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CLINICAL AND RADIOLOGICAL OUTCOMES OF THE NEUROMUSCULAR SCOLIOSIS TREATMENT WITH S2-ALAR-ILIAC SCREW BY INTRAOPERATIVE NAVIGATION

RESULTADOS CLÍNICO-RADIOLÓGICOS DO TRATAMENTO DA ESCOLIOSE NEUROMUSCULAR COM PARAFUSOS S2-ALAR-ILÍACO GUIADOS POR NAVEGAÇÃO INTRAOPERATÓRIA

RESULTADOS CLÍNICO-RADIOLÓGICOS DEL TRATAMIENTO DE LA ESCOLIOSIS NEUROMUSCULAR CON TORNILLOS S2-ALAR-ILÍACOS GUIADOS POR NAVEGACIÓN INTRAOPERATORIA

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ABSTRACT

Objective: Analyze the clinical and radiological aspects of the S2AI screw technique in patients with neuromuscular scoliosis undergoing deformity correction surgery by intraoperative navigation. Methods: Retrospective analysis of medical records of patients undergoing neuromuscular scoliosis correction surgery with the S2-alar-iliac technique between 2017-2020. Results: In the total sample of 35 patients, 18 (51.4%) were female, with an average age of 14.9. The average preoperative coronal curve was 100° ± 26.2, with an average correction of 55% ± 16.3, with an average coronal curve of 44.8°± 19.5 at the end of surgery and 45 ° ± 19.6 at the end of follow-up. The average preoperative pelvic obliquity was 27.9°± 10.9, with a correction rate of 66.1% ± 27.6, being 8.2° ± 5.4 at the end of surgery and 9 .4°± 7.0 at the end of the follow-up. The average of operated levels was 17.3± 0.7. All 70 S2 screws had a diameter of 7mm. The average duration of surgeries was 416 ± 86 minutes, with estimated intraoperative bleeding of 921 ± 394.1 ml. The average density of screws in the sample was 1.3 ± 0.2 screws per level, and the average density in the lumbosacral spine was 1.5 ± 0.2. Conclusions: Intraoperative navigation can contribute to the rate of complications related to the S2AI screw decrease; in addition, the length of this screw appears to have significant relevance in maintaining the correction throughout the follow-up. ***Level of evidence IV; Case series.***

Keywords: Scoliosis; Bone screws; Surgical Navigation.

RESUMO

Objetivo: Analisar os aspectos clínicos e radiológicos da técnica do parafuso S2AI em pacientes com escoliose neuromuscular submetidos à cirurgia de correção de deformidade com auxílio de navegação intraoperatória. Métodos: Análise retrospectiva de prontuários de pacientes submetidos a cirurgia de correção de escoliose neuromuscular com técnica S2-alar-ilíaco entre 2017-2020. Resultados: Do total da amostra de 35 pacientes, 18 (51,4%) eram do sexo feminino, com média de idade de 14,9. A média da curva coronal pré-operatória foi de 100° ± 26,2, com correção média de 55% ± 16,3, com uma média da curva coronal de 44,8°± 19,5 ao final da cirurgia e de 45° ± 19,6 ao final do seguimento. A obliquidade pélvica média pré-operatória foi de 27,9°± 10,9, com uma taxa de correção de 66,1% ± 27,6, sendo de 8,2° ± 5,4 ao final da cirurgia e de 9,4°± 7,0 ao final do seguimento. A média de níveis operados foi de 17,3± 0,7. Todos os 70 parafusos de S2 apresentavam diâmetro de 7mm. O tempo médio de duração das cirurgias foi 416 ± 86 minutos, com estimativa de sangramento intraoperatório de 921 ± 394,1 ml. A densidade média de parafusos da amostra foi de 1.3 ± 0.2 parafusos por nível e a densidade média na coluna lombossacra de 1,5 ± 0,2. Conclusões: A navegação intraoperatória pode contribuir com a diminuição da taxa de complicações relacionadas ao parafuso de S2AI, além disso, que o comprimento deste parafuso aparenta ter uma relevância significativa na manutenção da correção ao longo do seguimento. ***Nível de evidência IV; Série de casos.***

Descritores: *Escoliose; Parafusos ósseos; Navegação Cirúrgica.*

RESUMEN

Objetivo: Analizar los aspectos clínicos y radiológicos de la técnica del tornillo S2AI en pacientes con escoliosis neuromuscular sometidos a cirugía de corrección de deformidades con ayuda de navegación intraoperatoria. Métodos: Análisis retrospectivo de historias clínicas de pacientes sometidos a cirugía de corrección de escoliosis neuromuscular con la técnica S2-alar-ilíaca entre 2017-2020. Resultados: De la muestra de 35 pacientes, 18 (51,4%) eran mujeres, con una edad media de 14,9 años. La curva coronal media preoperatoria fue 100° ± 26,2, con una corrección media del 55% ± 16,3, con una curva coronal media de 44,8° ± 19,5 al final de la cirugía y de 45° ± 19,6 al final

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del seguimiento. La oblicuidad pélvica preoperatoria media fue de 27,9° ± 10,9, con una tasa de corrección del 66,1% ± 27,6, siendo de 8,2° ± 5,4 al final de la cirugía y de 9,4°± 7,0 al final del seguimiento. El promedio de los niveles operados fue de 17,3± 0,7. Los 70 tornillos S2 tenían un diámetro de 7 mm. La duración promedio de las cirugías fue de 416 ± 86 minutos. Sangrado intraoperatorio estimado de 921 ± 394,1 ml. La densidad media de tornillos en la muestra fue 1,3 ± 0,2 tornillos por nivel y la densidad media en columna lumbosacra fue 1,5 ± 0,2. Conclusiones: La navegación intraoperatoria puede contribuir a la disminución de complicaciones relacionadas con el tornillo S2AI, además, la longitud de este tornillo parece tener una relevancia significativa en el mantenimiento de la corrección durante todo el seguimiento. ***Nivel de evidencia IV; Series de casos.***

Descriptores: *Escoliosis; Tornillos Óseos; Navegación Quirúrgica.*

INTRODUCTION

Rigid spinopelvic fixation may be required for complex spinal pathologies such as neuromuscular or congenital deformities, adult scoliosis, high-grade spondylolisthesis, and pseudarthrosis.[1] The main options for performing this fixation are the Galveston technique, developed by Allen and Ferguson in 1984, the iliac screw (IS), and the S2-alar-iliac screw, described in 2007 by Sponseller et al. (S2AI).[2-6]

Patients with neuromuscular scoliosis present faster progression, more rigid and complex curves, and usually require surgical treatment.[7] Surgery aims to obtain a well-balanced spine in the sitting position, correct pelvic obliquity, give more independence to the upper limbs and stop the deterioration of lung function.[8] Therefore, the gold standard treatment for patients with neuromuscular scoliosis and increased pelvic obliquity usually includes pelvic fixation.[9,10]

The S2AI screw allows high pullout resistance, requiring less dissection of the paraspinal musculature and positioning in line with the other screws.[11] Also, this technique has a low rate of cutaneous prominence, pseudarthrosis, and mechanical stress in S1.[11-14]

The main complications associated with lumbopelvic instrumentation are implant failure (breakage or loosening of screws or nails), prominence of the synthesis material, pseudarthrosis, and postoperative infection. In a systematic review comparing the complications of the iliac screw with the S2-alar-iliac screw, Gao Z et al.[15] observed significantly lower complication rates in patients who used the S2AI screw. In addition, this group had a better correction of OP, considering the pediatric range.[16]

Therefore, the present study aims to analyze the clinical and radiological aspects of the S2AI screw technique in patients with neuromuscular scoliosis undergoing spinal deformity correction surgery with the aid of intraoperative navigation at a referral center.

METHODS

The study comprises a retrospective analysis of medical records of patients who underwent neuromuscular scoliosis correction surgery with the S2-alar-iliac technique between January 2017 and March 2020. Clinical information on in-hospital and outpatient post-surgical evolution and images performed in the postoperative control of these patients were collected and analyzed. Radiographs (XR) and tomography (CT) were performed during the preoperative period, immediate postoperative period, and the final radiograph of the segment was analyzed.

Inclusion criteria: patients were undergoing surgeries to correct neuromuscular scoliosis using the S2-alar-iliac technique, with outpatient follow-up of at least one year and postoperative control images (CT and/or X-ray). Exclusion criteria: incomplete records.

Measurements were obtained independently by two examiners with similar levels of experience. The analyzed data were: age; sex; underlying pathology; curve type; pre- and postoperative radiological parameters (pelvic obliquity, main curve cobb angle, thoracic or thoracolumbar kyphosis, lumbar lordosis, percentage of correction of scoliosis and pelvic obliquity, screw density); surgical time; estimated blood loss; intraoperative use of blood components; extension of arthrodesis (number of arthrodesis levels); screw length and diameter of S2; the presence of cerebrospinal fluid fistula, postoperative infection; new postoperative neurological deficits; length of stay in the hospital and intensive care unit; drain time and drainage volume and breakage or failure of screws or rods.

Continuous data were described by the average, and its respective standard deviation (SD) and 95% confidence interval (95%CI), and categorical data were described by the absolute frequency and respective categorical proportion. To compare the variables with the screw density of the curve and loss of pelvic obliquity, the T-Student test, the chi-square test, and Fisher's exact test were used when necessary. A type I error of up to 5% was accepted as a statistically significant difference. Statistical analyzes were performed by an independent statistician blinded to the data. The work was approved by the ethics and research committee of the institution - CAAE 51848821.8.0000.0022, exempt from the application of the TCLE.

RESULTS

The study analyzed 35 patients with neuromuscular scoliosis, 18 (51.4%) female. The average age of patients at the time of surgery was 14.9 ± 4.0 years. Most of the sample (62.9%) had a body mass index in the low weight category. Myelomeningocele was the main etiology, with 13 cases (37%), of neuromuscular deformities in the sample. All patients were non-ambulatory. The average postoperative follow-up time was 21.4 ± 10.3 months (Table 1).

The average preoperative coronal curve was 100° ± 26.2. Postoperatively, an average correction of 55% ± 16.3 was obtained, with an average coronal curve of 44.8°± 19.5 at the end of surgery and 45° ± 19.6 at the end of follow-up. The average preoperative pelvic obliquity was 27.9°± 10.9, with a correction rate of 66.1% ± 27.6, being 8.2° ± 5.4 at the end of surgery and 9 .4°± 7.0 at the end of follow-up (Table 2).

Regarding the surgical aspects, the average of levels operated was 17.3± 0.7. All 70 S2 screws had a diameter of 7 mm, with the screw on the concave side of the lumbar curve (place of the greatest ascension of the pelvis) having an average length of 75.3 ± 10.1 mm and the screw on the convex side of the lumbar curve a length average of 71.8 ± 14.9 mm.

The average duration of surgeries was 416 ± 86 minutes, with an average estimate of intraoperative bleeding of 921 ± 394.1 ml, requiring blood transfusion in five patients (14.3%). The length of hospital stay was 21.6 ± 10.3 days, and the length of stay in the

Table 1. Demographic Characteristics.

	N (%)
Sex	
Male	17 (48.6%)
Female	18 (51.4%)
Age	14.9 (4.0)
BMI	
Low weight	22 (62.9%)
Normal	7 (20.0%)
Overweight	6 (17.1%)
Etiology	
Cerebral Palsy	7 (20.0%)
Mielomeningocele	13 (37.1%)
TRM sequel	3 (5.8%)
Others	13 (37.1%)
Non-walkers	35 (100%)
Follow-up	21.4 (10.3)

intensive care unit was 1.2 ± 0.6 days. Surgical wound infection was observed in three cases (8.6%). There was nail breakage in two cases (5.7%), nail loosening in one case (2.9%), and S2 screw breakage in three cases (8.6%). There were no cases of a cerebrospinal fluid leak or worsening of the neurological condition after surgery (Table 3).

The average density of screws in the sample was 1.3 ± 0.2 screws per level, and the average density in the lumbosacral spine was 1.5 ± 0.2. As these are non-ambulatory patients with eminently lumbar curves and a high degree of pelvic obliquity, we assessed the density of lumbar spine screws differently to determine whether this parameter influenced the correction rates and complications of the deformities. We considered high screw density in those patients with density above the sample average, which was 1.5 screws per level in the lumbar spine. (Figures 1 and 2) We observed no significant differences in the percentage of curve correction, pelvic obliquity, or even the incidence of complications between patients with high and low density of screws in the lumbar spine (Table 4).

We observed that some patients lost pelvic obliquity correction during follow-up (Figure 3). The group of patients who lost part of the pelvic obliquity correction (n=14) at the end of the follow-up had an average of 13.8º ± 6.8º of obliquity, compared with 6.5º ± 5.6 of those who did not lose (p=0.001). Analyzing these groups in detail, we observed that patients who lost pelvic obliquity correction showed a significant difference in the mean length of the S2AI screw placed on the concave side of the deformity when compared to patients who did not lose obliquity (71.1 ± 8.1 vs. 78.1 ± 10.5; p=0.043). There were no differences between groups regarding biomechanical complications secondary to failure of the synthesis material (Table 5).

DISCUSSION

This was a retrospective analysis of 35 patients with severe neuromuscular scoliosis with an average principal curve magnitude of 100° ± 26.2° and pelvic obliquity of 27.9° ± 10.9°. We observed a biomechanical complication rate of 14.1%, an infection rate of 8.6%, with 17.1% of patients requiring unplanned surgical re-approach. Among the factors related to the assembly of fixation systems, we observed that the density of screws did not interfere with the rate and maintenance of correction, and the length of the S2AI screw may have an important role in maintaining the correction of pelvic obliquities.

Curve correction in neuromuscular scoliosis requires, in most cases, more extensive fixations to the pelvis, making the surgeries longer and more complex, which can lead to complications that are

Table 2. Radiographic data.

	initial	Immediate post-op	Final follow-up	% Correction
Thoracic kyphosis	37.3 (39.8)			
Cobb	100.0 (26.2)	44.8 (19.5)	45.0 (19.6)	55.0 (16.3)
Pelvic obliquity	27.9 (10.9)	8.2 (5.4)	9.4 (7.0)	66.1 (27.6)

Mean (Standard Deviation).

Table 3. Surgical Variables and Complications.

Average levels operated	17.3 (0.7)
Average screw density per total level	1.3 (0.2)
Average density of screws per lumbar level	1.5 (0.2)
Surgical time	06:56 (01:26) *
Blood loss	921 (394.1) **
Blood transfusion^	5 (14.3%)
S2 screw length (concave)	75.3 (10.1) ***
S2 screw length (convexity)	71.8 (14.9) ***
S2 average screw diameter	7.02 (0.26) ***
Infection	3 (8.6%)
Rod breaking	2 (5.7%)
S2-alar-iliac screw breaking	3 (8.6%)
Rod releasing	1 (2.9%)
Hospitalization time	21.6 (10.3) *****
ICU time	1,2 (0,6) ****
Unscheduled surgeries	6 (17.1%)

Average (Standard Deviation) / N (%). *hours; **milliliters; *** mm; **** days; ^ Red blood cell concentrate.

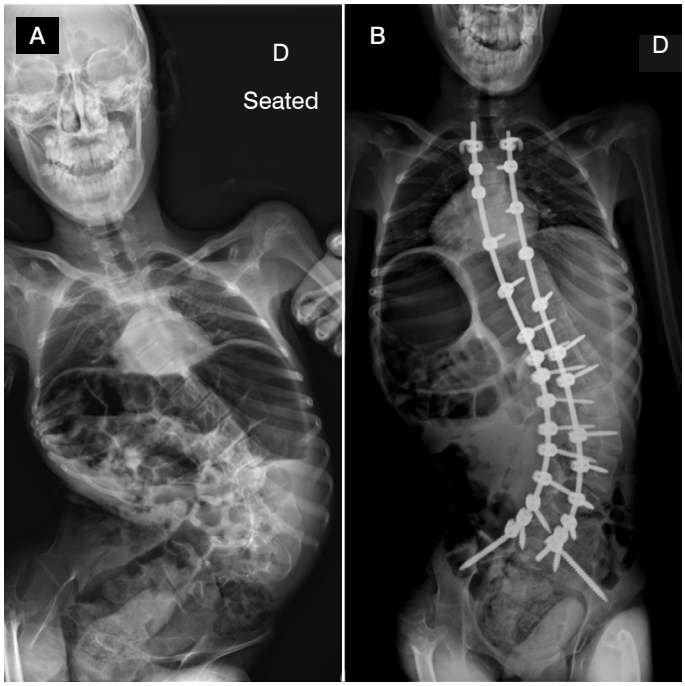

Figure 1. A 15-year-old male patient with Cerebral Palsy GMFCS 5. a) Preoperative panoramic radiograph demonstrating advanced scoliosis and pelvic obliquity b) Postoperative radiograph demonstrating correction of scoliosis and pelvic obliquity with a high-density mount of screws in the lumbar region.

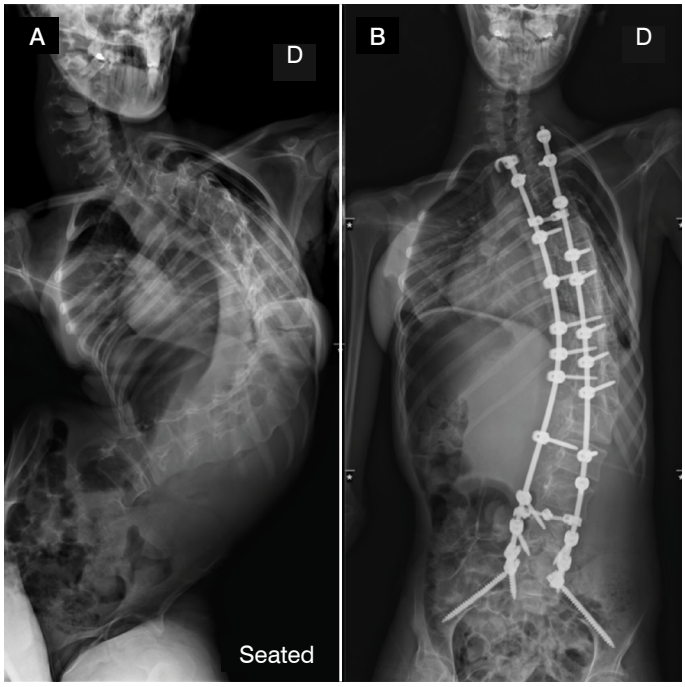

Figure 2. Female patient, 13 years old, with Cerebral Palsy GMFCS 5. a) Preoperative panoramic radiograph demonstrating advanced scoliosis and pelvic obliquity b) Postoperative radiograph demonstrating correction of scoliosis and pelvic obliquity with a low density of screws in the lumbar region.

Table 4. High lumbar density x Low lumbar density

	Low density	High density	p-value
Preoperative cobb	103.3 (30.2)	95.6 (19.8)	0.368
Preoperative OP	25.6 (11.8)	31.0 (9.0)	0.149
%Cobb correction	54.1 (17.7)	56.2 (14.8)	0.713
%OP correction	63.8 (29.0)	69.2 (26.3)	0.576
S2 screw length (concave)	74.0 (10.6)	77.0 (9.6)	0.394
S2 screw length (convexity)	74.3 (9.5)	68.5 (19.8)	0.266
Infection	2 (10.0%)	1 (6.7%)	0.610
Rod breaking	1 (5.0%)	1 (6.7%)	0.681
S2-alar-iliac screw breaking	1 (5.0%)	2 (13.3%)	0.390
Rod releasing	1 (5.0%)	0 (0%)	0.571

Average (Standard Deviation) / N (%). OP: pelvic obliquity.

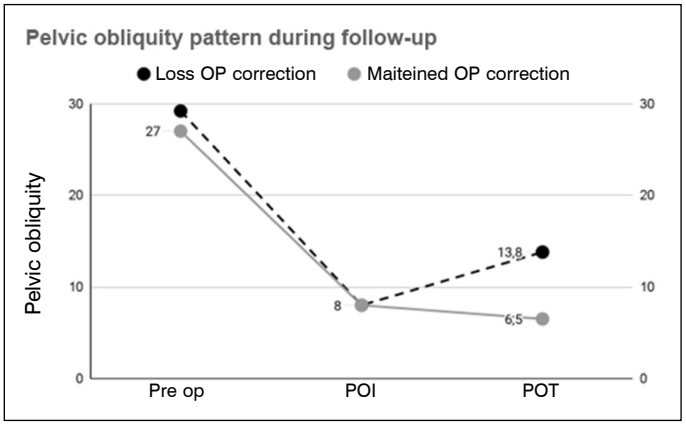

Figure 3. Graph illustrating the behavior of pelvic obliquity between the groups of patients who lost correction and those who maintained it.

Table 5. Pelvic Obliquity (OP) during follow-up.

	Loss op correction	Maintained op correction	p-value
Preoperative cobb	109.4 (24.0)	93.8 (26.3)	0.086
Preoperative OP	29.2 (10.8)	27.0 (11.1)	0.571
% correction OP	71.0 (20.3)	62.9 (31.7)	0.399
Final follow-up OP	13.8 (6.8)	6.5 (5.6)	0.001
S2 screw length (concave)	71.1 (8.1)	78.1 (10.5)	0.043
S2 screw length (convexity)	70.7 (7.8)	72.5 (18.3)	0.730
Stem breaking	1 (7.1%)	1 (4.8%)	0.647
S2-alar-iliac screw breakage	2 (14.3%)	1 (4.8%)	0.348
Stem releasing	1 (7.1%)	0 (0%)	0.400

Average (Standard Deviation).

usually related to the magnitude of the curve, the etiology of the deformity, and to the comorbidities presented by the patients. The main etiology of neuromuscular scoliosis in this sample was myelomeningocele (37%); in contrast to other realities, there was a higher frequency of spastic cerebral palsy.[12,13,17] This can be explained by the service being one of the country's main reference centers for treating and rehabilitating patients with spinal dysraphism. Patients with Myelomeningocele have additional difficulty understanding the anatomical lumbosacral transition and tend to have a higher rate of complications with the operative wound.[18] Despite this, we found an overall rate of surgical wound infection of 8.6% (n=3), similar to the literature. In all these cases, there was a need for reoperation for debridement, constituting a challenge in postoperative care, given the reduced mobility and comorbidities present in these patients.[19,20]

Six patients (17.1%) needed to return for unplanned surgeries. In three cases, surgical site infections occurred, as already mentioned. Regarding the others, one of the cases was a patient with Myelomeningocele who developed an ischial pressure ulcer, probably due to a change in the load area with the correction of the pelvic obliquity and required a surgical approach. The other two cases occurred in patients who had suffered sequelae from spinal cord trauma; one patient had to undergo arthrodesis revision due to breakage of the rod and S2AI screw, with significant worsening of pelvic obliquity; (Figure 4), and the other needed to remove one of the screws from the thoracic spine because it evolved with worsening of spasticity in the postoperative period. One hypothesis for a causal factor would be the positioning of the T8 screw that invaded the medial aspect of the pedicle. Unplanned surgeries are usually one of the main causes of dissatisfaction with treatment on the part of patients, in addition to generating a higher cost of treatment, whether from an individual point of view, as well as from a collective point of view with public or supplementary health. These patients need multidisciplinary care and rigorous preoperative planning to try to mitigate the damage caused by complications.[18-20]

Regarding the problems found with the synthesis material, we observed three cases of S2AI screw breakage (8.6%), two cases of rod breakage (5.7%), and one in which the rod releasing (2.9 %), totaling a failure rate per patient of 14.1%, lower than that observed in other series (20-29%).[13,21,22] In all these cases, intraoperative navigation was used for instrumentation. This important tool has helped the surgeon with anatomical aspects and in defining the best trajectory of the screws in the pelvis. This tool can contribute to a lower rate of implant malposition, as well as the insertion of screws with greater diameter and length, factors associated with a lower rate of biomechanical failures[13,23] (Figure 5).

The average diameter of the S2AI screw in the sample was 7.02 ± 0.26, considered low according to some evidence in the literature, as is the case of the study in which Sponseller et al. observed an increased rate of screw breakage in patients in whom screws with a diameter of less than 9 mm were implanted. Despite this, we observed a low rate of screw breakage of 8.6% (three cases). We believe that the choice of the best trajectory with the help of navigation may have influenced the result, allowing the screw to be inserted in a region with greater bone stock, contributing to better support and resistance during weight bearing in the sitting position and during daily activities.

When analyzing the screw density of the assemblies, we observed a low overall density (1.3 ± 0.2). Therefore, we chose to assess the lumbar region individually, as it is where most of the deformity is concentrated, together with the obliquity of the pelvis. The correction rate obtained in the coronal plane (55%) and the pelvic obliquity (65%), as well as its maintenance during the postoperative period, was not different between patients with low and high lumbar implant density (>1.5 screws per level), despite the high mean angular value of the sample deformities. These findings are consistent with other studies' evidence[24,25] (Table 4).

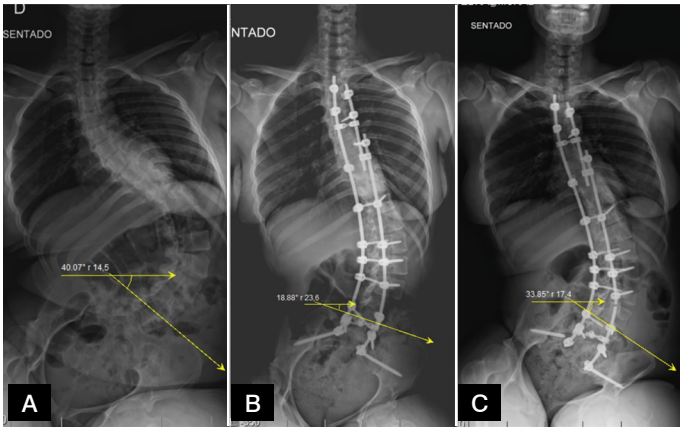

Figure 4. Female patient, 26 years old, with sequelae of spinal cord trauma and paraplegia. a) Panoramic radiograph demonstrating advanced scoliosis with 40º of pelvic obliquity in the preoperative period b) Immediate postoperative image with partial correction of the pelvic obliquity c) Image at the end of the follow-up with failure of the S2AI screw on the lumbar concavity side, rod breakage and loss of pelvic obliquity correction.

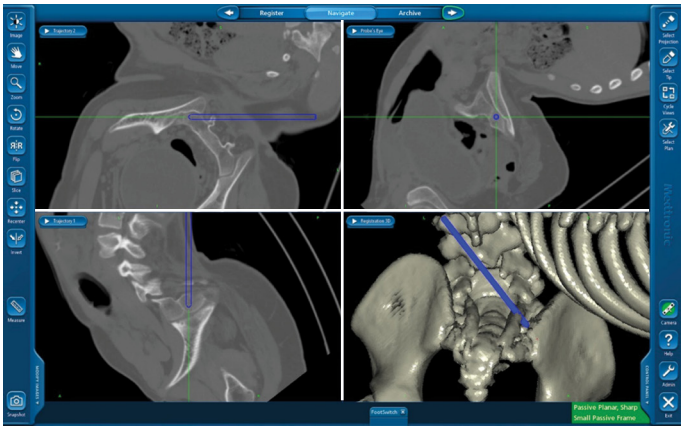

Figure 5. Male patient, 12 years old, with advanced neuromuscular scoliosis associated with Myelomeningocele with lumbar dysraphism and difficult anatomical understanding. Image of the neuronavigation system showing the best trajectory of the S2AI screw in the three-dimensional plane.

A group of 14 patients (40% of the sample) missed part of the pelvic obliquity correction during follow-up. At the end of the follow-up, these patients had a pelvic oblique of 13.8 ± 6.8 degrees, slightly more than twice the pelvic obliquity of patients with no loss of correction (6.5 ± 5.6; p = 0.001). The length of the S2AI screw inserted on the concave side of the curve (region subjected to greater distraction and stretching force during a correction) was significantly shorter in patients who lost correction (71.1 ± 8.1 vs. 78.1 ± 10 .5; p = 0.043). These data point to the importance of paying attention to the caliber of the screws and their length, which can be an important factor in maintaining the correction of pelvic obliquity during follow-up.

CONCLUSION

This study has some limitations, such as its retrospective nature, being carried out in only a single center, the limited sample size (although significant compared to studies in the literature), and the lack of a comparison group. In addition, we did not analyze the quality-of-life data through questionnaires applied to patients and caregivers.

On the other hand, this is a cohort of critically ill patients, complex from a clinical and surgical point of view, submitted to treatment with a high potential for complications and with an appropriate follow-up time. The data suggest that intraoperative navigation can contribute to decrease complications related to the S2AI screw. Additionally, the length of this screw appears to have significant relevance in maintaining the correction throughout the follow-up.

All authors declare no potential conflict of interest related to this article.

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REFERENCES

1. Santos ERG, Sembrano JN, Mueller B, Polly DW. Optimizing iliac screw fixation: a biomechanical study on screw length, trajectory, and diameter. J NeurosurgSpine.2011;14(2):219-25.
2. Mattei TA, Fassett DR. Combined S-1 and S-2 sacral alar-iliac screws as a salvage technique for pelvic fixation after pseudarthrosis and lumbosacropelvic instability. J Neurosurg Spine.2013;19(3):321-30.
3. Liu B, Wang J, Zhang L, Gan W. Radiographic study of iliac screw passages. J OrthopSurg Res. 2014;9:40.
4. Park SA, Kwak DS, You SL. Entry zone of iliac screw fixation to maintain proper entry width and screw length. EurSpine J. 2015;24(11):2573-9.
5. Moshirfar A, Rand FF, Sponseller PD, Parazin SJ, Khanna AJ, Kebaish KM, et al. Pelvic fixation in spine surgery. Historical overview, indications, biomechanical relevance, and current techniques. J Bone Joint Surg Am. 2005;87(2):89-106.
6. Sponseller PD. The S2 portal to the ilium. SeminarsSpineSurg. 2007;2:83-7.
7. Olafsson Y, Saraste H, Al-Dabbagh Z. Brace treatment in neuromuscular spine deformity. J PediatrOrthop. 1999;19(13):376-9.
8. Peelle MW, Lenke LG, Bridwell KH, Sides B. Comparison of pelvic fixation techniques in neuromuscular spinal deformity correction: Galveston rod versus iliac and lumbosacral screws. Spine. 2006;31(20):2392-8.
9. Neustadt JB, Shufflebarger HL, Cammisa FP. Spinal fusions to the pelvis augmented by Cotrel-Dubousset instrumentation for neuromuscular scoliosis. J PediatrOrthop. 1992;12(4):465-9.
10. Arlet V, Marchesi D, Papin P, Aebi M. The "MW"sacropelvic construct: an enhanced fixation of the lumbosacral junction in neuromuscular pelvic obliquity. EurSpine J. 1999;8(3):229-31.
11. Ravindra VM, Mazur MD, Brockmeyer DL, Kraus KL, Ropper AE, Hanson DS, et al. Clinical Effectiveness of S2-Alar Iliac Screws in Spinopelvic Fixation in Pediatric Neuromuscular Scoliosis: Systematic Literature Review. Global Spine J. 2020;10(8):1066-74.
12. Sponseller PD, Zimmerman RM, Ko PS, Gunne AFPT, Mohamed AS, Chang TL, et al. Low profile pelvic fixation with the sacral alar iliac technique in the pediatric population improves results at two- year minimum follow-up. Spine. 2010;35(20):1887-92.
13. Jain A, Kebaish KM, Sponseller PD. Sacral-Alar-Iliac Fixation in Pediatric Deformity: Radiographic Outcomes and Complications. SpineDeform. 2016;4(3):225-9.
14. Montero CS, Meneses DA, Alvarado F, Godoy W, Rosero DI, Ruiz JM. Outcomes and complications of S2 alar iliac fixation technique in patients with neuromuscular scoliosis: experience in a third level pediatric hospital. J SpineSurg. 2017;3(4):519-24.
15. Nakashima H, Kanemura T, Satake K, Ito K, Ishikawa Y, Ouchida J, et al. The Prevalence and Risk Factors for S2 Alar-Iliac Screw Loosening with a Minimum 2-Year Follow-up. AsianSpine J. 2020;14(2):177-84.
16. Gao Z, Sun X, Chen C, Teng Z, Xu B, Ma X, et al. Comparative radiological outcomes and complications of sacral-2-alar iliac screw versus iliac screw for sacropelvic fixation. EurSpine J. 2021;30(8):2257-70.
17. Hasan MY, Liu G, Wong HK, Tan JH. Postoperative complications of S2AI versus iliac screw in spinopelvic fixation: a meta-analysis and recent trends review. Spine J. 2020;20(6):964-72.
18. Araujo AO, Gomes CR, Fava D, Borigato EVM, Duarte LMR, De Oliveira RG. Short-term surgical complications of spinal fusion in myelomeningocele. Spine Deform. 2021;9(4):1151-9. doi: 10.1007/s43390-021-00304-8.
19. Sponseller PD, LaPorte DM, Hungerford MW, Bridwell KH, Lenke LG. Deep wound infections after neuromuscular scoliosis surgery. A multicenter study of risk factors and treatment outcomes. Spine. 2000;25(19):2461-6.
20. Aleissa S, Parsons D, Grant J, Harder J, Howard J. Deep wound infection following pediatric scoliosis surgery: incidence and analysis of risk factors. Can J Surg. 2011;54(4):263-9.
21. Myung KS, Lee C, Skaggs DL. Early pelvic fixation failure in neuromuscular scoliosis. J PediatrOrthop. 2015;35(3):258-65.
22. Phillips JH, Gutheil JP, Knapp DR Jr. Iliac screw fixation in neuromuscular scoliosis. Spine. 2007;32(14):1566-70.
23. Anari JB, Cahill PJ, Flynn JM, Spiegel DA, Baldwin KD. Intra-operative computed tomography guided navigation for pediatric pelvic instrumentation: A technique guide. World J Orthop. 2018;9(10):185-9.
24. Shen M, Jiang H, Luo M, Wang W, Li N, Wang L, et al. Comparison of low density and high density pedicle screw instrumentation in Lenke 1 adolescent idiopathic scoliosis. BMC MusculoskeletDisord. 2017;18(1):336.
25. Luo M, Wnag W, Shen M, Luo X, Xia L. Does higher screw density improve radiographic and clinical outcomes in adolescent idiopathic scoliosis? A systematic review and pooled analysis. J NeurosurgPediatr. 2017;19(4):448-57.