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CASE SERIES

Magnetic resonance imaging effectiveness in adolescent idiopathic scoliosis

Rafael Garcia de Oliveira[1] · **Alex Oliveira de Araújo**[1] · **Cícero Ricardo Gomes**[1]

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Abstract

Objective To assess the effectiveness of preoperative magnetic resonance imaging (MRI) in adolescent idiopathic scoliosis (AIS) patients with unremarkable history and physical examination.

Methods The imaging data of consecutive patients with presumed AIS treated with a posterior spinal fusion between 2010 and 2016 were reviewed. The presence of traditional risk factors, atypical curve patterns, and its association with relevant abnormalities on MRI were investigated. The number needed to diagnose (NND) and the number needed to misdiagnose (NNM) were calculated to measure MRI effectiveness.

Results A total of 198 consecutive patients were identified and divided according to the presence of MRI findings. Both groups predominantly consisted of females, with a mean age of 15 years and right thoracic curvature. Neural axis abnormalities were detected in 25 patients, and the groups had a similar proportion of atypical findings, as curve magnitude, thoracic kyphosis, curve direction, and sex. The NND was 7.9 patients and NNM was 66 patients, meaning that the management was changed before the spine fusion in 12% of patients with neural axis abnormalities. None of the traditional risk factors could predict a higher incidence of neural axis abnormalities in asymptomatic AIS patients.

Conclusion Traditional risk factors may not be predictive of patients with a higher risk of changes in MRI. Both NND and NNM are representations easily understood by clinicians. Using these indexes to define if a patient should be submitted for additional imaging tests may facilitate the decision of using MRI as a preoperative screening tool in AIS patients.

Level of evidence Level II

Keywords Adolescent idiopathic scoliosis · Magnetic resonance imaging · Neural axis abnormality · Posterior fusion · Clinical investigation

Introduction

Adolescent idiopathic scoliosis (AIS) is diagnosed on the basis of exclusion of other pathologies through clinical examination and complementary investigations. The investigation of choice to assess patients with AIS is a full spine radiograph in the standing position, which facilitates the identification of the curve pattern, severity, and flexibility, as well as the presence of congenital malformations. However, it cannot identify neural axis abnormalities in patients with AIS [1–3].

In the past decades, the MRI technique has improved and gradually become more accessible, resulting in greater recognition of neural axis and anatomical abnormalities with proven etiological importance where previously a diagnosis of idiopathic scoliosis was made [1–4]. The incidence of neural axis abnormalities in patients with unremarkable history and physical examination ranges from 4 to 26% [1, 2, 4–7]. The main types of identified abnormalities are Arnold–Chiari malformation, tethered cord, diastematomyelia, syringomyelia, lipoma and lipomeningocele, teratoma, neurenteric cyst, dermoid cyst, and epidermoid cyst [3, 8–10].

Due to the rare incidence of neural axis findings that may cause intraoperative or postoperative complications, statistical analysis with available sample sizes have been unattainable. Currently, MRI is commonly indicated in AIS patients with pain, neurological findings, atypical curve pattern (left

✉ Rafael Garcia de Oliveira
rafagaroli@gmail.com

[1] Department of Orthopedics, SARAH Network of Rehabilitation Hospitals, SMHS Qd 301 Bloco A, Brasília, DF 70335-901, Brazil

thoracic, short segment, rapid progression, thoracic kyphosis angle of > 30°), early-onset scoliosis, male sex, and presence of any associated anomaly [1–6].

The routine use of magnetic resonance imaging (MRI) is questioned as there is no evidence of differences in complication rates between normal and abnormal MRI patients. Furthermore, it may increase treatment costs as an additional test is performed, and some false-positive cases may need further unnecessary investigation and procedures [3, 4]. On the other hand, some authors defend the use of routine MRI as, despite a low rate of additional neurosurgical approach or interference in the scoliosis treatment, it leads to a deeper knowledge of the patient's anatomy, an individualized choice of surgical resources and correction maneuvers, and avoidance of any future need to assess the spinal canal in the arthrodesis area [6, 8–10].

Diagnostic tests are not perfect, as they can have false-positive and false-negative results. Additional measures of test effectiveness have been developed to investigate and facilitate the test result interpretation, such as sensitivity, specificity, predictive values, accuracy, and likelihood ratio [11]. MRI findings may be relevant, but do not change the patient management or may indicate the need for further neurosurgical approaches. Therefore, inspired by the idea of number needed to treat and number needed to misdiagnose, we propose two new indexes to evaluate the MRI effectiveness in AIS patients [11, 12]. Additionally, we evaluated the reliability of traditional risk factors indicating MRI in the preoperative decision-making process in AIS patients.

Materials and methods

Our institutional review board approved the study. A total of 207 consecutive patients with presumed AIS who were surgically treated between 2010 and 2016 were included. Patients with syndromes known to be associated with spinal deformities, congenital anomalies, neuromuscular disorders, pre-existing neural axis abnormalities, and neoplasia, or any evidence of non-idiopathic scoliosis like any neurological findings were excluded. The medical records of 198 patients were reviewed to determine the following patient characteristics: age at presentation, sex, and age at the time of surgery. Radiological parameters, such as curve type according to the Lenke classification system, direction and magnitude of the main curve, and thoracic kyphosis were measured on whole-spine standing radiographs and supine side-bending radiographs [13]. Thoracic kyphosis was measured from the superior endplate of T5 to the inferior endplate of T12 using the Cobb method.

MRI findings considered relevant were syringomyelia, neoplasia, Arnold–Chiari malformation, and basilar invagination. Disc hernias, spondylolysis, Tarlov cyst, dural ectasia, neurenteric cyst, dermoid cyst, and epidermoid cyst, or non-spinal changes were not considered relevant, as they do not interfere in the curve or surgery. Two board-certified radiologists of the institution evaluated all MRI examinations.

The number needed to diagnose (NND) is the number of patients who must be tested to find one relevant MRI finding. It is calculated as 1/(relevant MRI finding rate). The number needed to misdiagnose (NNM) is the number of patients who must be tested to find one indication of neurosurgical approach. It is calculated as 1/(neurosurgical approach rate).

Data were submitted for statistical analysis using STATA—statistics/data analysis (Stata v14.2, StataCorp, College Station, Texas). The normal distribution of continuous data was assessed using the Shapiro–Wilk test, non-parametric data were analyzed using the Mann–Whitney *U* test, categorical variables using the Chi-square test, and statistical significance was defined as $p < 0.05$.

Results

After including 207 patients initially, two were excluded because they did not undergo preoperative MRI, and 7 had neurological deficit findings at initial evaluation. Among the remaining 198 patients evaluated, 25 (12.6%) had abnormal neural axis on the whole-spine MRI findings: syringomyelia in 16, Arnold–Chiari malformation in 4, basilar invagination in 4, and neoplastic lesions in 2 patients (Fig. 1). One patient with Arnold–Chiari malformation also had concomitant syringomyelia. Among these 25 patients, the management approach in 3 (12%) patients was changed before spine fusion, which corresponds to 1.5% of the present cohort. The NND in this cohort was 7.9 patients, while the NNM was 66 patients. We pooled the data of recently published studies, which included 1835 asymptomatic AIS patients, had an NND of 10 patients and an NNM of 38.2 patients (Table 2).

All patients were divided into two groups according to the presence of relevant changes in MRI (Table 1). The mean age of patients with changes detected on MRI was similar to that of those without changes (14.8 vs. 15.1, $p = 0.89$). The number of male patients was higher in the group with changes in MRI, 20% vs. 11%, but it was not significant ($p = 0.19$). The proportion of patients with left thoracic curve was 24% in patients with and 18.5% in those without findings on MRI ($p = 0.51$). According to the Cobb method, the mean thoracic kyphosis from T5 to T12 (TK) was 23.2° and 25.3°, and the magnitude of the main curve on the coronal plane was 71.2° and 67.8° in patients with and without relevant MRI changes, respectively. They also did not differ significantly, $p = 0.52$ and $p = 0.23$, respectively. Concerning Lenke's classification, between-group differences in types 1–6 were not significant.

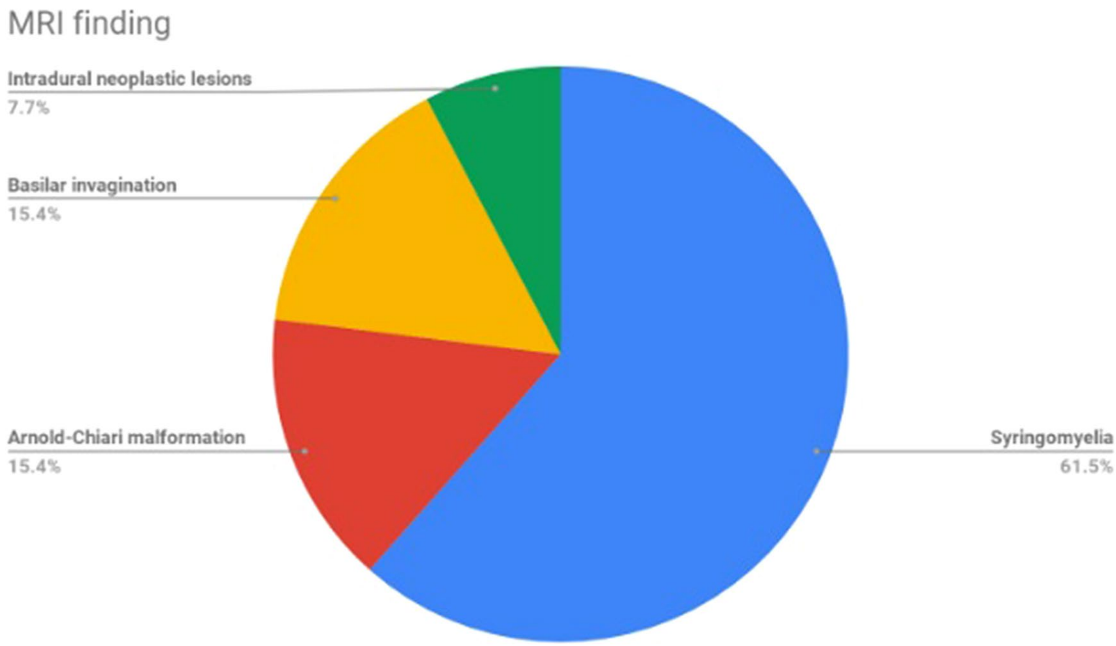

Fig. 1 Graphic showing the frequency of each relevant neural axis abnormality among 25 patients with MRI findings. MRI: magnetic resonance imaging

Table 1 Comparison of clinical and radiological characteristics between the groups

Variable	Relevant MRI changes	Not relevant MRI changes	*p*
n	25	173	
Age (years)[a]	15 (± 2.1)	15.1 (± 2.2)	0.89
Left thoracic curve (%)	24	18.5	0.51
Male gender (%)	20	11	0.19
Thoracic kyphosis [a]	23.2º (± 13.6)	25.3º (± 14.7)	0.52
Lenke classification (%)			0.91
1	20	17	
2	28	20	
3	16	23	
4	16	19	
5	8	7	
6	12	14	
Main curve magnitude[a]	71.2º (± 15.9)	67.8º (± 16.7)	0.23

MRI magnetic resonance imaging

[a]Mean (standard deviation)

Patients with abnormal findings were referred to a neurosurgeon for further evaluation. Three patients were indicated a neurosurgical approach prior to scoliosis treatment. One female patient was suspected with low-grade astrocytoma; therefore, avoiding arthrodesis at the midline tumor level (T7–T8) was recommended. The deformity was corrected, and after 6 years of clinical follow-up, MRI findings remained unchanged (Fig. 2). She had a 52° left curve and TK was 44°. In another case, a boy showed an increase in medullar gauge from T2 to T4 on MRI, and after further investigation, the patient underwent a laminectomy with biopsy before spinal fusion. A neoplastic lesion was excluded, and the deformity was corrected. He had a 74° right thoracic curve and TK was 4°. Both cases were not regarded as false positives, as their surgical strategies were definitely modified (avoidance of midline arthrodesis or biopsy). Future evaluation and approach to these lesions would be disrupted by the implants, and maybe even require implant excision for better imaging; hence, they were considered true positives. In the third case, a female patient had a type 1 Arnold–Chiari malformation with a syringomyelic cavity from C2 to T11, which was surgically treated before the spinal fusion because of its severity and the large syringomyelic cavity (Fig. 3). She had an 81° right thoracic curve and TK was 30°.

In two cases, noteworthy changes not related to scoliosis were found: one patient had a moderate-volume bronchogenic cyst in the mediastinum, and the other had a congenital diaphragmatic hernia.

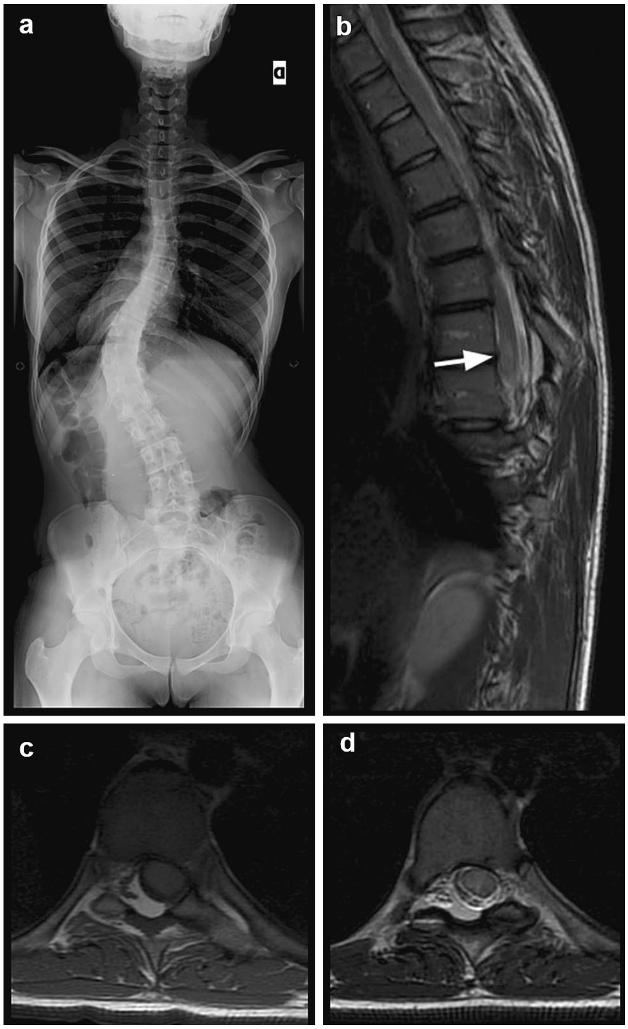

Fig. 2 A 14-year-old girl. **a** Full spine standing anteroposterior radiograph showing a left thoracolumbar curve. **b** Sagittal magnetic resonance image showing an expansive lesion at T7–8 (white arrow). **c**, **d** Transverse section magnetic resonance image through T7–T8 showing an expansive lesion in the center-right of the medullary cord

Discussion

Thinking in terms of patients rather than probabilities might be more intuitive [11]. To the author's knowledge, this is the first study that characterized MRI indication expressed in terms of NND and NNM.

We found a consistent incidence of neural axis abnormalities in presumed AIS. Among every 7.9 patients in our cohort, 1 had some relevant MRI finding (NND), and none of the traditional risk factors showed statistical significance in predicting neural axis abnormalities. The number of supposed AIS patients who needed to undergo MRI analysis to have a neurosurgical intervention was 66

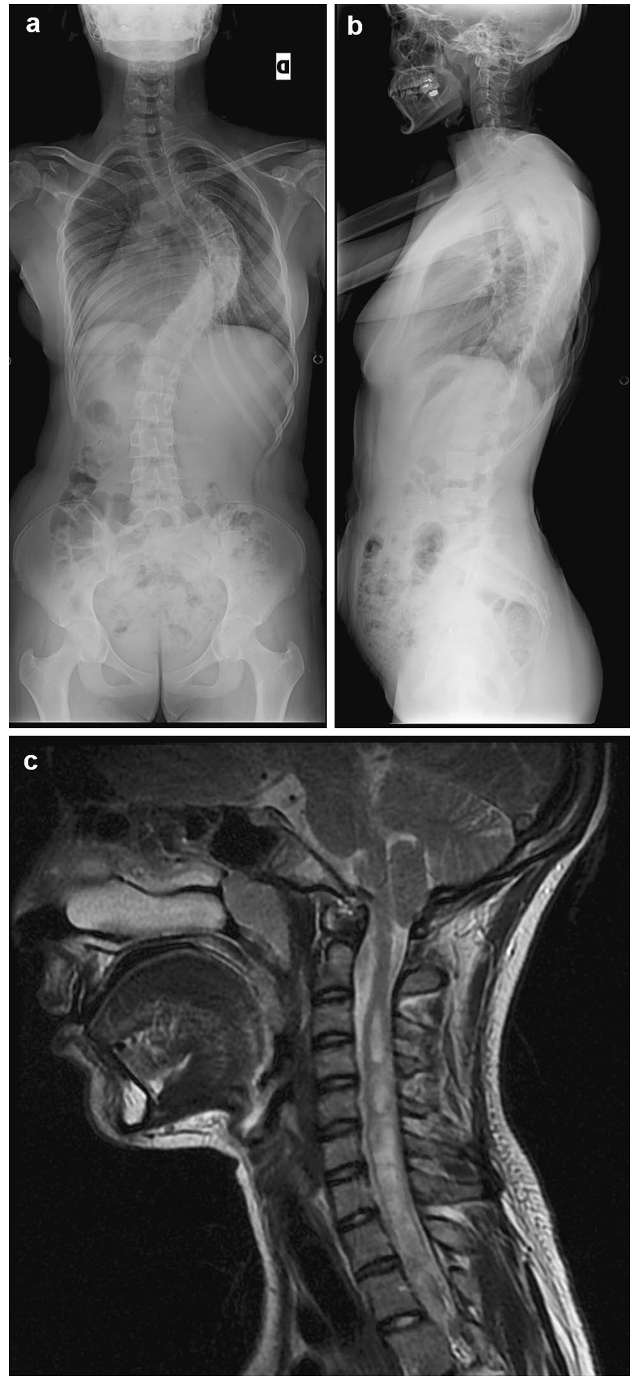

Fig. 3 An 11-year-old girl. **a** Full spine standing anteroposterior radiograph showing right thoracic curve Lenke 2AN. **b** Full spine standing lateral radiograph showing a normal thoracic kyphosis. **c** Sagittal MRI showing type 1 Arnold–Chiari malformation and syringomyelia cavity extending from C2 to T11

(NNM). These values are not supposed to change current practice, but they aim to facilitate the understanding and ameliorate the debate of the effectiveness of MRI in this population.

NND and NNM

The current recommendation is that patients with spinal cord findings should be evaluated by a neurosurgeon before spinal fusion, although neurosurgical procedures in asymptomatic patients remain controversial, as it relies on subjective analysis of the neurosurgeon and is not clear whether these findings may lead to excessive treatment in some patients [14, 15]. For instance, one patient of this cohort might be considered false positive, following a negative biopsy and may have been overtreated. In patients with syringomyelia, the size that would indicate surgical intervention or whether correction maneuvers might lead to neurological complications or worsening of the syrinx remains to be elucidated, with evidence demonstrating that hydromyelia is correlated with higher incidence of intraoperative electrophysiological alterations, but its clinical significance remains uncertain [15].

Some authors do not recommend the use of preoperative MRI in AIS patients, arguing rather that detailed clinical examination is paramount, with attention to subtle alterations such as asymmetry or absence of cutaneous-abdominal reflex [5, 10, 16]. Do et al. found that only 2% of patients had neural axis abnormalities among the 327 patients with AIS in their prospective study, corresponding to an NND of 50 patients, suggesting that preoperative MRI is not necessary for neurologically intact patients [17]. This finding may be related to the increment in MRI image quality, image definition, and the fact that only 42% of their cohort had preoperative MRI.

More recent studies have found similar results to our data (Table 2). In 2010, Ozturk et al. evaluated 249 patients and found 20 (8%) with an unexpected intraspinal anomaly resulting in an NND of 12.4 patients [1]. Three (1.2%) underwent neurosurgical procedures that translate to an NNM of 83 patients. More recently, in 2017, Lee's study evaluated 378 patients and found 24 (6.3%) abnormal neural axis findings, revealing an NND of 15.8 patients. Among them, 3 (0.8%) needed neurosurgical intervention, which reveals an NNM of 126 patients [3]. In 2019, Swarup evaluated 259 patients and found 41 (15.8%) with abnormal neural axis finding that leads to an NND of 6.3 patients, and 1 patient needed neurosurgical decompression, meaning an NNM of 259 patients [6]. This high data variability among studies may be related to the particularities of the patients of each service, the overall low incidence of neurosurgical approach prior to spinal fusion, and limited sample sizes.

Despite the low rate of neurosurgical procedures or the low frequency of relevant findings, the full spine MRI is routinely used in some services owing to the possible irreversible or catastrophic results of a misdiagnosed abnormality. Moreover, taking into account that the incidence of neurological changes in AIS surgery varies from 0.3 to 1.4% [18], any minimal possibility of increment in this rate would be reasonable to advocate MRI preoperative use. However, so far, there is no substantial evidence supporting the increment of neurological deficits in patients who did not undergo MRI preoperatively. Although it may not alter the AIS management, our study shows that it is necessary to have 7.9 full spine MRI in preoperative AIS patients to address a proper diagnosis and establish a follow-up routine if indicated.

Table 2 NND and NNM calculate for different studies

	n	NND	NNM
Present cohort (2020)	198	7.9	66
Swarup et al. (2019) [6]	259	6.3	259
Lee et al. (2017) [3]	378	15.8	126
Ameri et al. (2015) [19]	271	10	19.4
Ozturk et al. (2010) [1]	249	12.4	83
Singhal et al. (2010) [7]	206	10.3	18.7
Davids et al. (2004) [5]	274	10.1	21.1
Pooled data	1835	10	38.2

NND number needed to diagnose, *NNM* number needed to misdiagnose

We found that 66 preoperative MRI in AIS patients would prevent missing one change in the decision-making process, including avoidance of midline arthrodesis, neurosurgical procedure, or avoidance of over-corrective maneuvers. Some studies show an even higher rate of decision-making changes, as reported by Davids et al., which showed an NND of 10 patients and a high NNM of 21 patients [5]. Singhal et al. found an NND of 10.3 and an NNM of 18.7 [7]. The comparison to Davids' study is limited and must be carefully analyzed, as MRI was only ordered for some specific presumed AIS patients with atypical curve patterns but also included those with physical examination findings.

Both pooled indexes (Table 2) call attention to a substantial rate of findings in this population and are valuable tools to help providers weigh the cost of the MRI and possible missed pathology.

Risk factors

A majority of the current studies involving AIS and MRI attempt to identify predictive factors of central nervous system abnormalities in those who are asymptomatic and do not present any neurological changes on physical examination. The main indications for MRI in AIS patients are pain, neurological alterations during the physical examination, and atypical curve pattern [5, 16, 17]. Left thoracic curve, male sex, and increased thoracic kyphosis are some of the atypical findings correlated to the presence of relevant MRI changes [2, 3, 6].

However, this study did not show a significant correlation between neurological abnormalities and any of these factors. Other studies also showed a lack of correlation of the traditional risk factors, as Diab et al., who reviewed MRI of 923 patients, including juvenile idiopathic scoliosis, found only two factors associated with neural axis abnormalities: juvenile presentation and hyperkyphosis (> 40°) [4]. Recent studies have found no association between thoracic kyphosis, coronal curve magnitude, or direction to neural axis abnormalities [19, 20]. In 2018, a meta-analysis did not identify differences in neural axis abnormalities between right and left curves, or between sexes, although it included some papers that did not include only AIS patients [19]. Therefore, more current evidence highlights that the traditional criteria may not be sensitive enough to detect asymptomatic patients with a higher risk of relevant MRI findings.

Recommendations in using preoperative MRI for AIS patients greatly varies among different centers worldwide. According to our results, there is a lack of correlation of traditional predictive factors to ensure the overall safety of patients undergoing spinal deformity correction and fusion without preoperative MRI. Conversely, the low rate of postoperative complications associated with spinal arthrodesis, independent of neural axis alterations found in entirely asymptomatic patients, makes the treatment of patients with scoliosis possible in centers that lack this resource as a cost-effectiveness analysis is not available.

Indeed, this study has some limitations. Its retrospective nature, despite the prospective and consecutive data collection, the limited sample size, and the fact that it is a single-center study, may limit external validation. Therefore, a prospective multicenter study should be conducted to provide more substantial data and evidence. Besides, some studies with shorter MRI sequences may show sufficient evidence to diagnose the primary abnormalities in the neural axis. Another relevant point would be to compare the cost of an MRI and the total cost of fusion surgery to assess its cost-effectiveness. A meta-analysis to assess the MRI test effectiveness, using pooled data for both NND and NNM in asymptomatic AIS patients, would also bring more clear data to help in the decision-making process.

Traditional risk factors may not be predictive of patients with a higher risk of changes in MRI. Both NND and NNM are representations easily understood by clinicians. Using these indexes to determine if a patient should be submitted to additional imaging tests will improve the debate on the effectiveness of MRI as a preoperative screening tool in AIS patients.

Author contributions RGO, AOA and CRG made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data; or the creation of new software used in the work; drafted the work or revised it critically for important intellectual content; approved the version to be published; agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Ethical approval Research Ethics Committee approval: 2.751.862; 07/03/2018.

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