Archives of Orthopaedic and Trauma Surgery
https://doi.org/10.1007/s00402-021-04332-x

ORTHOPAEDIC SURGERY

Long-term outcomes of ilio-sacral screws in minimally invasive bipolar fusionless technique for neuromuscular scoliosis: a retrospective study in 167 patients

Mathilde Gaume[1] · Pierre Gerard[1] · Nejib Khouri[1] · Christophe Glorion[1] · Jean Dubousset[2] · Lotfi Miladi[1]

Received: 28 June 2021 / Accepted: 21 December 2021

Abstract

Introduction Pelvic fixation in patients with neuromuscular scoliosis is difficult, due to their fragile general condition and poor bone quality. Many techniques have been described, associated with high rates of mechanical complications. The objective of this work was to evaluate the mechanical complications and long-term radiological results of ilio-sacral screw pelvic fixation.

Materials and methods 167 consecutive patients with neuromuscular scoliosis who underwent minimally invasive bipolar fixation with ilio-sacral screw pelvic fixation were retrospectively reviewed. The instrumentation consisted in a bilateral sliding rods construct extended from T1 to the sacrum, anchored proximally by double-hook claws and distally by ilio-sacral screws through a minimally invasive approach. Mechanical complications and radiographic measurements (angle of the major coronal curve, pelvic obliquity, lumbar lordosis) were evaluated preoperatively, postoperatively, and at the last follow-up.

Results Mean operative age was 12 ± 3 years, and follow-up 6.4 years (3.0–10.4 years). Pelvic obliquity decreased from 20° preoperatively to 5° (77% correction) at last follow-up, Angle of the major coronal curve from 75° to 36° (52% correction), and lumbar lordosis from 28° to 38°. 16 mechanical complications in nine patients occurred: screw prominence ($n = 1$), connector failure ($n = 4$), screw malposition ($n = 11$). Unplanned surgery was required in seven cases, two were managed during rod lengthening, seven did not require treatment.

Conclusion In this series of neuromuscular patients operated by ilio-sacral screws as pelvic fixation, the results were stable with a mean follow-up of more than 6 years and the complication rate was reduced comparatively to the literature.

Level of evidence 4

Keywords Neuromuscular scoliosis · Minimally invasive fusionless surgery · Bipolar construct · Pelvic rod anchoring · Ilio-sacral screw

Introduction

Neuromuscular scoliosis starts to develop at an early age and usually worsens over time despite conservative treatment, due to the muscle tone and trunk balance disorders. It is most often located in the thoraco-lumbar region and may extend to the pelvis, resulting in pelvic obliquity [1]. Arthrodesis in adolescence, following orthopaedic treatment is the common therapeutic scheme for these scoliosis [2, 3]. In cases of rapidly progressive deformities, orthopaedic treatment is ineffective and early growth-sparing surgical procedures may be used in order to obtain a better correction of the deformity and to preserve spinal and thoracic growth [4]. However, if a pelvic fixation is required, a higher rate of mechanical complications has been reported in the literature. One of the main risk factors for these complications is the poor bone quality in these fragile patients, whose nutritional status is often severely impaired. In addition, the large lever arm imposed by long constructs applies considerable constraints on the pelvic anchors during trunk movements. Sponseller et al. [5] compared different pelvic fixation techniques

✉ Lotfi Miladi
l.miladi@aphp.fr

[1] Pediatric Orthopedic Surgery Department, Paris Descartes University, Assistance Publique Hôpitaux de Paris (AP-HP),Necker Hospital, 149 rue de Sevres, 75015 Paris, France

[2] French National Academy of Medicine, Paris, France

Published online: 18 January 2022

(iliac screws, iliac rods, S-rods, and sacral fixation) and reported between 16.5 and 30% of mechanical complications related to the implants. Furthermore, the wide variety of pelvic fixation techniques described to date also reflects the difficulty in finding a satisfactory solution [6–8]. In the minimally invasive bipolar fusionless technique for the treatment of neuromuscular scoliosis [9], the use of ilio-sacral screws as pelvic fixation may reduce the mechanical complication rate [10–12].

The first description of ilio-sacral fixation was made by Paul Harrington in 1969 to treat L5/S1 spondylolisthesis, using a trans-ilio sacral Steinmann pin [13]. In 1972, Jean Dubousset used this technique to treat neuromuscular scoliosis, with a cannulated superior femoral epiphysiolysis screw. Since then, and with the development of the Cotrel–Dubousset instrumentation, the technique has improved. The screws are now connected to the rods by a specific poly-axial open connector, and a dedicated ancillary is used to insert the ilio-sacral screws percutaneously [11].

The main aim of this work was to evaluate the long-term mechanical complications rate of ilio-sacral screw fixation used for minimally invasive bipolar technique to treat neuromuscular scoliosis. The secondary objective was to evaluate the correction of pelvic obliquity and its stability over time.

Materials and methods

Study design and data collection

The medical charts of all patients with neuromuscular scoliosis who underwent bipolar fusionless surgery with ilio-sacral screw fixation at our department between January 2011 and December 2017 were retrospectively reviewed. The indication for pelvic fixation was a pelvic obliquity > 10° in the frontal plane, or in case of frontal or sagittal trunk imbalance > 10°. T

he study was approved by the ethics committee (CPP, ID-EUDRACT # 2014 A019043 44). For each patient, all mechanical complications, whether or not related to the implant (screw malposition, screw migration, connector breakage or loosening), as well as neurological complications such as impingement with the S1 nerve root were collected. The following radiographic parameters were also analysed before surgery, immediately after surgery, and at the last follow-up: angle of the major coronal curve, pelvic obliquity, thoracic kyphosis, and lumbar lordosis [14, 15]. Pelvic obliquity was defined as the angle in degrees between a line drawn between the midpoint of T1 and the midpoint of S1 and the perpendicular to the line joining the iliac crests or the foot of the sacro-iliac joints on seated full antero-posterior radiographs of the spine.

Operative technique

The surgery was performed under moderate intraoperative traction, applied asymmetrically in the case of an oblique pelvis, and under spinal cord monitoring to analyse somesthetic and motor evoked potentials. It was performed by 5 different senior spine surgeons of the department. Proximal fixation was vertebral, extended over the first 5 thoracic vertebrae and ensured by a double claw of supralaminar [16] and pedicle hooks on each side (E-Spine®, Euros, La Ciotat, France), separated by a free vertebra. Distal fixation was performed by ilio-sacral screws passing through a specific connector (Tanit®, Euros, La Ciotat, France), which links them to the rods. The connector is multiaxial and is inserted into a hole made between the articular process of L5-S1 and the first posterior sacral foramen with a dedicated bone chisel. A specific guide attached to the multiaxial connector is used to guide the insertion of the cannulated ilio-sacral screw (7 mm in diameter) through a small incision (Fig. 1). The direction is oblique from posterior to anterior in order to pass in front of the spinal canal and to reach the body of S1 (Fig. 2).

The technique of ilio-sacral screw fixation used in the study population was published in 1997 and in 2010 on two series of posterior arthrodesis [10, 12]. In the present study, the surgical technique, the implants, and ancillaries have been improved: the new connector is open and poly-axial, and also ensures locking of the ilio-sacral screw. Its deep position and low profile make this connector suitable for patients who are very young or thin. The position of the ilio-sacral connector in the alignment of the pedicle screws and its poly-axiality make the insertion of the rods easier [11]. Three crosslinks complete the stability of this

Fig. 1 The specific guide is attached to the multiaxial connector, to allow percutaneous introduction of the ilio-sacral screw through the iliac ala

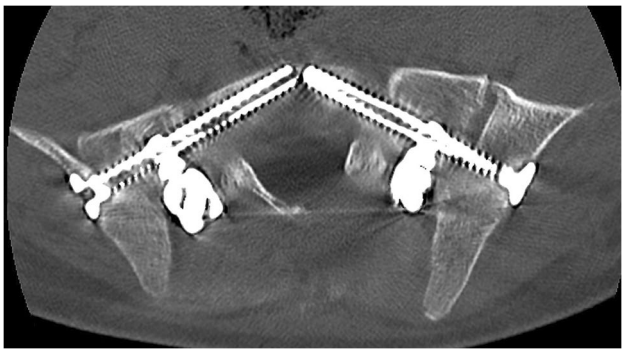

Fig. 2 Transverse plane on CT-scan. The direction of the screw is oblique from outside to inside, and from back to front, passing in front of the spinal canal to reach the body of S1

construct: two proximal and one distal located just above the ilio-sacral connector. Various intraoperative navigation tools can also be used to facilitate and to secure the implantation of the screw in the pelvis, reducing the risk of mispositioning that could cause injury to the first sacral root, the spinal canal or the lateral foramen [17].

In this series, the patients operated on at the beginning of our experience did not have control of screw placement by intraoperative CT scan. Its use has become recently systematic. Additional surgery for rod lengthening was performed secondarily on request, to follow bone growth in a child operated on at a young age, or to perfect the correction of a residual deformity, whether spinal or pelvic. Patients were allowed to sit and stand upright from the first postoperative days, without external support.

Statistical analysis

Variables were described as mean (range). Changes in radiological parameter values from baseline to the early postoperative assessment and to last follow-up were evaluated by applying the pairwise Student's *t* test. *P* values below 0.05 were considered significant. Complications were described as n (%).

Results

Table 1 reported the main features of the population.167 patients were included, 86 females and 81 males, with a mean age at surgery of 12 ± 3 years (range, 8.6–15.4 years). The diagnoses were cerebral palsy ($n = 95$), syndromic neuromuscular disease ($n = 20$), spinal muscular atrophy ($n = 15$), muscular dystrophy ($n = 8$), spina bifida ($n = 6$) and other neuromuscular disorders ($n = 23$). Mean body mass index (BMI) was 16.3 (range 12.4–20.1). At surgery, 38 (22.8%) patients were classified as GMFCS 4, the remaining 129 were GMFCS 5. Mean follow-up was 6.4 years (3.0 to 10.4 years). A mean of 1.3 (0 to 4) lengthening procedures were performed, with a mean interval of 1.4 ± 0.3 years between each procedure. 67 patients did not require a lengthening procedure. One procedure was performed in 54 patients, 2 procedures in 31 patients, 3 procedures in 11 patients, and 4 procedures in 1 patient.

Evaluation of the mechanical complication rate due to ilio-sacral screw fixation

Table 1 details the 16 mechanical complications observed in 9 (5.4%) patients: screw prominence ($n = 1$), connector

Table 1 Mechanical complications of the ilio-sacral screw and their management ($n = 16$, in 9/167 patients)

Year	Screw prominence	Connector failure	Screw mal-position	Total	Number of fusionless surgeries per year (*n*)
2011	0	0	0	0	5
2012	0	0	1	1	13
2013	1	1	1	3	17
2014	0	3	3	6	43
2015	0	0	2	2	37
2016	0	0	1	1	36
2017	0	0	1	1	16
2018	0	0	0	0	–
2019	0	0	2	0	–
Total	1	4	11	14	167
Unplanned surgery (*n*)	1/1	0	6/11	–	–
Revision during a planned rod lengthening procedure (*n*)	0	4/4	0	–	–
No revision required	0	0	5/9	–	–

failure ($n=4$), and screw malposition ($n=11$). The patient with ilio-sacral screw prominence was 10 years old and had severe malnutrition with a BMI of 14.0. One patient required two revision surgeries, one due to connector failure and then a few months later due to screw malposition. Connector failure without clinical consequence occurred in 4 walking patients, related to high flexion–extension stresses of the trunk, and was managed during the next scheduled lengthening procedure (Fig. 3).

Of the 11 cases of ilio-sacral screw malposition, five had no clinical or mechanical consequences, but six required unplanned surgery for ilio-sacral screw replacement, due to irritation of the S1 root causing neuropathic pain. These improved after revision surgery. A non-ambulatory patient reported intermittent low back pain. No cases of ilio-sacral screw pull-out or breakage were recorded in this series.

Evaluation of other mechanical complications and infections

Nine cases of rod fracture (5.3%) occurred in cerebral palsy patients: three of them were walking, two were dystonic, and four had major kyphosis > 50°. Proximal hook migration requiring repositioning occurred in five patients. The rate of surgical site infection was 22.1% (32 patients). Seven of them required complete removal of the material because of the chronicity of the infection. The material was replaced one year later, because of an increase of the deformity in two patients. The five others were not re-instrumented thanks to the stability of the correction over time.

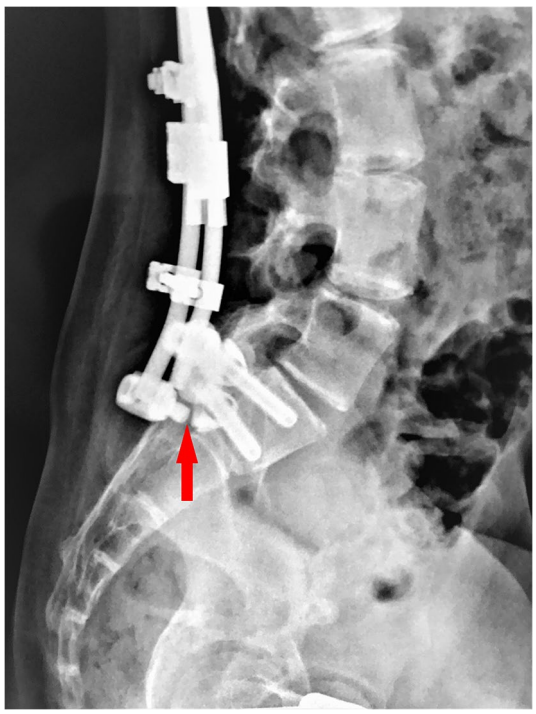

Fig. 3 Example of mechanical complication with connector failure

Evaluation of the pelvic obliquity correction and its maintenance over time

All the radiological data are reported in Table 2. The preoperative radiological parameters were as follows: major angle curve, 74.7° (46.1°–103.3°); pelvic obliquity, 20.2° (3.8°–24.0°); lumbar lordosis, 27.7° (−1.8° to 57.2°), and thoracic kyphosis, 45.4° (17.9°–73.0°). Preoperative pelvic obliquity was > 10° in 114 children (68.2%). In the other cases, it was < 10° but patients had significant trunk imbalance in the frontal or sagittal plane, including 19 walking patients. The mean correction of the major angle curve was 52.5% (37.4%–75.7%) at last follow-up, and 77.2% for pelvic obliquity.

Discussion

Long-term follow-up of the patients in this series, operated on by minimally invasive bipolar fusionless technique with pelvic fixation by ilio-sacral screw was associated with stable radiographic outcomes and a reduced rate of mechanical complications (Figs. 4–5). Many studies have reported high rates of mechanical complications after fusionless surgery for neuromuscular scoliosis. For example, Sponseller et al. [5] compared various methods of pelvic fixation in 36 patients, and reported 10 mechanical complications involving pelvic fixation, including five iliac screw fractures, three distal screw prominences, and two distal screw pull-out. In 2016, Brooks et al. [18] compared the results of pelvic

Table 2 Radiological data

Angle of mean coronal curve angle ° (mean)	
Preoperative	74.7° (46.1–103.3°)
Postoperative	32.8° (16–49.7°)
Last follow-up	36° (18.4–53.4°)
Pelvic obliquity °(mean)	
Preoperative	20.2° (3.8–24°)
Postoperative	4.8° (0.77–8.8°)
Last follow-up	4.7° (0.43–9°)
Thoracic kyphosis °(mean)	
Preoperative	45.4° (17.9–73°)
Postoperative	30.3° (17.6–43.1°)
Last follow-up	31.3° (18.2–44.4°)
Lumbar lordosis °(mean)	
Preoperative	27.7° (1.8–57.2°)
Postoperative	39.2° (26.9–51.4°)
Last follow-up	38.0° (25–51°)

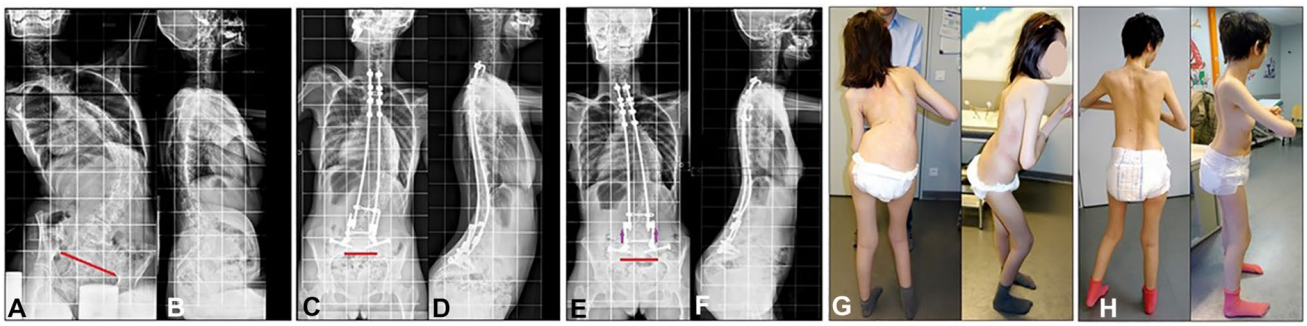

Fig. 4 **a**–**e** Radiographs and photographs of an 11-year-old girl with Rett syndrome and 30° pelvic obliquity. **a** pre-operative radiographs. **b** 18 months post operatively (before rod lengthening). **c** 2.5 years postoperatively, after rod lengthening. **d** pre-operative photographs of this patient. **e** after 4-years follow-up

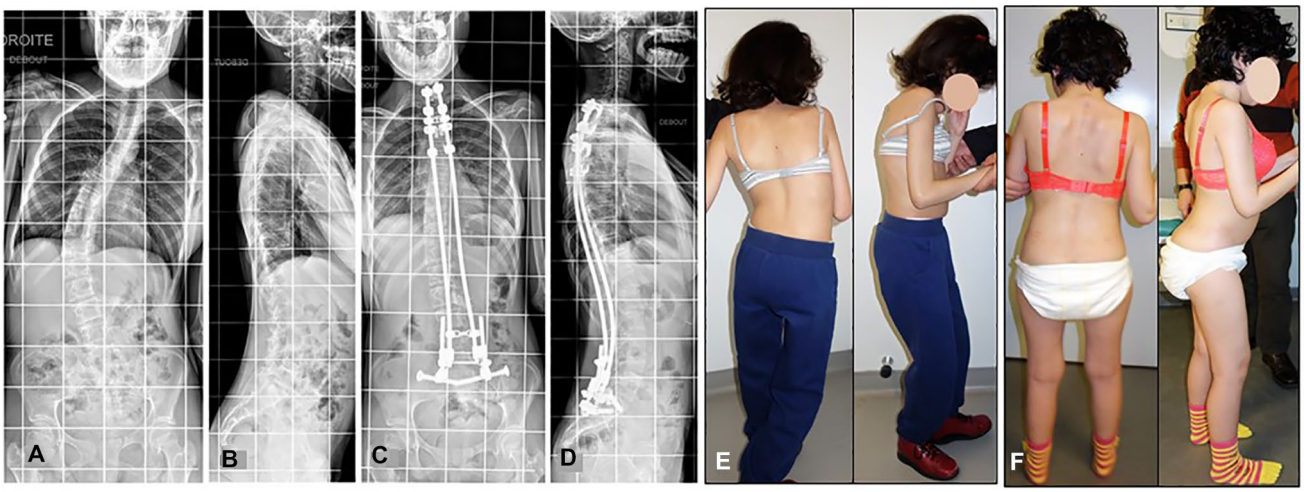

Fig. 5 **a**–**d** Radiographs and photographs of a 12-year-old girl with cerebral palsy, pelvic obliquity < 10° but severe trunk imbalance. **a** pre-operative radiographs. **b** postoperative radiographs. **c** preoperative photograph. **d** after 5-years follow-up

fixation at the ilium and sacrum versus at the sacrum only in 38 patients followed for at least 4 years. Distal anchorage failure occurred in six (15.7%) patients, including one sacral fixation (S1 foramen fracture with screw pull-out) and five iliac fixations (screw pull-out, $n=3$; iliac screw rupture, $n=1$ and iliac screw sweep, $n=1$). A multi-center evaluation [19] of Dunn–McCarthy pelvic hook fixation with proximal costal anchorage in patients with early scoliosis showed a pelvic fixation complication rate of 50%, with an unscheduled revision surgery rate of 5.6%. Gait was impaired in 40% of walking patients, 6% reported postoperative neuropathic pain, up to 14% in another study with Dunn–McCarthy fixation [20]. In the present series, five patients reported neuropathic pain due to a sacral root impingement which improved after screw path revision. One non-ambulatory patient presented intermittent low back pain without radiculalgia, which were solved under medical treatment.

The results in the present series were as satisfactory as other studies using ilio-sacral pelvic fixation for neuromuscular scoliosis in PSF. In Miladi et al. retrospective study of 154 consecutive patients [10], the Cobb angle was corrected by 53–70% and correction of pelvic obliquity was 60–84%. In Zahi et al. prospective series of 62 neuromuscular patients [12], postoperative angular parameters showed a good correction of spinal deformity. Patients with preoperative pelvic obliquity had a satisfactory and stable correction at final follow-up. In Ould-Slimane et al. adults' series [21], the ilio-sacral screw pelvic fixation adequately provided frontal and sagittal corrections, increased stability, and reduced instrumentation-related complications.

The rather high surgical site infection rate in the present series should be compared to other techniques with caution as neuromuscular scoliosis fixed to the pelvis are known to be associated with a higher rate of infectious complications, especially in case of cerebral palsy and spina bifida [22–24]. In addition, the technique used in this series required repetitive rod lengthening surgeries. The advent of a new self-expanding rod using with the same bipolar construct but

avoiding repeated surgeries should decrease the infectious risk [25].

The stability and strength of the bipolar construct with pelvic fixation by ilio-sacral screws are based on its geometric design. To our knowledge, this is the only construct in which the rod is connected to the middle of the pelvic implant, and not at the extremity of the screw. In all other types of pelvic fixation, the rods are attached to the screw head, either directly or through a small connecting rod. The rod connection in the middle of the ilio-sacral screw distributes the stresses evenly over the two halves of the screw. The proximal part fits in the iliac ala and the distal part is held in the body of S1. We hypothesize that the screw-rod connection may also minimize the risk of screw pull-out, even in patients with fragile bones, as it is located deeply within the bone and remains firmly in contact with bone all along its path (Fig. 1). Moreover, the position and orientation of the ilio-sacral screw, which passes behind the sacro-iliac joint toward the sacrum, preserves and stabilizes the sacro-iliac joint. The cross-link that connects the rods on either side of the pelvis also reinforces this stabilization. This protective effect may explain the absence of pain from sacro-iliac joint degeneration, even in ambulatory patients. Screw malposition with S1 root irritation mostly happened at the beginning of our experience, when ilio-sacral screws were inserted free-hand without intraoperative imaging control. Whether pelvic fixation in neuromuscular growing constructs is required remains controversial. The extension of the fixation to the pelvis must be discussed case-by-case. In non-walking patients, the goal of pelvic fixation is to correct pelvic obliquity and trunk imbalance, thereby improving sitting comfort. In walking patients, the rate of mechanical complications was higher. That is why we reinforced the construct with two additional rods. The ilio-sacral connector was also modified to be stronger. In the present series, the indications for pelvic fixation were a pelvic obliquity more than 10°, or trunk imbalance > 10° in the sagittal and/or coronal plane.

The paramedian position of the ilio-sacral screws creates a powerful lever arm that allow severe pelvic obliquity correction by applying strong distraction or compression manoeuvres. Additional in situ bending can also be performed to improve residual coronal and/or sagittal deformities.

In a recent publication [26] of 13 neurological scoliosis aged between 11 and 22 years, operated on using the same technique with an average follow-up of 3 years, the correction of pelvic obliquity was 82%, and 63% for the main coronal curve angle. The overall complication rate was 15%. In our practice, we propose this technique even for skeletally mature neuromuscular patients instead of PSF as we have observed that the construct was stable overtime at long-term follow-up thanks to a progressive spinal stiffening due to fibrosis and auto-fusion. None of our patients required a PSF after more than 10 years for the first cases [27].

This fusionless technique was also proposed in adults' patients with encouraging preliminary results in 48 cases (mean age 45 years) with major coronal or sagittal deformities. 14.5% of mechanical complications were related to pelvic fixation [28].

Compared to PSF, fusionless surgery is faster and less haemorrhagic and thus particularly beneficial in fragile neuromuscular patients. Compared with other types of scoliosis, complication rates of PSF procedures in neuromuscular scoliosis shows the highest rate of complications (24–75%), followed by congenital (10.6%) and idiopathic (6.3%) etiologies [29].

The present study has some limitations. It is monocentric and retrospective without comparative group. Moreover, a biomechanical study with other fixation techniques could support the clinical findings. However, research is ongoing on the biomechanical properties of this pelvic fixation, and results will be published in the future.

Conclusion

In this series of neuromuscular patients operated by ilio-sacral screws as pelvic fixation, the results were stable with a mean follow-up of more than 6 years and the complication rate was reduced comparatively to the literature.

Author contributions MG: study design, statistics, data interpretation, manuscript drafting, and approval of the final version to be published. PG: study design, statistics, manuscript drafting and revision for important intellectual content, and approval of the version to be published. NK: approval of the final version to be published. PG: approval of the final version to be published. JDD: revision for important intellectual content and approval of the final version to be published. LM: study design, manuscript drafting, revision for important intellectual content and approval of the final version to be published.

Funding Euros® is the manufacturer of the ilio-sacral screws. It had no role in the design of the study, collection of the data, analysis or interpretation of the results, writing of the article, or decision to submit it. No author of this article received any financial or nonfinancial contribution related to this study.

Declarations

Conflict of interest L. Miladi has intellectual property rights with Euros company.

Ethical approval CPP, ID-EUDRACT # 2014 A019043 44.

Informed consent Informed consent was obtained from all participants.

References

1. Thometz JG, Simon SR et al (1988) Progression of scoliosis after skeletal maturity in institutionalized adults who have cerebral palsy. J Bone Joint Surg Am 70:1290–1296
2. Rumalla K, Yarbrough CK, Pugey AJ (2016) Spinal fusion for pediatric neuromuscular scoliosis: national trends, complications and in hospital outcomes. J Neurosurg Spine 25:500–508
3. Miller A, Temple T, Miller F (1996) Impact of orthoses on the rate of scoliosis progression in children with cerebral palsy. J Pediatr Orthop 16:332–335
4. McElroy MJ, Sponseller PD, Dattilo JR et al (2012) Growing rods for the treatment of scoliosis in children with cerebral palsy: a critical assessment. Spine 37:E1504–E1510
5. Sponseller PD, Yang JS, Thompson GH, McCarthy RE et al (2009) Pelvic fixation of growing rods: comparison of constructs. Spine 34:1706–1710
6. Anari J, Spiegel D, Baldwin K (2015) Neuromuscular scoliosis and pelvic fixation in 2015: where do we stand? World J Orthop 6(8):564–566
7. Dayer R, Ouellet JA, Saran N (2012) Pelvic fixation for neuromuscular scoliosis deformity correction. Curr Rev Musculoskelet Med 5(2):91–101
8. Peele MW, Lenke LG, Bridwell KH et al (2006) Comparison of pelvic fixation techniques in neuromuscular spinal deformity correction: galveston rod versus iliac and lumbosacral screws. Spine 31(20):2392–2398 (**discussion 2399**)
9. Miladi L, Gaume M, Khouri N, Johnson M et al (2018) Minimally invasive surgery for neuromuscular scoliosis: results and complications in a series of one hundred patients. Spine 43:E968–E975
10. Miladi LT, Ghanem IB, Draoui MM et al (1997) Ilio-sacral screw fixation for pelvic obliquity in neuromuscular scoliosis. A long-term follow-up study. Spine 22:1722–1729
11. Dubousset J, Gaume M, Miladi L (2021) Ilio-sacral screw pelvic fixation when correcting spinal deformities with or without pelvic obliquity: our experience over 40 years. Spine Deform 9(3):665–670. https://doi.org/10.1007/s43390-020-00263-6
12. Zahi R, Vialle R, Abelin K et al (2010) Spinopelvic fixation with ilio-sacral screws in neuromuscular spinal deformities: results in a prospective cohort of 62 patients. Childs Nerv Syst 26(1):81–86
13. Harrington P, Tullos H (1971) Spondylolisthesis in children: observations and surgical treatment. Clin Orthop Relat Res 79:75–84
14. Akbarnia BA, Breakwell LM, Marks DS et al (2008) Dual growing rod technique followed for three to eleven years until final fusion: the effect of frequency of lengthening. Spine 33:984–990
15. Thompson GH, Akbarnia BA, Campbell RM et al (2007) Growing rod techniques in early-onset scoliosis. J Pediatr Ortho 27:354–361
16. Gaume M, Persohn S, Vergari C, Glorion C et al (2020) Biomechanical cadaver study of proximal fixation in a minimally invasive bipolar construct. Spine Deform 8(1):33–38
17. Sun X, Li S, Qiu Y et al (2018) Anatomical study of a novel ilio sacral screw placement for sacrum-pelvis in adult via computed tomography reconstruction. Spine 43(13):E740–E745
18. Brooks JT, Jain A, Sanchez-Perez-Grueso F, Skaggs DL et al (2016) Outcomes of pelvic fixation in growing rod constructs: an analysis of patients with a minimum of 4 years of follow-up. Spine Deform 4:211–216
19. Ramirez N, Flynn JM, Smith JT et al (2015) Use of the S-hook for pelvic fixation in rib-based treatment of early-onset scoliosis: a multicenter study. Spine 40:816–822
20. Walick KS, King JT, Johnston CE et al (2008) Neuropathic lower extremity pain following Dunn-McCarthy instrumentation. Spine 33:E877–E880
21 Ould-Slimane M, Miladi L, Rousseau MA, Bonaccorsi R (2013) Catonnes-Y, Lazennec JY, Moussellard HP (2013). Sacropelvic fixation with iliosacral screws: applications and results in adult spinal deformities. J Spinal Disord Tech. 26(4):212–217
22. Reames DL, Smith JS, Fu KM, Polly DW Jr, Ames CP, Berven SH, Perra JH, Glassman SD, Mc Carthy RE, Knapp RD Jr, Heary R, Shaffrey CI (2011) Complications in the surgical treatment of 19,360 cases of pediatric scoliosis: a review of the scoliosis research society morbidity and mortality database. Spine (Phila Pa 1976) 36(18):1484–1491
23. Sharma S, Wu C, Andersen T, Wang Y, Hansen ES, Bünger CE (2013) Prevalence of complications in neuromuscular scoliosis surgery: a literature meta-analysis from the past 15 years. Eur Spine J 22(6):1230–1249
24. Cognetti D, Keeny HM, Samdani AF, Pahys JM, Hanson DS, Blanke K, Hwang SW (2017) Neuromuscular scoliosis complication rates from 2004 to 2015: a report from the scoliosis research society morbidity and mortality database. Neurosurg Focus 43(4):E10
25. Miladi L, Khouri N, Pradon J, Elie C, Treluyer JM (2021) One way self-expanding rod for early onset scoliosis: early results of a clinical trial of 20 patients. Eur Spine J 30(3):749–758
26. Palmisani M, Dema E, Palmisani R, Cervellati S (2020) Surgical treatment of neuromuscular spine deformity with minimally invasive fusionless surgery: an innovative technique. Giornale Italiano di Ortopedia e Traumatologia 46:1–8
27 Gaume M, Vergari C, Khouri N, Skalli W, Glorion C, Miladi L (2021) Minimally invasive surgery for neuromuscular scoliosis: results and complications at a minimal follow-up of 5 years. Spine (Phila Pa 1976). https://doi.org/10.1097/BRS.0000000000004082
28. Wolff S, Habboubi K, Sebaaly A et al (2019) Correction of adult spinal deformity with a minimally invasive fusionless bipolar construct: preliminary results. Orthop Traumatol Surg Res 105:1149–1155
29. Toll BJ, Samdani AF, Janjua MB, Gandhi S, Pahys JM et al (2018) Perioperative complications and risk factors in neuromuscular scoliosis surgery. J Neurosurg Pediatr 22(2):207–213