Original Article

Deformity correction from the convexity of the curve in neuromuscular scoliosis

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Background: "Convex Pedicle Screw Technique" reduces the theoretical risk of neurovascular injury. Our aim is to evaluate the efficacy of this technique in patients with neuromuscular scoliosis (NMS).

Methods: Retrospective study of 12 patients who underwent a Convex Pedicle Screw Technique and were diagnosed with NMS. Patients who had undergone previous spinal surgery were excluded. The minimum follow-up required was 24 months. Demographic data, intraoperative data, neurovascular complications and neurophysiological events requiring implant repositioning, as well as pre- and postoperative radiological variables were collected.

Results: Twelve patients diagnosed with NMS underwent surgery. The median operative time was 217 minutes. Mean blood loss was 3.8±1.1 g/dL hemoglobin (Hb). The median postoperative stay was 8.8±4 days. A reduction of the Cobb angle in primary curve of 49.1% (from 52.8°±18° to 26.5°±12.6°; P<0.001) and in secondary curve of 25.2% (from 27.8°±18.9° to 18.3°±13.3°; P=0.10) was achieved. Coronal balance improved by 69.4% (7.5±46.2 *vs.* 2.3±20.9 mm; P=0.72) and sagittal balance by 75% (from −14.1±71.8 *vs.* −3.5±48.6 mm; P=0.50). There were no neurovascular complications. There were no intraoperative neurophysiological events requiring implant repositioning, nor during reduction maneuvers. No infections were reported.

Conclusions: The correction of the deformity from convexity in NMS achieves similar results to other techniques, and a very low complication rate.

Keywords: Neuromuscular scoliosis (NMS); scoliosis; Convex Pedicle Screw Technique; pedicle screw instrumentation

Submitted Oct 31, 2023. Accepted for publication Feb 23, 2024. Published online May 09, 2024.
doi: 10.21037/jss-23-128
View this article at: https://dx.doi.org/10.21037/jss-23-128

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Introduction

Background

Neuromuscular scoliosis (NMS) includes a broad spectrum of spinal deformities secondary to neurological and muscular diseases. It has an incidence ranging from 25–100%, depending on the underlying disease. NMS, unlike adolescent idiopathic scoliosis (AIS), develops in patients with chronic diseases at an earlier age and creates curves with greater deformities, more rapid progression and sometimes associated with neurological malformations (1,2).

A significant proportion of these patients will require surgical treatment, as it will usually be associated with respiratory restriction and the curve may continue to progress after the end of growth (2). Previous publications have shown an improvement in quality of life in those patients treated surgically, facilitating the care of these patients by improving the ability to ambulate, sit up and perform transfers (1-3).

Rationale and knowledge gap

Posterior instrumentation with pedicle screws is currently considered to have more advantages in terms of safety and degree of correction than older techniques, such as Luque (4) instrumentation with sublaminar wires, Cotrel-Dubousset instrumentation or Harrington rods (5-8).

Classically, curve correction has been performed mainly by instrumenting the concavity area when the profile was hypo- or normokyphotic, and from the convexity when there was hyperkyphosis (9). However, we believe that correction from the convexity (10), regardless of the sagittal profile, has a lower risk of neurovascular injury and less risk of malposition of the screws (11), since it is on that side where the pedicles are thicker and more exposed (9,12,13). Furthermore, as it is technically simpler, surgical time is reduced.

Objective

Our aim is to present the results obtained in the correction of scoliotic deformity from the convexity of the curve. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-128/rc).

Highlight box

Key findings

- Correction from the convexity of the curve in neuromuscular scoliosis (NMS) can provide similar results to other techniques.

What is known and what is new?

- On the convex side, the pedicles are more exposed, wider, and further away from neurovascular structures. This facilitates the insertion of free-hand screws and correction of the deformity from the convexity.
- In our article, we present the first published results on NMS using the "Convex Pedicle Screw Technique".

What is the implication, and what should change now?

- Correction of the deformity from the convexity in NMS should be considered as a feasible alternative to correction from the concavity.

Methods

Patient selection and data collection

The study was approved by the ethics committee of General University Hospital Gregorio Marañón (Code: ESCOLI1), and was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The patients' guardians or the patients themselves provided their informed consent to participate in the study. This is a retrospective case-control study of 12 patients treated at our centre from 2013 to 2021, diagnosed with NMS with curves greater than 40° in which a rapid progression has been observed with respect to previous controls, as well as those curves that prevent an adequate seated position due to pelvic imbalance. If the pelvic obliquity was greater than 15°, the instrumentation was extended to the pelvis. All patients were operated by the same team of surgeons, specialised in spinal surgery. Prior to the study, a selection of patients was made, excluding from the final sample those with previous spinal surgery and those in whom no assessable teleradiographs were obtained. The minimum follow-up required was 24 months. The exclusion criteria were: not meeting the minimum follow-up, and scoliosis of idiopathic or syndromic origin.

The following variables were collected: age, sex, diagnosis associated with NMS, instrumented levels, blood loss in litres (using the Nadler Equation), post-surgical length of stay, surgical time, intraoperative neurophysiological events and postoperative complications. In addition, the implant density was calculated in each case (defined by the number of pedicle screws divided by the number of fused levels).

Pre- and post-operative radiological data were also collected, including: Cobb angle of the primary and secondary curve, coronal balance (distance in millimeters

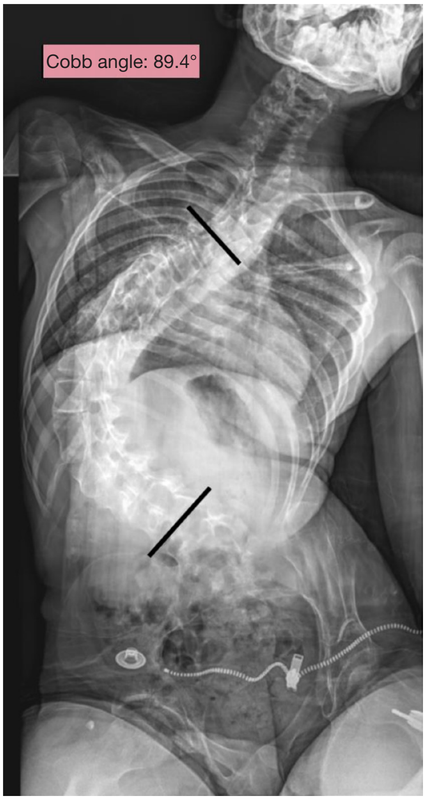

Figure 1 Preoperative teleradiograph of a 17-year-old male patient diagnosed with cerebral palsy. The black lines represent the endplate of the two terminal vertebrae.

between the central sacral line and C7 mid body), sagittal balance (distance in millimeters between a C7 vertical plumb line with the S1 superior-posterior corner), thoracic kyphosis, lumbar lordosis, pelvic incidence and pelvic obliquity. All of these were subsequently compared.

All patients were followed up at 4 weeks, 3 months and annually after the intervention.

Surgical technique

Cefazolin 30 mg/kg was administered 30 minutes before the incision, (which was maintained on admission every 8 hours until Redon type drainages removal) and amikacin 15 mg/kg as a single dose. Cefazolin was repeated every 4 hours, or in case of excessive bleeding. Surgery was performed with the patient in prone position, under general anaesthesia and intraoperative neurophysiological monitoring by stimulation of each of the screws to assess proximity to radicular and spinal cord structures, as well as neurophysiological monitoring of long spinal cord tracts during correction maneuvers. An isolated posterior approach was performed in all cases.

First, the posterior elements were dissected subperiosteally, up to the transverse processes on both sides, and the curve was made flexible by means of wide facetectomies. From caudal to cranial, pedicle screws (monoaxial at the apex and polyaxial at the ends of the construct) were inserted using the "free hand" technique (9), and iliac screws in cases of fixation to the pelvis. All the pedicles of the convexity of the structured curve(s) were instrumented and, in the concavity, only the limits of the curve were instrumented. In all cases, descending transverse hooks were implanted in the last proximal instrumented vertebra. After verification of the screw thresholds by direct stimulation with neurophysiology, the deformity was corrected by bending a titanium rod to the optimal profile, bringing the spine closer to the rod. Subsequently, in-situ bending and segmental vertebral derrotation to optimise the curve, placing tubes in the monoaxial screws of the apex, and adding small compression and distraction maneuvers, above all in distal and proximal areas, to horizontalise the pelvis and shoulders. Subsequently, a rod is placed in the concave support area with hardly any additional maneuvers, nor derrotating on it. The iliosacral fixation was performed with simple iliac screws or S2 Alar-Iliac screws, according to each surgeon's preference. The arthrodesis was performed by decorticating all the posterior elements, including the transverse elements, and heterologous bone was not necessary (*Figures 1,2*).

Statistical analysis

IBM SPSS Statistics, Version 26 (IBM Corp., Armonk, New York, USA) was used. A P value of less than 0.05 was set for significance. Student's *t*-test for paired samples was used to compare quantitative variables.

Results

A total of 12 patients were included in the study, diagnosed with NMS [9 of them secondary to cerebral palsy—6 from Lonstein Group 1 and 3 from Lonstein Group 2 (14), two to myelomeningocele, and one to Duchenne muscular dystrophy]. Six of the patients were ambulant, and six were non-ambulant. Eight of the patients were female, and four were male. In 4 of the patients the pelvis was instrumented as they had a pelvic obliquity greater than 15°.

The mean age at the time of surgery was 13±3.53 years. The median operative time was 217 minutes, with 13.1±3.1

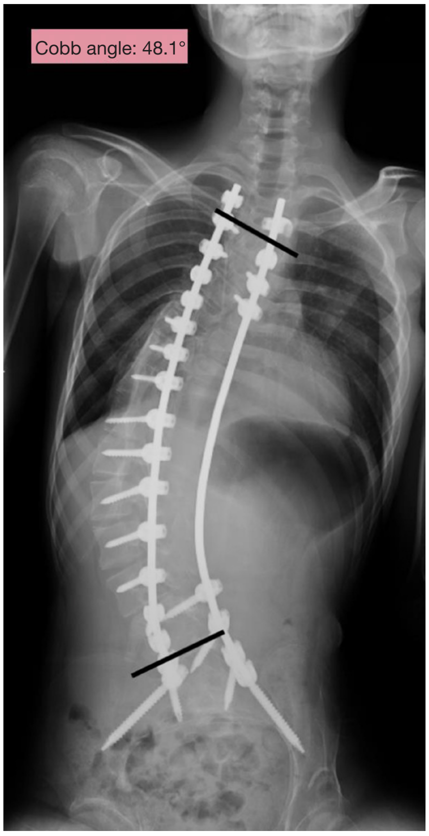

Figure 2 Postoperative teleradiograph one year after surgery in the same patient, a 17-year-old male, diagnosed with cerebral palsy. The black lines represent the endplate of the two terminal vertebrae.

mean number of instrumented levels. Mean blood loss was 0.997±0.382 L. The mean postoperative stay was 8.8±4 days. In 3 of the 12 patients (25%), heterologous blood transfusions were required during admission. The mean implant density was 1.47±0.24 implants per level.

We achieved a reduction in the Cobb angle in the primary curve of 49.1% (from mean 52.8°±18° to mean 26.5°±12.6°; P<0.001) and in the secondary curve of 25.2% (from mean 27.8°±18.9° to 18.3°±13.3°; P=0.10). Coronal balance improved by 69.4% (mean 7.5±46.2 *vs.* 2.3±20.9 mm; P=0.72) and sagittal balance by 75% (mean −14.1±71.8 to −3.5±48.6 mm; P=0.50).

The preoperative thoracic kyphosis was 42.1°±13.6° and the postoperative kyphosis was 32.9°±16.7°. This represented a decrease of almost 22% (P=0.09). The preoperative lumbar lordosis was 46.8°±14.7° and the postoperative lordosis was 42.1°±14.6° (P=0.45).

Pelvic obliquity improved from 11°±11.3° preoperatively to 6.46°±6.7°, representing an improvement of 41.9% (P=0.001). Preoperative pelvic tilt was 18.6°±5.7° and postoperative pelvic tilt was 22.7°±3.1° (P=0.20). A summary of these data can be found in *Table 1*.

There were no postoperative vascular complications, nor were there any neurological complications secondary to screw malposition or correction maneuvers. There were no intraoperative neurophysiological events requiring implant repositioning or during reduction maneuvers. No surgical wound infections were reported. One patient (8.3%) developed pneumonia during admission. At postoperative follow-up, one patient was diagnosed with proximal junctional kyphosis and required reoperation, extending the proximal instrumentation from T10-L2 to T2.

Discussion

Surgical criteria in NMS is established after 45°, or when the patient's quality of life is affected. It is essential in these patients to provide a safe, fast and reproducible method for the three-dimensional correction of the curve, in order to avoid greater morbidity and mortality. In addition, it is essential that patients and their families are assessed by a multidisciplinary team (1,3,15,16).

The scoliotic curve in NMS is usually C-shaped, causing a coronal imbalance reflected in an increased pelvic obliquity, which limits the ability to sit or ambulate (1).

There is great individual variability in vertebral pedicle morphology in patients with scoliosis, due to the pedicle hypoplasia found in these patients, mainly in the thoracic periapical concavity (3,9). Watanabe's clinical classification (17) of pedicle morphology helps the surgeon to "feel" what type of pedicle he is faced with, finding that more than 30% of them have a narrow channel, or cortical bone. In addition, there are significant differences with respect to the side of the deformity, with pedicles in the convexity being wider than in the concavity, and at the level of the proximal thoracic spine. In curves >80°, they showed that this narrowing tendency of the pedicles was maintained (17).

Regarding the risk of suffering an intraoperative event according to the morphology of the spinal canal in the concavity of the curve, it was observed that the "type 3" vertebrae of the Sielatycki classification (18) presented a very high risk of invasion of the canal when the screw was introduced, this morphological type being more frequent in younger patients and in larger curves.

While there are multiple reports of pedicle morphology in AIS (17,19,20), less are reported of pedicle morphology

Table 1 Demographic data and pre- and postoperative (pre-op and post-op) radiological variables

Patient No.	Sex	Age (years)	Neuromuscular disease	Risser	Ability to ambulate	Number of levels instrumented	Cobb primary curve		Cobb secondary curve		Thoracic kyphosis		Pelvic obliquity	
							Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
1	M	17	Cerebral palsy	0	No	13	89.4°	48.1°	48.8°	31.3°	38.7°	36.7°	6.7°	2.9°
2	M	10	Myelomeningocele	2	Yes	10	49.5°	36.6°	20.3°	7.9°	45°	13.3°	5°	3.6°
3	F	16	Cerebral palsy	4	Yes	7	41.3°	35.1°	–	–	31.7°	15.2°	2.8°	3.2°
4	F	13	Cerebral palsy	2	Yes	16	64°	10.6°	–	–	29.7°	35.9°	7°	7.2°
5	F	16	Cerebral palsy	2	Yes	15	33.7°	26.7°	–	–	52.8°	24.1°	14.8°	13.9°
6	M	14	Duchenne muscular dystrophy	2	Yes	16	49.2°	40.9°	29.4°	6.7°	18.8°	19.7°	19.1°	9.7°
7	F	16	Cerebral palsy	4	Yes	16	35.4°	28.3°	–	–	58°	52°	13.8°	7°
8	F	15	Cerebral palsy	1	Yes	10	76°	10.2°	–	–	46.9°	17.3°	3.2°	0.7°
9	M	11	Cerebral palsy	2	No	17	52°	11.6°	–	–	60.2°	58.6°	43.1°	23.6°
10	F	7	Myelomeningocele	2	Yes	13	27°	28.3°	20.2°	12.1°	24°	26.7°	7.8°	0.8°
11	F	15	Cerebral palsy	3	No	14	62.6°	25.8°	–	–	43.1°	47.3°	4°	2.9°
12	F	7	Cerebral palsy	4	No	10	53.2°	12.3°	48.8°	33.9°	56°	46.5°	4.8°	2.1°

M, male; F, female.

in NMS. In a study by Wang in 2012 (21), it was observed that the narrowest pedicles were found at the level of the apex of the curve, on the concavity side, in patients with NMS secondary to Chiari malformation/syringomyelia. Furthermore, it is accepted that the dural sac at this level is further away on the convexity side (9).

Given that, in theory, pedicle screw insertion in the thoracic spine admits only a translational error of less than 1 mm and a rotational error of less than 5° (9), and that more than 60 screws placed "free-hand" under the guidance of an experienced surgeon are necessary to obtain an adequate level of safety (22), there is an obvious need to clarify at which level and on which side of the curve pedicle screw insertion may present a lower risk of complications arising from the structures that may be injured.

On the left side at the upper thoracic level, anterior penetration places the aorta artery and oesophagus at risk, while in the right thoracolumbar area, it is the vena cava and azygos vein that are at risk (23,24). In addition, aortic imprinting by pedicle screws has been reported (25), with lateral wall violation found in up to 12.5% of implanted screws (11). In other studies, the lateral wall violation rate ranges from 1.5% to 43% (4,26-28), although these rates are expected to decrease with the implementation of new techniques assisted by robotic surgery (29,30), although this type of surgery is not yet available in most centres.

To our knowledge, unlike in AIS (10) there are no published results of scoliotic deformity correction in the subgroup of patients with NMS using the Convex Pedicle Screw Technique.

Regarding the correction of the Cobb angle of the greater curve, our results (49.1%) are similar to those of previously published literature using posterior instrumentation with pedicle screws, reporting corrections between 62.1% (31) and 69.8% (32); although in the latest systematic and narrative reviews, the percentage tends to be closer to 50%, given the heterogeneity and intrinsic difficulty of the curves of these patients (3,33).

Correction of pelvic obliquity is considered an essential parameter to be corrected in NMS, as this leads to a significant improvement in comfort and the development of chronic ulcers due to hyper-support areas in patients who move around in wheelchairs. Our improvement percentage is 41.9%, which is similar to results published with techniques with pedicle screw fixation (31).

In coronal balance, we obtained a correction of 69.4%, similar to previous studies with other techniques, between 57.2% and 86.4% (15,16). Sagittal balance in our study improved by 75%, which favours postural control in both sitting and ambulation. Kyphosis experienced a variation towards hypokyphosis of 22%, which although not statistically significant, did exhibit some tendency towards it. This not significant result is probably due to the small sample size, as the reduction technique used has been shown to reduce kyphosis in previous studies (34).

The mean postoperative stay was 8.8 days, shorter than in previous publications, probably due to the improvement in perioperative optimisation in recent years (15,35-37). The median operative time in our series (217 min) is shorter than that published in recent series (33), although it depends above all on the number of levels instrumented and the previous experience level of the surgical team. Correcting the deformity from the convexity of the curve allows screws to be implanted in an anatomically safer area, which may have influenced the operative time, but studies with a larger sample size and control group are needed to be able to make this assertion.

Surgical wound infection, in our case 0%, is very low compared to that published in recent systematic reviews, up to 10.9% (4,26). These results are not comparable due to the small sample size, which, if increased, would probably be closer to the percentage of infections published in these studies. The fact of better perioperative nutritional management (3) of these patients may have contributed to this infection rate. According to the latest data from the Scoliosis Research Society, surgical wound infection decreased since 2004-07 compared to the period 2012–2015 by 10% (8).

It is common for patients with NMS to have greater blood loss than those with AIS (31). The mean blood loss was almost one litre (0.997 L), similar to that reported in previous studies using pedicle screws for deformity correction in NMS, being between 1 and 1.5 L (32).

Previous systematic reviews (26) have reported a 3% rate of general neurological complications after NMS surgery, whereas we report no intraoperative neurophysiological events and no cases of postoperative neurological deficits or neuropathic pain. A durotomy rate of 1.9% has been reported in paediatric patients with spinal deformities, especially in revision surgery, some of them associated with insertion of the probe in preparation of the pedicle screw hole (38).

The increase in the number of screws in the convexity, technically easier and with less neurovascular risk, makes it unnecessary to implant them in the apex of the concavity or bilaterally, reaching equally good corrections. The Convex Pedicle Screw Technique is an additional technique to the existing ones, especially useful in highly rotated columns with narrow pedicles, supported by sufficient evidence previously published on the anatomical advantages (3,9,17,18,21,23,24) for the implantation of pedicle screws on the convexity side of the curve. Since patients with NMS suffer from higher perioperative complications due to their baseline condition and chronic pathologies, it seems logical to opt for screw instrumentation in order to make the surgery as easy and reproducible as possible.

Our study is not without limitations, given its retrospective nature and small sample size. In addition, the infection rate obtained probably corresponds to a selection bias, as we did not include in the study patients with previous interventions or with non-assessable teleradiographies, which usually correspond to patients with a worse baseline condition in whom standard radiological variables are impossible to measure. However, the aim of the study was to show the possibility of correcting the deformity from convexity in patients with NMS, in order to provide evidence in this regard, which may be extended in subsequent studies.

Conclusions

In conclusion, in our experience in the correction of paediatric scoliotic deformity secondary to neuromuscular diseases, we believe it is feasible to correct the deformity from the convexity, as the insertion of pedicle screws in this area is anatomically more favourable than from the concavity, and achieves results similar to those of other techniques.

Acknowledgments

Funding: None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-128/rc

Data Sharing Statement: Available at https://jss.amegroups.com/article/view/10.21037/jss-23-128/dss

Peer Review File: Available at https://jss.amegroups.com/article/view/10.21037/jss-23-128/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-23-128/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are 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. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of General University Hospital Gregorio Marañón (Code: ESCOLI1). The patients' guardians or the patients themselves provided their informed consent to participate in the study.

References

1. Sarwark J, Sarwahi V. New strategies and decision making in the management of neuromuscular scoliosis. Orthop Clin North Am 2007;38:485-96, v.
2. Vialle R, Thévenin-Lemoine C, Mary P. Neuromuscular scoliosis. Orthop Traumatol Surg Res 2013;99:S124-39.
3. Kim HS, Kwon JW, Park KB. Clinical Issues in Indication, Correction, and Outcomes of the Surgery for Neuromuscular Scoliosis: Narrative Review in Pedicle Screw Era. Neurospine 2022;19:177-87.
4. Turturro F, Montanaro A, Calderaro C, et al. Rate of complications due to neuromuscular scoliosis spine surgery in a 30-years consecutive series. Eur Spine J 2017;26:539-45.
5. Modi HN, Suh SW, Fernandez H, et al. Accuracy and safety of pedicle screw placement in neuromuscular scoliosis with free-hand technique. Eur Spine J 2008;17:1686-96.
6. Lenke LG, Kuklo TR, Ondra S, et al. Rationale behind the current state-of-the-art treatment of scoliosis (in the pedicle screw era). Spine (Phila Pa 1976) 2008;33:1051-4.
7. Halawi MJ, Lark RK, Fitch RD. Neuromuscular Scoliosis: Current Concepts. Orthopedics 2015;38:e452-6.
8. Cognetti D, Keeny HM, Samdani AF, et al. Neuromuscular scoliosis complication rates from 2004 to 2015: a report from the Scoliosis Research Society Morbidity and Mortality database. Neurosurg Focus 2017;43:E10.
9. Kim YJ, Lenke LG, Bridwell KH, et al. Free hand pedicle screw placement in the thoracic spine: is it safe? Spine (Phila Pa 1976) 2004;29:333-42; discussion 342.
10. Tsirikos AI. Correction of Adolescent Idiopathic Scoliosis Using a Convex Pedicle Screw Technique: A Novel Technique for Deformity Correction. JBJS Essent Surg Tech 2019;9:e9.
11. Smorgick Y, Millgram MA, Anekstein Y, et al. Accuracy and safety of thoracic pedicle screw placement in spinal deformities. J Spinal Disord Tech 2005;18:522-6.
12. Hu X, Siemionow KB, Lieberman IH. Thoracic and lumbar vertebrae morphology in Lenke type 1 female adolescent idiopathic scoliosis patients. Int J Spine Surg 2014;8:30.
13. Sakti YM, Lanodiyu ZA, Ichsantyaridha M, et al. Pedicle morphometry analysis of main thoracic apex adolescent idiopathic scoliosis. BMC Surg 2023;23:34.
14. Lonstein JE, Akbarnia A. Operative treatment of spinal deformities in patients with cerebral palsy or mental retardation. An analysis of one hundred and seven cases. J Bone Joint Surg Am 1983;65:43-55.
15. Piazzolla A, Solarino G, De Giorgi S, et al. Cotrel-Dubousset instrumentation in neuromuscular scoliosis. Eur Spine J 2011;20 Suppl 1:S75-84.
16. González López JL, Soleto Martín FJ, López Valverde S, et al. Resultados de la instrumentación Galveston-Luque en la escoliosis neuromuscular. Rev Ortop Traumatol 2002;46:227-33.
17. Watanabe K, Lenke LG, Matsumoto M, et al. A novel pedicle channel classification describing osseous anatomy: how many thoracic scoliotic pedicles have cancellous channels? Spine (Phila Pa 1976) 2010;35:1836-42.
18. Sielatycki JA, Cerpa M, Baum G, et al. A novel MRI-based classification of spinal cord shape and CSF presence at the curve apex to assess risk of intraoperative neuromonitoring data loss with thoracic spinal deformity correction. Spine Deform 2020;8:655-61.
19. Liljenqvist UR, Allkemper T, Hackenberg L, et al. Analysis of vertebral morphology in idiopathic scoliosis with use of magnetic resonance imaging and multiplanar reconstruction. J Bone Joint Surg Am 2002;84:359-68.
20. Catan H, Buluç L, Anik Y, et al. Pedicle morphology of

the thoracic spine in preadolescent idiopathic scoliosis: magnetic resonance supported analysis. Eur Spine J 2007;16:1203-8.
21. Wang G, Sun J, Cui X, et al. Pedicle morphology of the thoracic and lumbar spine in scoliosis associated with Chiari malformation/syringomyelia: comparison with adolescent idiopathic scoliosis. J Spinal Disord Tech 2012;25:168-72.
22. Gang C, Haibo L, Fancai L, et al. Learning curve of thoracic pedicle screw placement using the free-hand technique in scoliosis: how many screws needed for an apprentice? Eur Spine J 2012;21:1151-6.
23. Vaccaro AR, Rizzolo SJ, Allardyce TJ, et al. Placement of pedicle screws in the thoracic spine. Part I: Morphometric analysis of the thoracic vertebrae. J Bone Joint Surg Am 1995;77:1193-9.
24. Vaccaro AR, Rizzolo SJ, Balderston RA, et al. Placement of pedicle screws in the thoracic spine. Part II: An anatomical and radiographic assessment. J Bone Joint Surg Am 1995;77:1200-6.
25. Choi JB, Han JO, Jeong JW. False aneurysm of the thoracic aorta associated with an aorto-chest wall fistula after spinal instrumentation. J Trauma 2001;50:140-3.
26. Sharma S, Wu C, Andersen T, et al. Prevalence of complications in neuromuscular scoliosis surgery: a literature meta-analysis from the past 15 years. Eur Spine J 2013;22:1230-49.
27. Faldini C, Barile F, Viroli G, et al. Freehand power-assisted pedicle screw placement in scoliotic patients: results on 5522 consecutive pedicle screws. Musculoskelet Surg 2024;108:63-8.
28. Demura S, Ohara T, Tauchi R, et al. Incidence and causes of instrument-related complications after primary definitive fusion for pediatric spine deformity. J Neurosurg Spine 2023;38:192-8.
29. Vardiman AB, Wallace DJ, Crawford NR, et al. Pedicle screw accuracy in clinical utilization of minimally invasive navigated robot-assisted spine surgery. J Robot Surg 2020;14:409-13.
30. Gonzalez D, Ghessese S, Cook D, et al. Initial intraoperative experience with robotic-assisted pedicle screw placement with stealth navigation in pediatric spine deformity: an evaluation of the first 40 cases. J Robot Surg 2021;15:687-93.
31. Modi HN, Suh SW, Yang JH, et al. Surgical complications in neuromuscular scoliosis operated with posterior- only approach using pedicle screw fixation. Scoliosis 2009;4:11.
32. Stiel N, Özden J, Ridderbusch K, et al. Pedicle screw instrumentation with or without pelvic fixation in neuromuscular scoliosis: Outcome and complications in a series of 37 patients with a minimum 2-year follow-up. Surgeon 2020;18:e7-e12.
33. Shao ZX, Fang X, Lv QB, et al. Comparison of combined anterior-posterior approach versus posterior-only approach in neuromuscular scoliosis: a systematic review and meta-analysis. Eur Spine J 2018;27:2213-22.
34. Pesenti S, Clément JL, Ilharreborde B, et al. Comparison of four correction techniques for posterior spinal fusion in adolescent idiopathic scoliosis. Eur Spine J 2022;31:1028-35.
35. Murphy NA, Firth S, Jorgensen T, et al. Spinal surgery in children with idiopathic and neuromuscular scoliosis. What's the difference? J Pediatr Orthop 2006;26:216-20.
36. Auerbach JD, Spiegel DA, Zgonis MH, et al. The correction of pelvic obliquity in patients with cerebral palsy and neuromuscular scoliosis: is there a benefit of anterior release prior to posterior spinal arthrodesis? Spine (Phila Pa 1976) 2009;34:E766-74.
37. Beckmann K, Lange T, Gosheger G, et al. Surgical correction of scoliosis in patients with severe cerebral palsy. Eur Spine J 2016;25:506-16.
38. West JL, Arnel M, Palma AE, et al. Incidental durotomy in the pediatric spine population. J Neurosurg Pediatr 2018;22:591-4.

Cite this article as: Hernández Mateo JM, Flores Gallardo J, Riquelme García O, García Martín A, Igualada Blázquez C, Solans López MC, Muñoz Núñez L, Esparragoza Cabrera LA. Deformity correction from the convexity of the curve in neuromuscular scoliosis. J Spine Surg 2024;10(2):224-231. doi: 10.21037/jss-23-128