

Surgical treatment of scoliosis in neurofibromatosis type I: A retrospective study on posterior-only correction with third-generation instrumentation

ABSTRACT

Background: Scoliosis is the most common orthopedic complication of neurofibromatosis type I. Scoliosis can be occurred with two patterns: dystrophic or idiopathic-like. In adolescence, in consideration of bone dystrophy, osteopenia, and often associated hyperkyphosis, most of the authors recommend an anterior-posterior approach. According to other authors, modern instrumentations could be sufficient to sustain a solid posterior arthrodesis.

Materials and Methods: Ten patients were diagnosed with scoliosis in neurofibromatosis type I aged between 8 and 25 years, Cobb angle of the thoracic curve >45°, and minimum follow-up (FU) of 1 year and treated with posterior-only approach with third-generation high-density instrumentations. Radiographic measurements were performed on the coronal and sagittal planes. Nonparametric tests (Friedman test and Wilcoxon test) were applied to evaluate the reducibility of the preoperative curve (T0), the postoperative surgical correction (T1), and its maintenance on FU.

Results: Statistics showed results compared to those evaluated in the literature with a combined approach regarding surgical correction and its maintenance on FU. On T1, a median correction of 53.5% of the scoliotic curve and of 33.7% of the thoracic hyperkyphosis was observed. On FU, the correction was maintained. A global improvement in balance was appreciated. The curves, despite rigid, showed a relative reducibility to bending tests and traction. No significant complications occurred.

Conclusions: The posterior-only approach produces a satisfactory correction of the dystrophic neurofibromatosis scoliosis if associated with the use of high-density third-generation instrumentations. We are confident in recommending posterior-only approach in dystrophic neurofibromatosis scoliosis with coronal curves till 110° and coexisting thoracic kyphosis till 80°.

Keywords: Hooks, hybrid instrumentations, pedicle screws, posterior approach, sublaminar bands

INTRODUCTION

Neurofibromatosis type I (NF-I) is an autosomal dominant genetic disorder (mutation of the NF-1 encoding the neurofibromin protein).^[1-4] Scoliosis is the most common orthopedic complication of NF-I which is present in 10%–55% of the cases who occurred with two patterns, dystrophic or idiopathic-like, often progressively evolving.^[5-7] Idiopathic-like curves can be treated with decision-making criteria similar to idiopathic scoliosis and needed close observation.^[8] Dystrophic curves need aggressive treatment because of their inexorable evolution; the treatment with brace resulted unsuccessful.^[3] This monocentric retrospective study aims to evaluate the correction of dystrophic scoliosis in NF-I

**PASQUALE CINNELLA, SILVIA AMICO¹,
ALESSANDRO RAVA², MATTIA CRAVINO³,
GIOSUÈ GARGIULO, MASSIMO GIRARDO**

Spine Surgery Unit, Orthopaedic and Trauma Centre, Città della Salute e della Scienza di Torino, University of Turin, Turin, ¹Department of Clinical and Molecular Sciences, School of Medicine, Università Politecnica delle Marche, Ancona, ²Department of Orthopaedic and Traumatology, Orthopaedic and Trauma Centre, Città della Salute e della Scienza di Torino, University of Turin, ³Department of Pediatric Orthopaedic, Regina Margherita Pediatric Hospital, Turin, Italy

Address for correspondence: Dr. Alessandro Rava, Department of Orthopaedic and Traumatology, Orthopaedic and Trauma Centre, Città della Salute e della Scienza and Università Politecnica delle Marche, University of Turin, Via Zuretti 29, 10121, Turin, Italy. E-mail: dralessandrorava@gmail.com

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obtained with posterior-only approach performing with high-density hybrid instrumentations.

MATERIALS AND METHODS

From January 2008 to December 2018, 195 consecutive scoliotic patients who underwent a surgical treatment by the same spine surgical team were retrospectively analyzed.

Ten patients, 6 males and 4 females, were selected according to the following inclusions criteria: diagnosis of dystrophic scoliosis in NF-1, age between 8 and 25 years, thoracic coronal curve Cobb angle $\geq 45^\circ$, surgical treatment with posterior-only approach with hybrid instrumentations (pedicle screws, sublaminar bands and hooks), implant density ≥ 0.70 and FU period of at least 1 year.^[9,10] General data of cases are reported in Table 1. The median age at surgical time is 13.5 years (range: 11–23 years). The median of FU timing is 4 years (range: 2–5 years).

Dystrophic features were studied: all ten patients had vertebral scalloping. According to the classification system proposed by Li *et al.*,^[11] on a total of 280 pedicles of the vertebrae constituting the thoracic curve, evaluated on computed tomography (CT) images with reconstruction according to the axial plane of each vertebra, the results were as follows: A: 22; B: 96; C: 127; D: 35; and E: 0. The details are shown in Table 2 and Figure 1. On the sagittal plane, wedging of vertebral bodies is present in three patients, and on the coronal plane, it is present in all ten patients. Rotation was assessed on CT images with reconstruction according to the axial plane of the apical vertebra.^[12] The median of the rotation angle is equal to 40.5° (range: 28° – 45°). Nine patients had a scoliotic curve with short-range angular deviation. Five patients had rib penciling. A single patient had rib dislocation with dislocation of the head of the rib in the vertebral canal. The patient was asymptomatic without neurological deficits.

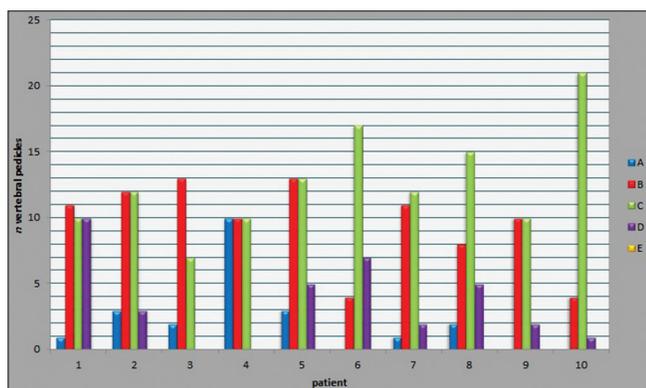


Figure 1: Bar chart on the frequency of vertebral pedicles

Resection of the head of the rib was not performed in the operative site [Figure 2]. No patient had paraspinal or intraspinal soft-tissue masses. Dystrophic elements on simple are recapped in Table 3.^[3]

Radiographic data collection was performed by two independent operators. All radiographic measurements were made on the preoperative time (T0), on immediate postoperative time (T1), and on FU.^[13] All patients underwent magnetic resonance imaging and CT scan that were performed before surgery in order to evaluate the presence of spinal cord malformation.^[14–20]

Cobb angle measurements of coronal thoracic curve and coronal balance were achieved on standing posteroanterior X-rays. Kyphosis and sagittal balance were determined on standing lateral X-rays. Curve flexibility was evaluated on

Table 1: General information of the 10 cases treated

Variables	Values
<i>n</i>	10
Median age (years), range	13.5, 11-23
Gender (male:female)	6:4
Follow-up (years), range	4, 2-5
Pattern of the curve	Dystrophic
Treatment	PSF Apical asymmetric Ponte osteotomy
Median of implant density, range	0.73, 0.70-0.86
Hypokyphosis (<i>n</i>)	1
Hyperkyphosis (<i>n</i>)	9
Normokyphosis (<i>n</i>)	0

PSF - Posterior spinal fusion

Table 2: Frequency distribution of vertebral pedicles

Patient	A	B	C	D	E	Total
1	1	11	10	10	0	32
2	3	12	12	3	0	30
3	2	13	7	0	0	22
4	10	10	10	0	0	30
5	3	13	13	5	0	34
6	0	4	17	7	0	28
7	1	11	12	2	0	26
8	2	8	15	5	0	30
9	0	10	10	2	0	22
10	0	4	21	1	0	26
Total	22	96	127	35	0	280

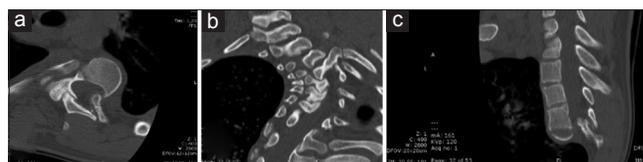


Figure 2: Rib dislocation with dislocation of the head of the rib in the vertebral canal on computed tomography image. (a) Axial view; (b) coronal view; (c) sagittal view

the preoperative side-bending and traction anteroposterior radiographs.^[21]

One patient had thoracic hypokyphosis (<25°), and nine patients had hyperkyphosis (>50°).

The patients underwent posterior high-density arthrodesis with third-generation instrumentations. Asymmetric apical Ponte osteotomies were performed in patients who had hyperkyphosis. For spinal fusion, autologous decorticated bone was used with a homologous supplement from the bone bank.

No patients were lost during FU.

Collected data are expressed as median (range). The Friedman test and Wilcoxon test were performed to show differences in angular values of coronal and sagittal thoracic curves, in values of coronal and sagittal imbalance, and in values of flexibility. The level of significance was set as $P < 0.05$. Statistical analysis was performed using MedCalc® software (omicX, 72 rue de la république 76140 Le-Petit-Quevilly France).

RESULTS

Radiographic results on preoperative (T0), postoperative (T1), and follow-up

Data collection are reported in Table 4.

Table 3: Dystrophic elements on cases treated

Dystrophic features	Simple
Vertebral scalloping (n)	10
Rib penciling (n)	5
Vertebral pedicles	
A	22
B	96
C	127
D	35
E	0
Coronal wedging of vertebral bodies (n)	10
Sagittal wedging of vertebral bodies (n)	3
Median apical rotation (°), range	40.5, 28-45
Short curve (n)	9
Rib head dislocation into the spinal canal (n)	1

Statistical results concerning reducibility of thoracic curves

The Wilcoxon test showed significant differences ($P = 0.0020$) between thoracic curve angles measured on standing posteroanterior X-rays on T0 (median: 93°, range: 60°–111°) and thoracic curve angles measured on preoperative side-bending anteroposterior radiographs (median: 77.5°, range: 57°–90°). The median percentage of bending test reducibility is 17.1% (range: 3.3%–30.5%).

The same procedure showed significant differences ($P = 0.0020$) between thoracic curve angles measured on standing posteroanterior X-rays on T0 and thoracic curve angles measured on preoperative traction anteroposterior radiographs (median: 75.5°, range: 40°–97°). The median percentage of the correction in the traction test is 15.9% (range: 8.3%–51.2%). Data are summarized in Table 5.

Statistical results on coronal plane

On the coronal plane, significant differences ($P < 0.00001$) were found, using the Friedman test, as regards Cobb angle measured on the three different times T0, T1, and FU. The Wilcoxon test was applied between T0 and T1 and between T1 and FU. A significant difference between Cobb angle on T0 and Cobb angle on T1 (median: 45°, range: 25°–55°) is demonstrated ($P = 0.0020$). The median correction was obtained as 53.5% (range: 21.7%–71.6%). ID on postoperative time was also calculated: the median was 0.73 (range: 0.70–0.86). There were no significant differences ($P = 0.2969$) between Cobb angle on time T1 and Cobb angle on time FU (median: 43°, range: 27°–56°). The median value of the correction loss at FU was 2% (range: 8%–16.3%).

The coronal imbalance was assessed using the Friedman test, which showed a significant difference ($P = 0.0433$) among the measurements taken on T0, T1, and FU. The Wilcoxon test was applied to evaluate the imbalance between T0 and T1, between T1 and FU, and then between T0 and FU. Statistics showed no significance ($P = 0.9102$) between the time T0 (median: 15 mm, range: 0–38 mm) and T1 (median: 19 mm, range: 0–39 mm). The median value concerning the variation of the imbalance between T0 and T1 was 9.5 mm (range: 0–29 mm). A significant

Table 4: Radiographic results on preoperative (T0), postoperative (T1) and follow-up

	Median			
	Thoracic curve (Cobb°)	Coronal imbalance (mm)	Kyphosis (Cobb°)	Sagittal imbalance (mm)
Before surgery (T0)	93 (60-111)	15 (0-38)	59.5 (24-83)	23.5 (0-72)
Bending	77.5 (57-90)	-	-	-
Traction	75.5 (40-97)	-	-	-
After surgery (T1)	45 (25-55)	19 (0-39)	40.5 (29-51)	42 (0-67)
FU	43 (27-56)	4.5 (0-21)	46 (32-57)	12.5 (0-39)

FU - Follow-up

difference ($P = 0.0156$) between T1 and FU (median: 4.5 mm, range: 0–21 mm) was demonstrated. The median variation of the imbalance between T1 and FU is 10 mm (range: 0–29 mm). Significant differences ($P = 0.0488$) between the median of the coronal imbalance on T0 and on FU were verified. The median variation of the imbalance between T0 and FU is 13.5 mm (range: 2–24 mm) [Figure 3].

Statistical results on sagittal plane

On sagittal plane, hypokyphosis was excluded from the sample. The Friedman test was applied: there was a significant difference ($P = 0.0003$) in the comparison between Cobb angle, concerning thoracic kyphosis, measured in the three different times T0, T1, and FU. The Wilcoxon test was applied between T0 and T1 and between T1 and FU. The results showed significant differences ($P = 0.0090$) between kyphosis angle on T0 (median: 60° , range: 51° – 83°) and the value on T1 (median: 41° , range: 31° – 51°). The median percentage correction of thoracic hyperkyphosis on the postoperative time was 33.7% (range: 14.8%–46.1%). There were no significant differences ($P = 0.3528$) between Cobb angle measured on T1 and the value measured on FU (median: 47° , range: 35° – 57°). The median variation on FU compared to T1 was 11.7% (range: 2%–22.5%). Concerning the case with hypokyphosis (24°), the percentage correction between T0 and T1 was 16%. The loss of correction between T1 and FU was 8%.

Table 5: Statistical results concerning flexibility of thoracic curves

	Thoracic curve
Wilcoxon test T0 versus bending (P)	0.0020
Wilcoxon test T0 versus traction (P)	0.0020
Bending correction (%), range	17.1, 3.3-30.5
Traction correction (%), range	15.9, 8.3-51.2

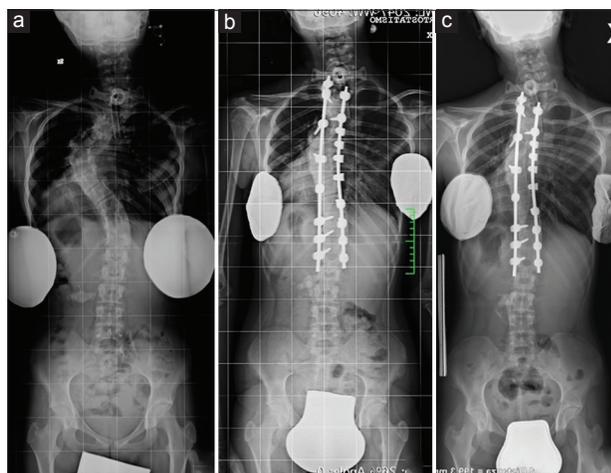


Figure 3: Patient 1 (female, 14 years old). X-ray examinations on coronal plane: (a) before surgery (T0); (b) immediate postoperative time (T1); (c) 4-year follow-up

Sagittal imbalance was evaluated using the Friedman test, which showed a significant difference ($P = 0.0047$) between the measurements taken on times T0, T1, and FU. The Wilcoxon test was applied to evaluate the difference in sagittal imbalance between T0 and T1, between T1 and FU, and between T0 and FU. Statistics showed no significant differences ($P = 0.6953$) between imbalance on T0 (median: 23.5 mm, range: 0–72 mm) and on T1 (median: 42 mm, range: 0–67 mm). The median value concerning the variation of the sagittal imbalance between T0 and T1 was 25 mm (range: 1–59 mm). Statistics showed a significant difference ($P = 0.0137$) between sagittal imbalance on T1 and FU (median: 12.5 mm, range: 0–39 mm). The median variation of the sagittal imbalance between T1 and FU was 31.5 mm (range: 5–87 mm). The difference between sagittal imbalance on T0 and on FU was not significant ($P = 0.0547$). The median variation of the sagittal imbalance between T0 and FU was equal to 17.5 mm (range: 0–111 mm) [Figure 4].

In Table 6, there is a recap of statistical results.

Clinical and operative results

The rate of early and late intraoperative and postoperative surgical complications was zero. A frontal pressure injury and an allergic reaction to antibiotic therapy with vancomycin occurred. There were no cases of coronal or sagittal decompensation and no neurological and infectious complications. The median of intraoperative blood losses was 1650 ml (range: 600–3974 ml). The median of the duration of the surgery is 412.5 min (range: 275–520 min).

DISCUSSION

This study intends to support the thesis of the effectiveness of posterior-only spinal fusion in dystrophic scoliotic curves.^[22-26]

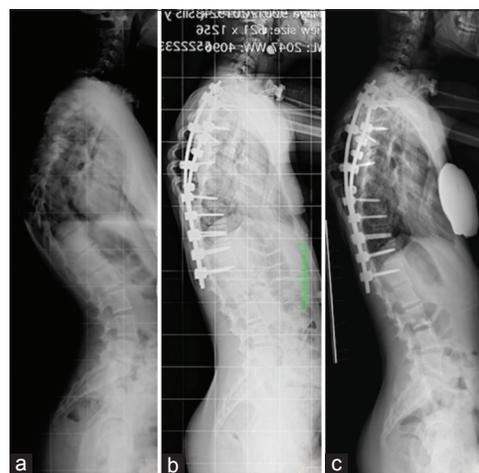


Figure 4: Patient 1 (female, 14 years old). X-ray examinations on sagittal plane: (a) before surgery (T0); (b) immediate postoperative time (T1); (c) 4-year follow-up

Table 6: Statistical results on coronal and sagittal planes

	Thoracic curve	Coronal imbalance	Kyphosis*	Sagittal imbalance
Friedman test T0, T1, FU (P)	<0.00001	0.0433	0.0003	0.0047
Wilcoxon test T0 versus T1 (P)	0.0020	0.9102	0.0090	0.6953
Wilcoxon test T1 versus FU (P)	0.2969	0.0156	0.3528	0.0137
Wilcoxon test T0 versus FU (P)	-	0.0488	-	0.0547

*Level of significance sets as $P < 0.05$ hypokyphosis was excluded. FU - Follow-up

In adolescence, in consideration of bone dystrophy, osteopenia, and often associated hyperkyphosis, most of the authors recommend to associate an apical anterior arthrodesis release to the posterior arthrodesis.^[27-30] According to other authors, modern instrumentations could be sufficient to sustain a solid and effective posterior arthrodesis.^[22-26,31]

The anterior instrumented arthrodesis allows a good correction saving fusion levels. However, several complications are reported in the anterior approach, such as injury to the large vessels and adjacent organs, and reduced functionality pulmonary.^[32]

The posterior instrumentation involves the use of pedicle screws, hooks, and sublaminar bands in hybrid constructions. Nowadays, such equipment are widely used for the effectiveness of the correction and the relatively low complication rate in the treatment of idiopathic scoliosis.^[33]

The combined anterior-posterior approach includes the anterior release, followed by posterior instrumentation and fusion, which is in the same surgical session or deferred.

The statistical significance concerning the reducibility of the curve at the bending test and at traction suggests a flexibility that is still partially persistent with optimistic prediction when opting for correction and surgical stabilization. Despite this, the percentage of reducibility to the bending test is still to be considered, which is in any case $< 25\%$, thus decreeing these curves as rigid. The median age of the sample, equal to 13.5 years, the bone immaturity and the altered quality of the bone and soft tissues, found in the context of NF-I, could explain the relative flexibility of the dystrophic curve. The evaluation in the following study regarding the reducibility of dystrophic scoliotic curves was not taken into consideration in the studies available in the literature on the surgical treatment of deformity in neurofibromatosis. There are some scientific articles that evaluate the “flexibility” of idiopathic scoliosis.^[34,35]

The duration of the surgical timing and intraoperative blood losses are compatible with the greater complexity of the surgery due to the dystrophy and the stiffness of the

curves compared to the surgery of idiopathic scoliosis. In addition, the high ID of the instrumentations partially justifies intraoperative bleeding. It should also be remembered that two patients had coagulation disorders on preventive hematology tests.

Invasiveness can be considered minor, due to the presence of a single access and the need for only one surgical time, which reduces the operative duration compared to a combined approach; however, the high ID could theoretically increase the risk of complications including infections, pseudoarthrosis, and bad positioning of the screws with possible vascular and nervous complications. However, no intraoperative either postoperative complications were detected in the studied sample.

On coronal plane, the effectiveness of surgical correction has been demonstrated statistically with a median percentage (53.5%) that is satisfactory, consistent with the surgical corrections evaluated in the literature. No significative differences between the measurements on the postoperative time and on the FU demonstrate the maintenance of the correction thanks to a third-generation instrumentation that has allowed an optimal stabilization.

On coronal plane, the imbalance does not seem to improve on immediate postoperative time, probably due to the severe impact of the surgical trauma, but it decreases in the FU leading to a good overall balance.

The statistical significance between the measurements of the kyphotic curves on preoperative time and those on postoperative time has demonstrated the effectiveness of the correction of hyperkyphosis in some cases even severe. This result was possible through the good control of the sagittal curves allowed by the posterior access. The data must be compared with the previous scientific literature which proposed, in the case of hyperkyphosis above 50° , the combined anterior-posterior approach.^[28] However, this recommendation could not take into consideration the potential of actual instrumentations that allow, through the use of hybrid constructs, good stability thanks also to the possibility of increasing the ID. The high ID (≥ 0.70), in cases of pedicle dystrophy which does not allow the safe and

stable positioning of the pedicle screws, is guaranteed in these curves by the use of the sublaminar bands. The patient with hypokyphosis (24° Cobb) had a flat back. In this case, the correction was performed in the opposite direction also improving in sagittal radiographic and clinical profile.

Regard to the sagittal imbalance, there is an improvement of balancing the immediate postoperative time, probably caused by severe surgical trauma. Even in the absence of statistical significance, in the long run, there is a reduction of imbalance on FU.

CONCLUSIONS

Considering the available case studies and the scientific literature found, the potential of the new generation instrumentations and posterior-only approach was evaluated, providing the real possibilities that technology can offer at the present moment.

It has been concluded that the posterior-only approach produces a satisfactory correction of the dystrophic neurofibromatosis thoracic curves if associated with the use of third-generation high-density implant instrumentations. The effectiveness is also demonstrated in cases where severe thoracic kyphosis is present, also allowing good control, as well as hypokyphosis, with a substantial improvement in all cases of the sagittal profile. The correction is stable over time.

Based on recent scientific literature and the retrospective study conducted, we are confident in recommending the posterior-only approach in dystrophic neurofibromatosis scoliosis with coronal curves till 110° and coexisting thoracic kyphosis till 80° as these high-density third-generation instruments. The implants allow to achieve results that until now were mainly achieved with the combined anterior-posterior approach, ultimately concretizing the possibility for the patient to undergo a single surgical session and therefore avoiding exposure to complications of the anterior release.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

- Feldman DS, Jordan C, Fonseca L. Orthopaedic manifestations of neurofibromatosis type 1. *J Am Acad Orthop Surg* 2010;18:346-57.
- Le C, Bedocs PM. Neurofibromatosis. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2020 Jan-. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK459329/>. [Updated 2019 Nov 29].
- Tsirikos AI, Saifuddin A, Noordeen MH. Spinal deformity in neurofibromatosis type-1: Diagnosis and treatment. *Eur Spine J* 2005;14:427-39.
- Dulai S, Briody J, Schindeler A, North KN, Cowell CT, Little DG. Decreased bone mineral density in neurofibromatosis type 1: Results from a pediatric cohort. *J Pediatr Orthop* 2007;27:472-5.
- Koptan W, ElMiligui Y. Surgical correction of severe dystrophic neurofibromatosis scoliosis: An experience of 32 cases. *Eur Spine J* 2010;19:1569-75.
- Akbarnia BA, Gabriel KR, Beckman E, Chalk D. Prevalence of scoliosis in neurofibromatosis. *Spine (Phila Pa 1976)* 1992;17:S244-8.
- Yoshida Y, Ehara Y, Koga M, Imafuku S, Yamamoto O. Epidemiological analysis of major complications requiring medical intervention in patients with neurofibromatosis 1. *Acta Derm Venereol* 2018;98:753-6.
- Seop Park Y. Spinal deformity in neurofibromatosis: Classification and management. *J Spine* 2014;3:1-5.
- Tonsgard JH. Clinical manifestations and management of neurofibromatosis type 1. *Semin Pediatr Neurol* 2006;13:2-7.
- Cinnella P, Rava A, Mahagna AA, Fusini F, Masse A, Girardo M. Over 70° thoracic idiopathic scoliosis: Results with screws or hybrid constructs. *J Craniovertebr Junction Spine* 2019;10:108-13.
- Li Y, Luo M, Wang W, Shen M, Xu G, Gao J, *et al.* A computed tomography-based comparison of abnormal vertebrae pedicles between dystrophic and nondystrophic scoliosis in neurofibromatosis type 1. *World Neurosurg* 2017;106:898-904.
- Lam GC, Hill DL, Le LH, Raso JV, Lou EH. Vertebral rotation measurement: A summary and comparison of common radiographic and CT methods. *Scoliosis* 2008;3:16.
- Girardo M, Rava A, Coniglio A, Cinnella P, Aprato A, Massè A, *et al.* Importance of polymethylmethacrylate augmentation in the treatment of thoracolumbar osteoporotic vertebral fractures. *Minerva Ortop Traumatol* 2019;70:65-9.
- Girardo M, Rava A, Fusini F, Lea S, Massè A, Cinnella P. Dysraphism in scoliosis: A case report of diastematomyelia in severe right thoracolumbar congenital kyphoscoliosis. *Minerva Ortop Traumatol* 2019;70:107-11.
- Palmisani M, Dema E, Rava A, Palmisani R, Girardo M, Cervellati S. Surgical treatment of spinal deformities in Marfan syndrome: Long-term follow-up results using different instrumentations. *J Craniovertebr Junction Spine* 2019;10:172-8.
- Girardo M, Zenga F, Bruno LL, Rava A, Massè A, Maule M, *et al.* Treatment of aggressive vertebral hemangiomas with poly vinyl alcohol (PVA) microparticles embolization, PMMA, and short segment stabilization: Preliminary results with at least 5 years of follow-up. *World Neurosurg* 2019;128:e283-8.
- Sanguinetti C, Specchia N, Gigante A, de Palma L, Greco F. Clinical and pathological aspects of solitary spinal neurofibroma. *J Bone Joint Surg Br* 1993;75:141-7.
- Rava A, Fusini F, Cinnella P, Massè A, Girardo M. Is cast an option in the treatment of thoracolumbar vertebral fractures? *J Craniovertebr Junction Spine* 2019;10:51-6.
- Gargiulo G, Girardo M, Rava A, Coniglio A, Cinnella P, Massè A, *et al.* Clinical comparison between simple laminectomy and laminectomy plus posterior instrumentation in surgical treatment of cervical myelopathy. *Eur J Orthop Surg Traumatol* 2019;29:975-82.
- Girardo M, Rava A, Gargiulo G, Coniglio A, Artiaco S, Massè A, *et al.* Clinical and radiological union rate evaluation of type 2 odontoid fractures: A comparison between anterior screw fixation and halo vest in elderly patients. *J Craniovertebr Junction Spine* 2018;9:254-9.
- Oestreich AE, Young LW, Young Poussaint T. Scoliosis circa 2000: Radiologic imaging perspective. I. Diagnosis and pretreatment evaluation. *Skeletal Radiol* 1998;27:591-605.

22. Li M, Fang X, Li Y, Ni J, Gu S, Zhu X. Successful use of posterior instrumented spinal fusion alone for scoliosis in 19 patients with neurofibromatosis type-1 followed up for at least 25 months. *Arch Orthop Trauma Surg* 2009;129:915-21.
23. Sun D, Dai F, Liu YY, Xu JZ. Posterior-only spinal fusion without rib head resection for treating type I neurofibromatosis with intra-canal rib head dislocation. *Clinics (Sao Paulo)* 2013;68:1521-7.
24. Zhao X, Li J, Shi L, Yang L, Wu ZX, Zhang DW, *et al.* Surgical Treatment of dystrophic spinal curves caused by neurofibromatosis type 1: A retrospective study of 26 patients. *Medicine (Baltimore)* 2016;95:e3292.
25. Li Y, Yuan X, Sha S, Liu Z, Zhu W, Qiu Y, *et al.* Effect of higher implant density on curve correction in dystrophic thoracic scoliosis secondary to neurofibromatosis Type 1. *J Neurosurg Pediatr* 2017;20:371-7.
26. Wang Z, Fu C, Leng J, Qu Z, Xu F, Liu Y. Treatment of dystrophic scoliosis in neurofibromatosis Type 1 with one-stage posterior pedicle screw technique. *Spine J* 2015;15:587-95.
27. Crawford AH. Pitfalls of spinal deformities associated with neurofibromatosis in children. *Clin Orthop Relat Res* 1989;(245):29-42.
28. Parisini P, Di Silvestre M, Greggi T, Paderni S, Cervellati S, Savini R. Surgical correction of dystrophic spinal curves in neurofibromatosis. A review of 56 patients. *Spine (Phila Pa 1976)* 1999;24:2247-53.
29. Hsu LC, Lee PC, Leong JC. Dystrophic spinal deformities in neurofibromatosis. Treatment by anterior and posterior fusion. *J Bone Joint Surg Br* 1984;66:495-9.
30. Betz RR, Iorio R, Lombardi AV, Clancy M, Steel HH. Scoliosis surgery in neurofibromatosis. *Clin Orthop Relat Res* 1989;(245):53-6.
31. Shen JX, Qiu GX, Wang YP, Zhao Y, Ye QB, Wu ZK. Surgical treatment of scoliosis caused by neurofibromatosis type 1. *Chin Med Sci J* 2005;20:88-92.
32. Betz RR, Harms J, Clements DH, Lenke LG, Lowe TG, Shufflebarger HL, *et al.* Comparison of anterior and posterior instrumentation for correction of adolescent thoracic idiopathic scoliosis. *Spine (Phila Pa 1976)* 1999;24:225-39.
33. Maruyama T, Takeshita K. Surgery for idiopathic scoliosis: Currently applied techniques. *Clin Med Pediatr* 2009;3:CMPed.S2117.
34. Hamzaoglu A, Talu U, Tezer M, Mirzanli C, Domanic U, Goksan SB. Assessment of curve flexibility in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2005;30:1637-42.
35. Liu RW, Teng AL, Armstrong DG, Poe-Kochert C, Son-Hing JP, Thompson GH. Comparison of supine bending, push-prone, and traction under general anesthesia radiographs in predicting curve flexibility and postoperative correction in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2010;35:416-22.