.

Additional signs of hidden neuraxial pathology may be male gender[1,6,14,16,17,20,21] thoracic kyphosis > 40°Cobb,[1,15,17,21,22] chronic back pain,[23] abnormal reflexes,[5,16,18] apex of deformity in thoracolumbar region,[17] apical vertebrae rotation.[24] Reflex changes and evaluating subtle neurological symptoms pose challenges due to their subjective nature. A more promising avenue for precise assessment lies in the quantitative gait analysis.[25] This approach holds particular potential for yielding valuable insights in cases involving Chiari anomaly and syringomyelia accompanied by scoliosis, offering a more objective and informative perspective on neurological conditions.

Our research confirms that male patients with suspected idiopathic scoliosis (IS) who developed the condition before the age of 10 and have left-sided thoracic or right-sided lumbar curve, thoracic kyphosis >40°Cobb have a greater probability of having latent neuraxial pathology. Chronic back pain is not a risk factor, and the study of reflexes is quite subjective. The degree of vertebral rotation is not practical as a predictor of latent neuraxial pathology. CT scans are commonly used to assess vertebral rotation accurately, but performing a CT scan before surgery increases the radiation load on the patient. Modern MRI can successfully replace CT. The severity of the deformity is also not practical as a sign of neuraxial pathology. MRI should be done in the early stages of scoliosis because, in some cases of latent neuraxial pathology, neurosurgical procedures at an early stage can prevent the progression of scoliosis.

Does asymptomatic neuroaxial pathology must be operated on before deformity correction?

Intraspinal anomalies must be categorized as "actionable" or "non-actionable". Primary tumor treatment is necessary in cases of scoliosis with silent tumors. Spinal cord tumors require special treatment before deformity correction.

Some studies have shown that preventive surgery is unnecessary in some asymptomatic patients, and deformity correction can be performed alone. This is predominantly true for split cord malformation (SCM) type II, filum terminal lipoma with normal conus medullaris position and without any symptoms.[26]

According to medical recommendations, the treatment of syringomyelia depends on its characteristics. A neurosurgical procedure is not required if syringomyelia is mild and non-tense or secondary to scoliosis. If syringomyelia is tense, shunting should be performed before scoliosis correction. A preliminary neurosurgical procedure should be performed before deformity correction if a patient has a concurrent Chiari anomaly type I with syringomyelia. At the same time, some surgeons recommend operating on Chiari 1 without

Table 3. Main characteristics of two groups of patients: patients with true idiopathic scoliosis (group 1) and patients with MRI-detected pathology of the spinal cord (group 2), statistic method, and parameter.

Total number = 401	Group 1, true IS (N=348)	Group 2, NAP (N=53)	Statistic
Gender	Male 73 (21%) Female 275 (79%)	Male 22 (42%) Female 31 (58%)	P-value = 0.004
Average age at onset of deformity	9.9±3.93 years old	8.9±3.77 years old	P-value = 0.045
Chronic thoracic and lumbar back pain	274 (79%)	31 (59%)	P-value = 0.005
Chronic cervical pain	2 (0.5%)	1 (2%)	P-value = 0.281
Chronic headaches	16 (5%)	3 (6%)	P-value = 0.012
Corset treatment	135 (39%)	19 (36%)	P-value = 0.409
Left-sided lower thoracic curve or right-sided lumbar	28 (8%)	11 (21%)	P-value = 0.016
Lenke type	1 – 143 (41%) 2 – 16 (5%) 3 – 114 (33%) 4 – 11 (3%) 5 – 29 (8%) 6 – 35 (10%)	1 – 25 (47%) 2 – 4 (8%) 3 – 14 (26%) 4 - 0 5 – 4 (8%) 6 – 6 (11%)	P-value = 0.985 P-value = 0.876 P-value = 0.889 P-value = 0.778 P-value = 0.118 P-value = 0.063
Lumbar modification	A – 130 (37%) B – 82 (24%) C – 136 (39%)	A – 21 (40%) B – 11 (21%) C – 21 (40%)	P-value = 0.262 P-value = 0.436 P-value = 0.121
Thoracic modification	Hypo – 83 (24%) Normal – 205 (59%) Hyper – 60 (17%)	Hypo – 9 (17%) Normal – 30 (57%) Hyper – 14 (26%)	P-value = 0.702 P-value = 0.266 P-value = 0.070
The average value of the main curve	65.5±24.58°Cobb	70.2±28.24°Cobb	P-value = 0.161

IS – idiopathic scoliosis, NAP - neuraxial pathology.

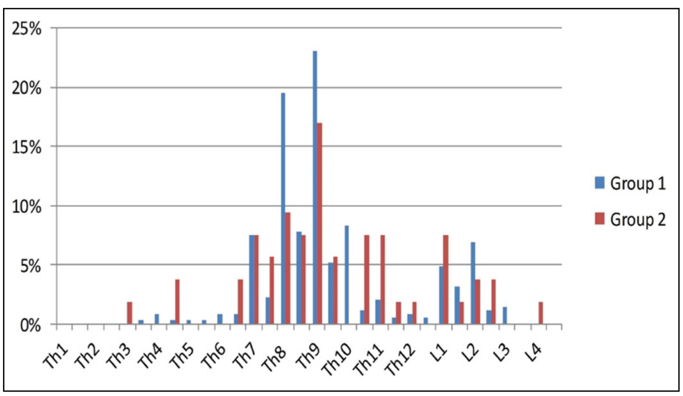

Figure 4. Location of the apical vertebra or disc of the main arch in patients in groups 1 (blue) and 2 (red).

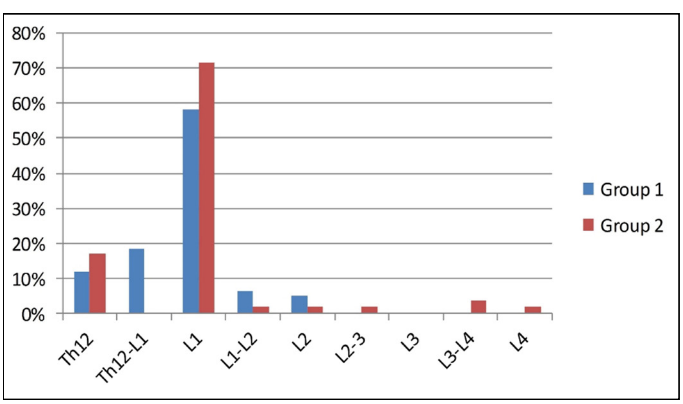

Figure 5. The conus medullaris is located in group 1 (blue) and group 2 (red).

syringomyelia and specific symptoms before deformity correction,[5,6,14,27] and some consider it not necessary.[21,28-33]

Safety of deformity correction without untethering is doubtful since the neurological symptoms of a fixed spinal cord may appear later;[34] in addition in patients with "asymptomatic" tethered cord and scoliosis, preventive untethering is recommended and can show improvement of scoliosis less than 45°Cobb.[35]

In our clinic, we recommend the following approaches for treating occult neuraxial pathology in idiopathic scoliosis:

For asymptomatic Chiari 1 without syringomyelia, non-tension syringomyelia, SCM type II, and filum terminal lipoma with normal conus medullaris position, we recommend correcting the deformity with subsequent observation.

We recommend a preliminary neurosurgical procedure before deformity correction for patients with tumors, Chiari I with syringomyelia, tense syringomyelia, SCM type I, and low-lying conus medullaris.

If a patient has a tumor, Chiari anomaly, or syringomyelia, an MRI of the brain is mandatory.

MRI is an alternative to X-ray and CT

CT scans on pediatric patients delivered a higher dose than on adults.[36] Since the 2000s, several methods have been developed to reduce radiation exposure during X-rays and CT in children. These methods include special pediatric tomography settings, low--dose tomography, biplanar slot scanning imaging, and scoliometer. Additionally, CT can be replaced with MRI and ultrasound, if possible. However, new studies indicate an increased risk of origin of malignant tumors after CT during life in children.[37-42] In addition, there is evidence that CT scans can affect the reproductive system in women, including females with AIS. For example, studies have found associations between CT radiation exposure and unsuccessful pregnancy attempts, spontaneous abortion, and congenital malformations in newborns. Therefore, minimizing radiation exposure during spine surgery in pediatric patients, including adolescent girls, is important.[43]

Several studies have compared the effectiveness of X-ray, CT, and MRI in assessing scoliosis and preoperative planning of screw size and trajectory. These studies have reported both positive and negative results.[44,45]

CONCLUSION

We believe an MRI of the spine should be performed in the early stages of IS. Several patients with IS may have hidden NAP, and a neurosurgical procedure can prevent scoliosis progression at the early stages. This pathology includes Chiari I anomaly, tethered spinal cord, some types of syringomyelia, and tumors. The main signs of hidden NAP in IS are early onset deformity, left-sided thoracic curve, male gender, and thoracic kyphosis > 40°Cobb.

MRI is also a useful tool for planning deformity surgery, reducing radiation load, and can replace preoperative CT.

Table 4. Comparison of the pedicle width of the Th1-L5 vertebrae measured by CT and MRI in five patients with different types of idiopathic scoliosis.

Patients	Patient 1 Lenke 1 Main curve 50°Cobb				Patient 2 Lenke 6 Main curve 53°Cobb				Patient 3 Lenke 6 Main curve 88°Cobb				Patient 4 Lenke 3 Main curve 103°Cobb				Patient 5 Lenke 6 Main curve 99°Cobb			
Method	**MRI**		**CT**		**MRI**		**CT**		**MRI**		**CT**		**MRI**		**CT**		**MRI**		**CT**	
Side	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	left	right	left
Th1	4.3	7.2	6.1	7.8	5.1	5.4	7.1	7.3	10.2	9.7	8.6	6.9	8.0	7.1	10.0	8.0	3.6	3.8	4.6	4.8
Th2	4.0	6.4	2.7	4.0	6.6	6.4	4.0	4.5	7.0	8.0	5.0	5.8	7.0	6.2	7.5	7.3	2.9	3.9	3.6	4.8
Th3	3.8	5.7	3.0	4.1	7.4	7.6	5.9	5.9	5.1	5.0	3.7	4.4	6.0	6.0	5.0	7.0	2.8	2.4	3.1	3.0
Th4	4.8	3.9	3.5	2.5	7.4	8.2	6.1	6.9	5.5	5.1	3.5	3.7	5.0	5.3	6.0	7.3	3.5	1.9	3.3	1.0
Th5	6.8	1.0	5.9	2.0	7.4	7.4	5.9	6.9	4.6	4.1	3.3	2.6	6.6	5.9	7.0	4.0	2.9	1.2	3.5	1.3
Th6	4.2	1.9	3.3	1.6	6.6	6.3	5.6	4.8	5.5	4.9	3.8	3.1	6.6	6.7	7.3	3.0	3.9	2.1	3.8	1.1
Th7	4.8	4.0	4.3	3.0	7.5	7.3	4.7	5.4	6.8	5.1	4.2	3.2	6.0	4.2	6.7	2.5	4.0	2.3	4.1	2.3
Th8	4.0	5.0	2.2	3.2	3.2	2.1	2.7		5.9	5.8	6.1	4.4	6.1	7.0	6.5	3.0	3.8	2.3	3.5	2.7
Th9	4.0	5.2	3.3	3.5	1.9	2.1	4.0	3.1	5.3	4.9	4.7	3.7	6.8	7.3	5.9	5.0	4.8	3.7	4.4	3.3
Th10	3.5	7.3	2.1	5.5	1.7	2.9	3.9	4.3	6.0	6.3	5.9	6.2	7.4	6.2	6.0	6.7	4.7	6.4	3.8	6.3
Th11	5.5	7.8	7.9	6.7	2.5	4.6	7.9	5.7	5.7	6.2	5.3	8.5	8.1	8.3	7.0	9.0	6.6	7.7	5.3	6.6
Th12	9.5	8.5	7.4	7.2	4.2	4.3	5.7	4.3	5.6	9.8	3.7	9.3	8.9	9.0	6.0	8.0	5.2	5.1	2.3	4.4
L1	8.4	7.6	6.3	5.5	6.1	4.5	8.6	6.7	5.1	6.4	3.8	5.5	6.4	6.6	8.0	6.0	4.4	4.4	3.8	4.1
L2	6.9	7.0	7.2	5.2	3.6	3.5	6.5	7.5	7.3	8.0	7.1	6.0	8.0	7.3	9.5	7.0	5.7	5.2	5.8	4.2
L3	9.2	6.1	10.3	8.3	7.0	3.5	11.6	10.8	9.5	8.4	8.6	7.8	9.6	9.7	10.0	9.0	6.9	7.0	7.8	6.4
L4	10.6	9.3	10.1	8.1	10.0	8.9	13.0	8.2	10.0	11.0	9.1	11.5	9.5	12.3	11.0	9.0	10.0	10.0	8.8	10.4
L5	11.6	11.3	13.6	13.0	9.4	7.0	10.7	8.0	15.0	13.0	12.3	16.4	16.0	16.0	16.0	14.0	11.0	13.0	12.0	15.0
p-value	0.399	0.293			0.605	0.438			0.065	0.209			0.937	0.654			0.586	0.904		

CT – computer tomography, MRI – magnetic resonance imaging.

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REFERENCES

1. Heemskerk JL, Kruyt MC, Colo D, Castelein RM, Kempen DHR. Prevalence and risk factors for neural axis anomalies in idiopathic scoliosis: a systematic review. Spine J. 2018;18(7):1261-71. doi:10.1016/j.spinee.2018.02.013.
2. Scaramuzzo L, Giudici F, Archetti M, Minoia L, Zagra A, Bongetta D. Clinical Relevance of Preoperative MRI in Adolescent Idiopathic Scoliosis: Is Hydromyelia a Predictive Factor of Intraoperative Electrophysiological Monitoring Alterations?. Clin Spine Surg. 2019;32(4):E183--e7. doi:10.1097/bsd.0000000000000820.
3. Kouri A, Herron JS, Lempert N, Oliver M, Hubbard EW, Talwalkar VR, et al. Magnetic Resonance Imaging in Infantile Idiopathic Scoliosis: Is Universal Screening Necessary?. Spine Deform. 2018;6(6):651-5. doi:10.1016/j.jspd.2018.04.007.
4. Swarup I, Derman P, Sheha E, Nguyen J, Blanco J, Widmann R. Relationship between thoracic kyphosis and neural axis abnormalities in patients with adolescent idiopathic scoliosis. J Child Orthop. 2018;12(1):63-9. doi:10.1302/1863-2548.12.170163.
5. Xu W, Zhang X, Zhu Y, Zhu X, Li Z, Li D, et al. An analysis of clinical risk factors for adolescent scoliosis caused by spinal cord abnormalities in China: proposal for a selective whole--spine MRI examination scheme. BMC Musculoskelet Disord. 2020;21(1):187. doi:10.1186/s12891-020-3182-z.
6. Zhang W, Sha S, Xu L, Liu Z, Qiu Y, Zhu Z. The prevalence of intraspinal anomalies in infantile and juvenile patients with "presumed idiopathic" scoliosis: a MRI-based analysis of 504 patients. BMC Musculoskelet Disord. 2016;17:189. doi:10.1186/s12891-016-1026-7.
7. de Oliveira RG, de Araújo AO, Gomes CR. Magnetic resonance imaging effectiveness in adolescent idiopathic scoliosis. Spine Deform. 2021;9(1):67-73. doi:10.1007/s43390-020-00205-2.
8. D'Eufemia P, Properzi E, Palombaro M, Lodato V, Mellino L, Tetti M, et al. Scoliosis secondary to ganglioneuroma: a case report and up to date literature review. J Pediatr Orthop B. 2014;23(4):322-7. doi:10.1097/bpb.0000000000000040.
9. Elnady B, Abdelgawaad AS, Elkhayat H. Giant intrathoracic ganglioneuroma with scoliosis treated by one-stage posterior resection and scoliosis correction: a case report. SICOT J. 2020;6:12. doi:10.1051/sicotj/2020012.
10. Oishi M, Fujisawa H, Tsuchiya K, Nakashima Y. Spinal cord subependymoma mimicking syringomyelia in a child: a case report. Childs Nerv Syst. 2021;37(8):2667-71. doi:10.1007/s00381-020-04940-9.
11. Tabibkhooei A, Sadeghipour A, Fattahi A. Thoracolumbar pilomyxoid astrocytoma concomitant with spinal scoliosis: A case report and literature review. Surg Neurol Int. 2019;10:235. doi:10.25259/sni_548_2019.
12. Faloon M, Sahai N, Pierce TP, Dunn CJ, Sinha K, Hwang KS, et al. Incidence of Neuraxial Abnormalities Is Approximately 8% Among Patients With Adolescent Idiopathic Scoliosis: A Meta-analysis. Clin Orthop Relat Res. 2018;476(7):1506-13. doi:10.1007/s11999.0000000000000196.
13. Tully PA, Edwards BA, Mograby O, Davis HSM, Arieskola O, Magdum S, et al. Should all paediatric patients with presumed idiopathic scoliosis undergo MRI screening for neuro--axial disease?. Childs Nerv Syst. 2018;34(11):2173-8. doi:10.1007/s00381-018-3878-7.
14. Ameri E, Andalib A, Tari HV, Ghandhari H. The Role of Routine Preoperative Magnetic Resonance Imaging in Idiopathic Scoliosis: A Ten Years Review. Asian Spine J. 2015;9(4):511-6. doi:10.4184/asj.2015.9.4.511.
15. Diab M, Landman Z, Lubicky J, Dormans J, Erickson M, Richards BS. Use and outcome of MRI in the surgical treatment of adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2011;36(8):667-71. doi:10.1097/BRS.0b013e3181da218c.
16. Nakahara D, Yonezawa I, Kobanawa K, Sakoda J, Nojiri H, Kamano S, et al. Magnetic resonance imaging evaluation of patients with idiopathic scoliosis: a prospective study of four hundred seventy-two outpatients. Spine (Phila Pa 1976). 2011;36(7):E482-5. doi:10.1097/BRS.0b013e3181e029ed.
17. Qiao J, Zhu Z, Zhu F, Wu T, Qian B, Xu L, et al. Indication for preoperative MRI of neural axis abnormalities in patients with presumed thoracolumbar/lumbar idiopathic scoliosis. Eur Spine J. 2013;22(2):360-6. doi:10.1007/s00586-012-2557-8.
18. Rajasekaran S, Kamath V, Kiran R, Shetty AP. Intraspinal anomalies in scoliosis: An MRI analysis of 177 consecutive scoliosis patients. Indian J Orthop. 2010;44(1):57-63. doi:10.4103/0019-5413.58607.
19. Zhang Y, Xie J, Wang Y, Bi N, Li T, Zhang J, et al. Intraspinal neural axis abnormalities in severe spinal deformity: a 10-year MRI review. Eur Spine J. 2019;28(2):421-5. doi:10.1007/s00586-018-5522-3.
20. Wu L, Qiu Y, Wang B, Zhu ZZ, Ma WW. The left thoracic curve pattern: a strong predictor for neural axis abnormalities in patients with "idiopathic" scoliosis. Spine (Phila Pa 1976). 2010;35(2):182-5. doi:10.1097/BRS.0b013e3181ba6623.
21. Lee CS, Hwang CJ, Kim NH, Noh HM, Lee MY, Yoon SJ, et al. Preoperative Magnetic Resonance Imaging Evaluation in Patients with Adolescent Idiopathic Scoliosis. Asian Spine J. 2017;11(1):37-43. doi:10.4184/asj.2017.11.1.37.
22. Richards BS, Sucato DJ, Johnston CE, Diab M, Sarwark JF, Lenke LG, et al. Right thoracic curves in presumed adolescent idiopathic scoliosis: which clinical and radiographic findings correlate with a preoperative abnormal magnetic resonance image?. Spine (Phila Pa 1976). 2010;35(20):1855-60. doi:10.1097/BRS.0b013e3181d4f532.
23. Inoue M, Minami S, Nakata Y, Otsuka Y, Takaso M, Kitahara H, et al. Preoperative MRI analysis of patients with idiopathic scoliosis: a prospective study. Spine (Phila Pa 1976). 2005;30(1):108-14. doi:10.1097/01.brs.0000149075.96242.0e.
24. Hooker MS, Yandow SM, Fillman RR, Raney EM. Pedicle rotation in scoliosis: a marker for occult intrathecal abnormalities. Spine (Phila Pa 1976). 2006;31(5):E144-8. doi:10.1097/01.brs.0000201326.00208.b4.
25. Dolganova TI, Aksenov AY, Garipov II, Sergeenko OM, Diachkov KA, Cherepanov ID, et al. Quantitative assessment of the sagittal and coronal balance of the axial skeleton using 3D motion capture. Genij Ortop. 2023;29(3):307-15. doi:10.18019/1028-4427-2023-29-3-307-315.
26. Jayaswal A, Kandwal P, Goswami A, Vijayaraghavan G, Jariyal A, Upendra BN, et al. Early

onset scoliosis with intraspinal anomalies: management with growing rod. Eur Spine J. 2016;25(10):3301-7. doi:10.1007/s00586-016-4566-5.
27. Pahys JM, Samdani AF, Betz RR. Intraspinal anomalies in infantile idiopathic scoliosis: prevalence and role of magnetic resonance imaging. Spine (Phila Pa 1976). 2009;34(12):E434-8. doi:10.1097/BRS.0b013e3181a2b49f.
28. O'Neill NP, Miller PE, Hresko MT, Emans JB, Karlin LI, Hedequist DJ, et al. Scoliosis with Chiari I malformation without associated syringomyelia. Spine Deform. 2021;9(4):1105-13. doi:10.1007/s43390-021-00286-7.
29. Ozturk C, Karadereler S, Ornek I, Enercan M, Ganiyusufoglu K, Hamzaoglu A. The role of routine magnetic resonance imaging in the preoperative evaluation of adolescent idiopathic scoliosis. Int Orthop. 2010;34(4):543-6. doi:10.1007/s00264-009-0817-y.
30. Singhal R, Perry DC, Prasad S, Davidson NT, Bruce CE. The use of routine preoperative magnetic resonance imaging in identifying intraspinal anomalies in patients with idiopathic scoliosis: a 10-year review. Eur Spine J. 2013;22(2):355-9. doi:10.1007/s00586-012-2538-y.
31. Fruergaard S, Ohrt-Nissen S, Dahl B, Kaltoft N, Gehrchen M. Neural Axis Abnormalities in Patients With Adolescent Idiopathic Scoliosis: Is Routine Magnetic Resonance Imaging Indicated Irrespective of Curve Severity?. Neurospine. 2019;16(2):339-46. doi:10.14245/ns.1836154.077.
32. Martin BD, McClung A, Denning JR, Laine JC, Johnston CE. Intrathecal Anomalies in Presumed Infantile Idiopathic Scoliosis: When Is MRI Necessary?. Spine Deform. 2014;2(6):444-7. doi:10.1016/j.jspd.2014.03.003.
33. Pazarlis K, Jonsson H, Karlsson T, Schizas N. Preoperative MRI and Intraoperative Monitoring Differentially Prevent Neurological Sequelae in Idiopathic Scoliosis Surgical Correction, While Curves >70 Degrees Increase the Risk of Neurophysiological Incidences. J Clin Med. 2022;11(9):2602. doi:10.3390/jcm11092602.
34. Lewandrowski KU, Rachlin JR, Glazer PA. Diastematomyelia presenting as progressive weakness in an adult after spinal fusion for adolescent idiopathic scoliosis. Spine J. 2004;4(1):116-9. doi:10.1016/j.spinee.2003.08.028.
35. Barutçuoğlu M, Selçuki M, Umur AS, Mete M, Gurgen SG, Selcuki D. Scoliosis may be the first symptom of the tethered spinal cord. Indian journal of orthopaedics. 2016;50(1):80-6. doi:10.4103/0019-5413.173506.
36. Paterson A, Frush DP, Donnelly LF. Helical CT of the body: are settings adjusted for pediatric patients? AJR American journal of roentgenology. 2001;176(2):297-301. doi:10.2214/ajr.176.2.1760297.
37. Meulepas JM, Ronckers CM, Smets A, Nievelstein RAJ, Gradowska P, Lee C, et al. Radiation Exposure From Pediatric CT Scans and Subsequent Cancer Risk in the Netherlands. J Natl Cancer Inst. 2019;111(3):256-63. doi:10.1093/jnci/djy104.
38. Larson AN, Schueler BA, Dubousset J. Radiation in Spine Deformity: State-of-the-Art Reviews. Spine Deform. 2019;7(3):386-94. doi:10.1016/j.jspd.2019.01.003.
39. Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ. 2013;346:f2360. doi:10.1136/bmj.f2360.
40. Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr. 2013;167(8):700-7. doi:10.1001/jamapediatrics.2013.311.
41. Ronckers CM, Land CE, Miller JS, Stovall M, Lonstein JE, Doody MM. Cancer mortality among women frequently exposed to radiographic examinations for spinal disorders. Radiation Res. 2010;174(1):83-90. doi:10.1667/rr2022.1.
42. Simony A, Hansen EJ, Christensen SB, Carreon LY, Andersen MO. Incidence of cancer in adolescent idiopathic scoliosis patients treated 25 years previously. Eur Spine J. 2016;25(10):3366-70. doi:10.1007/s00586-016-4747-2.
43. Goldberg MS, Mayo NE, Levy AR, Scott SC, Poîtras B. Adverse reproductive outcomes among women exposed to low levels of ionizing radiation from diagnostic radiography for adolescent idiopathic scoliosis. Epidemiology. 1998;9(3):271-8.
44. Sarwahi V, Amaral T, Wendolowski S, Gecelter R, Sugarman E, Lo Y, et al. MRIs Are Less Accurate Tools for the Most Critically Worrisome Pedicles Compared to CT Scans. Spine Deform. 2016;4(6):400-6. doi:10.1016/j.jspd.2016.08.002.
45. Sarlak AY, Buluç L, Sarisoy HT, Memişoğlu K, Tosun B. Placement of pedicle screws in thoracic idiopathic scoliosis: a magnetic resonance imaging analysis of screw placement relative to structures at risk. Eur Spine J. 2008;17(5):657-62. doi:10.1007/s00586-008-0639-4.