Neuromuscular Scoliosis Treated by Segmental Third-Generation Instrumented Spinal Fusion

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Abstract: We aimed to investigate whether the outcome and complications of surgical treatment of neuromuscular curves with segmental third-generation instrumentation could compare with those reported with standard second-generation instrumentation. The clinical and radiologic data of a single surgeon's consecutive series of patients with neuromuscular scoliosis treated with two types of newer-generation instrumentation and posterior or anteroposterior approaches were retrospectively and independently reviewed. The results of this study support the concept that third-generation instrumentation is able to provide at least as good results as second-generation instrumentation in the treatment of neuromuscular scoliosis patients, at the expense of a lower complication rate.

Key Words: neuromuscular scoliosis, spinal fusion, third-generation instrumentation

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The term "neuromuscular scoliosis" (NMS) describes a spectrum of spinal disorders that have in common the resulting disturbance of the musculoskeletal system because of altered innervation and/or muscle tone. As a consequence, the spine in these patients tends to lack its supportive properties, which makes ambulating and sitting problematic. Patients affected by NMS have a poor response to conservative treatment of spinal deformities, and the consequences of spinal deformity itself are more serious for them than for patients with idiopathic scoliosis, namely, in the cardiovascular and respiratory systems.[1] Surgical treatment, in the form of segmental instrumented spinal fusion (ISF) with second-generation instrumentation (eg, Luque–Galveston and unit rod constructs), has been considered the standard surgical technique for NMS surgery in the last two decades.[2] These techniques generally lead to improved quality of life with correction of coronal deformity and of pelvic obliquity in the range of 50–75% of preoperative values. Major complications, most commonly deep infection, instrument failure, and pseudoarthrosis, affect 7–45% of treated patients.[3–7]

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The widespread use of third-generation instrumentation (Cotrel-Dobousset and related implants) has changed our approach to the surgical treatment of both adolescent[8] and adult[9] idiopathic scoliosis. Surgery for idiopathic scoliosis using third-generation instrumentation techniques provides significant deformity correction and patient satisfaction, with an acceptable complication rate. Nevertheless, almost 20 years after the introduction of such devices, reports are lacking on the results of third-generation instrumentation for the treatment of NMS. Therefore, the aim of this study is to verify the hypothesis that treatment of NMS with third-generation ISF may provide at least as good results as second-generation ISF, with fewer complications. To do so, we report on a single surgeon's consecutive series of patients treated at two tertiary referral centers for spinal disorders and compare the results with the pertinent literature.

MATERIALS AND METHODS

Inclusion criteria for the study were a diagnosis of progressive scoliosis due to a neurologic or muscular disorder, treatment by posterior-only or anteroposterior spinal fusion by third-generation instrumentation, and a minimum follow-up of 2 years from surgery. Exclusion criteria were incomplete clinical and/or radiologic documentation at follow-up. The medical records and imaging of all patients operated on by the senior author from 1995 to 2000 who satisfied the above criteria were reviewed.

Patients aged up to 15 years were treated at a pediatric orthopedic institution, whereas older patients were treated at a separate spinal deformity unit. All patients were assessed preoperatively by the senior author and followed up postoperatively in his outpatient clinic. At every appointment, sitting (standing when possible) posteroanterior and lateral 50 × 115–cm radiographs were obtained. Posteroanterior traction (bending when possible) films were requested preoperatively. The coronal and sagittal components of the spinal deformity were measured by the Cobb method. Pelvic obliquity was measured as the angle described by a line tangential to both iliac crests and a line perpendicular to the spinous processes of L4 and L5.[10] When instrumentation, fusion mass, or removal of spinous process made this comparison unreliable, we drew a line intersecting the middle of the pedicles of L4 and L5 on the posteroanterior view.

Indications for surgery were based on (a) consideration of the magnitude and progression of the spinal deformity; (b) presence of functional deterioration; (c) evaluation of cardiopulmonary status, including echography where necessary (eg,

in myopathic patients) and pulmonary function tests in cooperative patients; (d) evaluation of nutritional status, including weight/height ratio, lymphocyte count, and serum albumin.[1–3,5–7] These evaluations were carried out by a team composed of a spinal deformity surgeon (senior author) with his fellow and resident, a dedicated anesthesiologist, a referring pediatrician/neurologist, specialist nurses, physiotherapists, nutritionists, and occupational therapists. Procedures were planned as posterior-only, anteroposterior on the same day under one anesthetic session (combined) or at a time interval of 1 week (staged), depending on etiology and flexibility of the curve, general health status, skeletal maturity, and anticipated intraoperative blood loss. Indications for posterior-only instrumented spinal fusion were given to patients affected by flaccid NMS due to Duchenne muscular dystrophy (DMD), to those whose cardiopulmonary function was not deemed suitable for a double approach, and to those skeletally mature patients whose deformities were flexible (above 50% correction on traction/bending films). Indications for anteroposterior spinal fusion were given, with the above exceptions, to patients featuring rigid coronal curves (below 50% correction on traction/bending films) and/or fixed pelvic obliquity, deficiency of posterior elements, and skeletal immaturity. Anterior instrumentation was used to correct fixed thoracolumbar and lumbar coronal and/or sagittal deformities whenever bone was judged of sufficient quality by the surgeon. The decision whether to perform an anterior instrumented versus noninstrumented fusion was taken both on the results of the preoperative screening (nutritional status, walking ability) and on the operative findings (bone quality and ability to withstand implants). Bone densitometry was not part of the screening tests of the study population. Combined procedures were selected by the surgical team whenever possible. Staging was reserved to those cases where significant intraoperative factors (ie, amount of blood loss and operating time) were anticipated to contraindicate same-day surgeries or when halo-tibial traction was used to progressively correct fixed sagittal deformities. Anterior procedures always preceded posterior ones. Two types of third-generation titanium instrumentation systems were used anteriorly and posteriorly as available in the two public health care institutions where patients were treated. The two systems used were the Synergy (Interpore Cross, Irvine, CA) and the Colorado (Medtronic Sofamor Danek, Memphis, TN). Indications for fusion to the pelvis by iliac screws were given to nonambulatory patients with sitting unbalance and to patients who had curves including the pelvis and/or fixed pelvic obliquity.

Surgical Technique

Anterior thoracic or thoracoabdominal approaches to the spine were done on the convex side of the deformity, through the rib bed correspondent to the highest spinal level to reach. The selected rib was excised, morselized, and used as autograft for the posterior spinal instrumented fusion. The diaphragm was divided peripherally in thoracolumbar approaches. Ligature of segmental vertebral vessels was done only in instrumented procedures. It was the surgeon's effort to perform release of the anterior longitudinal ligament, discectomy, and removal of vertebral endplates. This aimed to enhance mobilization of the spinal segments and chances of interbody fusion. Twenty to 40 mL of hydroxyapatite derived from marine coral was used as interbody graft material. Anterior instrumentation included segmentally the entire curve as measured preoperatively. Instrumentation consisted of 5.0- to 7.0-mm-diameter screws with washer and bicortical purchase in the vertebral bodies and a single 5.5-mm-diameter rod, tightened to each screw and derotated to achieve the necessary coronal and sagittal contour of the regional vertebral column. In thoracolumbar approaches, the diaphragm was closed in a continuous layer with the pleura over a suction drain.

Posterior approaches were done through a straight midline incision and subperiosteal exposure of the vertebral levels to be included in the fusion. Facetectomy was done at the same levels. Vertebral levels encompassed the entire thoracic (from T1 or T2) and lumbar spine according to the morphology of the deformity. Laminar, pedicle, and transverse process hooks were preferred at thoracic levels. Pedicle screws were positioned at lumbar and thoracolumbar levels. Sublaminar wires were used at lumbar and thoracolumbar levels in case of insufficient bone–implant purchase to achieve further fixation. Two 5.5-mm-diameter rods linked by cross-connectors were implanted in each patient. The technique of ileospinal fixation involved bilateral exposure of the posterior superior iliac spine through the same midline incision used for the lumbar exposure, perforation of the iliac crest with a pedicle finder directed toward the superior and lateral rim of the acetabulum, and use of 5.5- to 7.0-mm-diameter, 40- to 80-mm-long iliac screws. Bilateral S1, L5, or L4 screws and dedicated connectors completed the construct. Deformity correction was obtained by contouring of the rods, careful translation, and segmental compression/distraction. Morselized autografts, from harvested spinous processes, facet joint bone, and rib (where previously harvested), were all applied after decortication of the posterior elements. This was routinely augmented with 20–40 mL of hydroxyapatite derived from marine coral. The fascia was closed in a continuous layer followed by subcuticular and intradermal layers. No wound drains were used. No cell-saver was used intraoperatively on the patients included in the study. Patients received homologous blood transfusions intra- and postoperatively as needed by clinical conditions. Controlled hypotensive anesthesia (with a mean blood pressure above 60 mm Hg) was carried out to maintain a dry surgical field and to control blood losses, a feature of utmost importance in NMS surgery and ensuring critical perfusion of the vital organs. Recording of the somatosensory spinal-evoked potentials (SSEPs) was done routinely: A prolonged 50% decrease in SSEP trace amplitude was regarded as significant.[4] Intravenous antibiotics, a combination of aminoglycosides and β-lactamates for prophylaxis against gram-negative and gram-positive bacteria, were started perioperatively and continued for 72 hours.

Postoperative Care and Follow-Up

Postoperatively, patients were transferred to an intensive care unit (ICU) if they were still ventilated or to a high-dependency unit (HDU) if they were not ventilated and needed only specialized postoperative care. Patients were transferred from these units to their wards after extubation and fluid

balancing. Oral feeding was stimulated as soon as tolerated, whereas enteral or parenteral hyperalimentation was used in case oral feeding was not possible. Mobilization to a molded wheelchair or ambulation was also allowed as soon as tolerated, with the assistance of specialized physiotherapists. No brace was prescribed postoperatively. Clinical and radiologic outpatients' follow-up was done at 3, 6, and 12 months postoperatively and yearly thereafter with the modalities described above. Fusion and graft incorporation were routinely judged upon examination of posteroanterior and lateral radiographs. Oblique views and computed tomography scans were requested in cases of suspected pseudoarthrosis, namely, local tenderness, loss of correction, implant failure, or a combination of these factors.

An outcome questionnaire validated for flaccid NMS[5] only was adopted for review of spastic NMS cases too and mailed to patients' parents/caregivers at the final follow-up. The questionnaires were filled in by patients themselves or by parents or caregivers depending on the patients' intellectual abilities. The questionnaire includes a total of 20 questions concerning satisfaction with the surgical outcome, cosmesis, function, self-image, pain, patient care, pulmonary function, and quality of life. Every answer is graded −2 (worse) to +3 (major improvement) for a cumulative score ranging from −36 to +52.

Analysis of Data

Clinical and radiographic data were subdivided among treatment groups, that is, posterior-only (group 1), anteroposterior combined (group 2), and anteroposterior staged (group 3) surgeries. We considered sex, age, and weight at surgery, functional status, number of levels operated, operative time, intraoperative blood and estimated blood volume (EBV) loss, instrumentation type, ICU/HDU stay, hospital stay, complications, follow-up length, preoperative/postoperative/follow-up scoliosis, kyphosis, lordosis, and pelvic obliquity angles. Complications were divided into major and minor according to their effect on the course of recovery in hospital and on their potential life-, limb-, or function-threatening effect.[6,11,12] Major complications included pneumonia, pneumothorax requiring prolonged chest tube, tracheostomy, persistent neurologic deficit, deep wound infection, bowel ischemia, congestive heart failure and injury to a major vessel, urinary sepsis and gross hematuria, disseminated intravascular coagulation, rod breakage, implant loosening requiring revision, and pseudoarthrosis. Minor complications included upper respiratory tract or tracheostomy infections, spontaneously resolving pneumothorax, paresthesia, cerebrospinal fluid leak, superficial wound infection, wound dehiscence, pressure sore, ileus, gastritis, colitis, transient cardiac arrhythmia, urinary tract infection, and implant loosening not requiring revision.

Pearson correlation analysis was applied to data by means of an SPSS program (Chicago, IL). To test persistent effects, preoperative, postoperative, and follow-up scores were evaluated by the Wilcoxon signed rank test. Differences between groups were evaluated by the χ^2 test. For all comparisons, a P value of <0.05 (two tailed) was considered significant. Descriptive statistics were used for these and other outcomes, and the results were expressed as means ± SD, range, percentage, or total number of cases.

RESULTS

Of a group of 62 patients who satisfied the inclusion criteria, 5 were excluded because their follow-up data were incomplete owing to change of address and hospital care area. One (affected by arthrogryposis) was excluded because at the time of the latest follow-up, he had been treated with a long anterior instrumented fusion only and was being observed. Of the 56 patients (27 females, 29 males) included in the study cohort, mean age at surgery was 14 (range 8–21) years, mean weight at surgery was 46 (range 30–70) kg, and mean follow-up was 52 (range 24–85) months. Etiology of spinal deformity included spastic quadriplegic cerebral palsy (CP) in 36 patients, and DMD in 8 patients. Spina bifida, Friedreich ataxia, syringomyelia, spinal muscular atrophy (SMA), and poliomyelitis were the etiologies in the remaining 12 patients. Functional level was graded according to the World Health Organization classification of impairment, activity, and participation.[13] Forty-five patients (80%) included in this study were at functional level 5. Patients' functional levels and etiologies of spinal deformity are displayed in Table 1.

At the time of surgery, spinal growth in 35 patients (62.5%) was considered complete. This was defined on preoperative posteroanterior full spine radiographs as Risser 5 ossification of the iliac apophysis and closure of the triradiate cartilages.

Table 2 summarizes the main clinical features regarding the three treatment groups. There were 23 (41%) patients in group 1 (posterior-only), 24 (42%) in group 2 (anteroposterior combined), and 9 (17%) in group 3 (anteroposterior staged).

TABLE 1. Patients' Functional Level[13] and Etiology of Spinal Deformity

	No. of Patients (n = 56)	Etiology/No. of Patients
WHO functional level 1 = walkers without devices	—	—
WHO functional level 2 = walkers with limitations in community walking	6	CP/4, Friedreich ataxia/1, Syringomyelia/1
WHO functional level 3 = walkers with mobility devices	5	CP/2, DMD/2, syringomyelia/1
WHO functional level 4 = self-mobilized with either transport or power mobility outdoors	2	CP/1, DMD/1
WHO functional level 5 = self-mobilized with severe limitations	43	CP/29, DMD/5, spina bifida/4, Friedreich ataxia/2, syringomyelia/1, SMA/1, poliomyelitis/1

WHO, World Health Organization.

TABLE 2. Main Clinical Data

Group	Gender (M:F)	Age at Surgery (y)	Weight at Surgery (kg)	Operated Levels	Operative Time (min)	Blood Loss (mL) [EBV]	ICU/HDU Stay (h)	Hospital Stay (d)	Major Complications (no. of patients)	Minor Complications (no. of patients)	Follow-up Length (mo)
1 (n = 23)	14:9	14 ± 2	49 ± 12	16 ± 4	273 ± 67	2,815 ± 953 [1.1 ± 0.5]	34 ± 6	9 ± 8 $P < 0.05$	2	5 $P < 0.05$	56 ± 23
2 (n = 24)	9:15	14 ± 2.5	43 ± 9	24 ± 6	443 ± 175 $P < 0.05$	3,228 ± 1,253 [1.2 ± 0.6]	41 ± 10	13 ± 7	2	1	50 ± 14
3 (n = 9)	4:5	15 ± 3.3	44 ± 10	25 ± 6	383 ± 78	2,626 ± 1,584 [0.9 ± 0.5]	43 ± 15	17 ± 5	2	3	50 ± 16

Values are means ± SD.

Among the 23 patients in group 1, there were 11 affected by CP, 8 by DMD, 3 by Friedreich ataxia, and 1 by SMA; the last 7 were not deemed medically fit for a double approach. Among the 24 patients in group 2, 19 were affected by CP, 1 by poliomyelitis, and 4 by spina bifida. Among the nine patients in group 3, six were affected by CP and three by syringomyelia. Two patients in group 3, both affected by spastic quadriplegic CP and having a stiff thoracolumbar kyphosis as the main feature of their deformity, underwent a 1-week period of halotibial traction between stages. Sex, age, and weight at surgery, functional levels, and follow-up length were not significantly different among the three groups. On average, 8 levels (range 5–13) were operated on the 37 anterior and 16 levels (range 9–19) on the 56 posterior procedures. Of 37 anterior procedures, 25 (64%) were instrumented. Of 56 posterior procedures, 48 (86%) included the pelvis. The longest mean operative time was recorded in group 2, that is, combined approach (443 minutes; $P < 0.05$). The highest blood loss was recorded in group 2 (1.2 EBVs) and the lowest (0.85 EBVs; $P < 0.05$) in group 3, that is, staged approach. Blood loss was correlated with the degree of pelvic obliquity ($r = 0.29$) and number of operated levels in all groups: 1 ($r = 0.42$, $P < 0.05$), 2 ($r = 0.39$, $P < 0.05$), and 3 ($r = 0.42$, $P < 0.05$).

Significant intraoperative SSEP changes, that is, drops to below 50% of baseline trace amplitude, were observed in seven patients (12.5%). These were all false-positive intraoperative records; that is, they did not correlate with newly developed postoperative neurologic deficits.

The longest ICU/HDU stay (46 hours on average) was recorded in group 3, but this value did not reach statistical significance compared with the two other groups. Hospital stay in group 1 (9 days on average) was significantly shorter ($P < 0.05$) compared with the two other groups.

Major complications affected six patients (10.7%). Of a total of seven major complications, there was one pneumonia in a patient in group 2 who eventually required a long-term tracheostomy, one persistent pleural effusion due to chylothorax in a patient in group 3, two deep wound infections (both in group 1 patients, resolved with repeat operative debridement), two cases of ileosacral screw loosening requiring removal (one in group 1 same patient who had the deep wound infection[and one in group 2), and one pseudoarthrosis at the midthoracic level requiring a local revision and fusion procedure in a group 3 patient. No perioperative death occurred in this study cohort.

Minor complications affected nine patients (16.1%). Of a total of nine minor complications, there was one superficial infection that settled with intravenous antibiotics in group 1, one ischial pressure sore requiring a local flap procedure 6 weeks postoperatively in group 3 (same patient who had chylothorax), and four cases (four patients, two in group 1 and one each in groups 2 and 3) of urinary tract infection treated with oral antibiotics. Furthermore, there were three cases of implant prominence (proximal hooks and ileosacral screws) in thin patients, two in group 1 and one in group 3, not requiring removal at the date of follow-up. Major complications were not statistically different in the three groups of treatment. Minor complications prevailed significantly in group 1 (5 patients affected; $P < 0.05$).

One patient in the study group died of cardiac failure at age 19, 41 months after posterior-only spinal fusion. He had cardiomyopathy and restrictive lung disease, his primary diagnosis being Friedreich ataxia.

Outcome questionnaires[5] (Table 3) were returned by 46 of 56 (82%) parents/caregivers. The parents of the deceased patient refused to respond. Nine other patients had changed their address at the time of the postal survey, and we have been unable to track their new address. Their follow-up data are thus based only on recorded evidence of outpatient and radiology appointments made until a minimum follow-up of 2 years. The mean cumulative score of the outcome questionnaire was 26.3 (range 21–31) for 8 patients with flaccid NMS (7 by DMD and 1 by SMA) and 20.9 (range 10–37) for 38 patients with spastic

TABLE 3. Evaluation Questionnaire Scores[5]

	Flaccid NMS (n = 10)	Spastic NMS (n = 36)
Cumulative	26.1 ± 5.0	20.9 ± 6.5
Cosmesis	4 ± 1.4	4.2 ± 1.9
Function	6 ± 3.6	3.8 ± 3.8
Self-image	0.7 ± 0.9	0.7 ± 1.3
Pain	0.7 ± 0.9	0.7 ± 1.3
Patient care	1 ± 1.4	1.6 ± 3.9
Pulmonary function	0.7 ± 0.9	0.5 ± 1.6
Quality of life	4 ± 0.5	3 ± 3.2
Satisfaction	9 ± 2.5	6.4 ± 4.4

Note: Validated for flaccid NMS only. Scores are means ± SD.

NMS whose parents/caregivers completed the questionnaire. The highest scores in both flaccid and spastic patients were recorded in the areas of satisfaction, cosmesis, function, and quality of life. In flaccid patients, satisfaction and function scores were definitely higher than in spastic ones (on average 9 and 6 compared with 6.4 and 3.8, respectively). No statistical test was applied to these data because the questionnaire is not validated for spastic NMS cases. The lowest questionnaire score was recorded in the above-described patient affected by CP who required a long-term tracheostomy.

Table 4 summarizes the main radiographic data of the three study groups. On average, preoperative coronal deformity was lower in group 1 (58°) than in group 2 (72°; $P < 0.05$) and group 3 (86°; $P < 0.001$), whereas no significant differences were noted in preoperative kyphosis and lordosis angles. Again, main preoperative pelvic obliquity was lower in group 1 (8°) than in group 2 (19°; $P < 0.05$) and group 3 (18°; $P < 0.05$). Correction of scoliosis compared with preoperative values was statistically significant within groups, but no differences were significant among groups. At follow-up, loss of correction of the coronal deformity varied from 0% (group 1) to 2% (group 2). Variation of kyphosis values observed after treatment prevailed in group 1; differences with preoperative values were all statistically significant within groups, but no differences were significant among groups. More importantly, in all groups, an average return to values of kyphosis close to normality was observed postoperatively, without significant changes at follow-up. Variation of lordosis angles prevailed in group 2 (5°; $P < 0.05$ versus groups 1 and 3), with a corrective effect on lordosis (−2°) recorded in group 1. At follow-up, change of lordosis angles prevailed in group 1 (3°). Correction of pelvic obliquity compared with preoperative values was statistically significant in groups 2 and 3. At follow-up, loss of correction of pelvic obliquity prevailed in group 1 (3° or 38%). Figure 1 (A and B) illustrates a neuromuscular curve with pelvic obliquity in a 14-year-old girl with paraplegia due to spina bifida. Follow-up spinal radiographs (see Fig. 1, C and D) show the correction of deformity achieved with anteroposterior instrumented fusion.

DISCUSSION

There are no published randomized studies on conservative versus surgical treatment of progressive neuromuscular curves, spinal surgeons being divided between strong opponents and proponents of the treatment. Nevertheless, reports are increasingly being published on the favorable results of surgery on NMS patients. Areas of particular benefit are better nursing, fewer respiratory complications, improved feeding, and better cosmesis compared with the preoperative status. It is therefore not only a matter of curve correction and stabilization that may provide a satisfactory outcome in these surgically treated patients, but also of overall improved quality of life.

The use of postoperative means of external support (casts, braces) after second-generation ISF for NMS is common.[16] Third-generation segmental ISF has boosted our capability to correct spinal deformities and allow early ambulating/nursing

TABLE 4. Main Radiographic Data

Group	Scoliosis Reop. (Cobb) [% flexibility on bending/traction films]	Scoliosis Postop. (Cobb) [% correction]	Scoliosis f/Up (Cobb) [% lost]	Kyphosis Preop. (Cobb)	Kyphosis Postop. (Cobb)	Kyphosis Follow-up (Cobb) [° lost]
1 (n = 23)	69 ± 30 [64%]	24 ± 16 [65%] $P < 0.001$	24 ± 11 [0%]	52 ± 23	32 ± 19 $P < 0.001$	31 ± 19 [−1°]
2 (n = 24)	72 ± 21 [60%] $P < 0.05$	29 ± 11 [59%] $P < .05$	31 ± 18 [2%]	54 ± 19	41 ± 15 $P < 0.001$	44 ± 17 [3°]
3 (n = 9)	86 ± 16 [48%] $P < 0.001$	40 ± 19 [53%] $P < 0.001$	41 ± 16 [1%]	50 ± 30	38 ± 11 $P < 0.001$	41 ± 25 [3°]

Group	Lordosis Preop. (Cobb)	Lordosis Postop. (Cobb)	Lordosis Follow-up (Cobb) [° lost]	Pelvic Obliquity Preop. (Cobb)	Pelvic Obliquity Postop. (Cobb) [% correction]	Pelvic Obliquity Follow-up (Cobb) [% lost]
1 (n = 23)	31 ± 22	29 ± 15	32 ± 15 [3°]	8 ± 2	4 ± 4 [50%]	7 ± 2 [38%]
2 (n = 24)	22 ± 23	27 ± 15 $P < 0.05$	27 ± 18 [0°]	19 ± 10 $P < 0.05$	9 ± 8 [47%] $P < 0.05$	10 ± 8 [6%]
3 (n = 9)	30 ± 26	32 ± 16	33 ± 18 [1°]	18 ± 14 $P < 0.05$	9 ± 11 [50%] $P < 0.05$	10 ± 12 [5%]

Values are means ± SD, expressed as degrees.

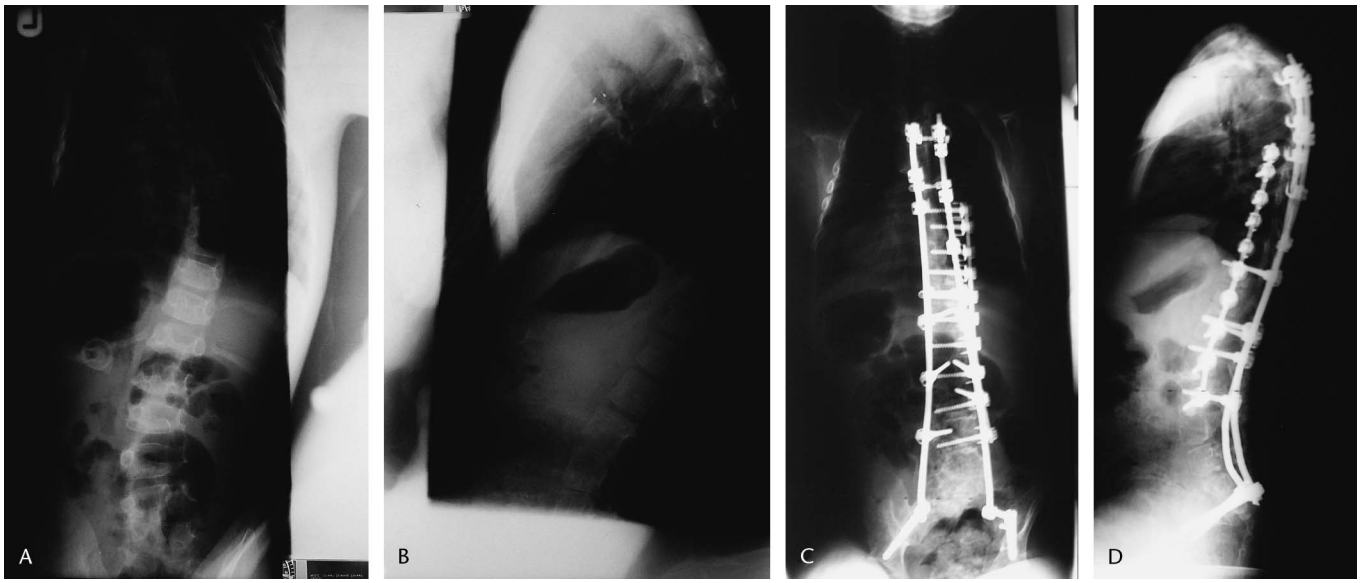

FIGURE 1. A–D, Posteroanterior, lateral preoperative, and follow-up radiographs following anteroposterior combined instrumented fusion in 12-year-old boy with spina bifida (see text).

without external supports in idiopathic scoliosis surgery.[8,9] There is so far no evidence that the same is true in NMS surgery.

It is widely reported that anteroposterior spinal fusion increases deformity correction and decreases the risk of pseudoarthrosis in NMS surgery with second-generation implants.[3,6,7,11,12,14–16] In our practice, anterior instrumentation of lumbar and thoracolumbar deformities with third-generation implants gives the spine satisfactory solidity, adding to the strength of posterior instrumentation, with the final result of a low loss of correction and pseudoarthrosis rate (see Tables 2 and 4; Fig. 1). This seems to reflect the experience of other authors with second-generation posterior implants.[16,17] Conversely, we did not find that anterior procedures with or without instrumentation increase deformity correction, as our data show that the greatest correction was achieved in the group of patients treated with posterior-only approaches. A likely explanation for this finding is that this group of patients had the greatest curve flexibility, because flaccid deformities prevailed in patients treated only posteriorly. A few studies have compared combined versus staged anteroposterior second-generation ISF in NMS, with results in terms of outcome and complications that are variably favorable to combined[7,15] or staged[12,14] procedures. The use of halo traction between stages has not been reported to provide higher correction rates.[16] Nevertheless, in the authors' experience, it can be used after anterior surgical release to make stiff sagittal deformities more flexible and less demanding to correct by posterior surgery.

Comparison of the results of this study with previous-generation instrumentation series was not performed because such a patient population was not available to the authors. Limitations of the present study include the retrospective study design and the diversity of diagnoses in the study group. Previous reports on second-generation ISF for NMS have similar biases, thus making the results of the present study comparable from the point of view of operative time, blood loss, hospital stay, deformity correction, and complications. Two points have to be acknowledged when comparing second-generation studies with the current one: (a) Patients in our series possibly received improved preoperative assessment and postoperative care, improved anesthetic techniques, and dedicated rehabilitation programs; (b) only crude numbers can be compared, statistical analysis being impossible owing to different data reports in the previous studies. Table 5 summarizes the main indexes of clinical and radiographic outcome by comparing the results of the current study (considering cohort values) with those of second-generation anteroposterior ISF in NMS patients.[5,6,11,12]

This retrospective analysis on a series of 56 patients consecutively treated by a single surgeon shows that at an average follow-up of >4 years, segmental ISF with third-generation implants in NMS patients provides improved quality of life with satisfactory correction of coronal deformity, sagittal deformities, and pelvic obliquity. There were statistically significant differences in the main indexes of clinical outcome (Table 2) among patients treated posteriorly only or anteroposteriorly: Patients treated with posterior-only procedures had the shortest hospital stay but the highest incidence of minor complications, whereas patients treated with anteroposterior combined procedures had the longest operating time and highest blood loss, the latter not being statistically significant. Blood loss correlated significantly with the number of operated levels (a parameter of the extent of surgery) in all types of procedures, but not with the number of complications. Blood loss also correlated with the degree of pelvic obliquity, a finding that is explained by the necessity for more extensive anterior and posterior surgeries with increasing pelvic obliquity.

The major complication rate (10.7% of patients) in this study cohort was remarkably lower than that generally reported for second-generation instrumentation (Table 5) with

TABLE 5. Comparison of Main Clinical and Radiographic Data of Current Study with Similar Reports on Second-Generation ISF in NMS

Report	No. of Patients	Operative Time (min)	Blood Loss (mL) [EBV]	Hospital Stay (d)	Questionnaire[5] Mean Cumulative Score	Scoliosis % Correction
Current study, cohort data	56	370	3250 [1.1]	14	26.1 (flaccid NMS)	59
Benson et al[6]	50	402	1839 [unknown]	20	Not applicable	65
Bridwell et al[5]	54	Unknown	Unknown	Unknown	17.5 (flaccid NMS)	51
Sarwahi et al[11]	111	Unknown	660 [unknown]	Unknown	Not applicable	Unknown
Tsirikos et al,[12] cohort data	45	420	2600 [1.6]	26	Not applicable	67

Report	Kyphosis (°), Follow-up Mean	Lordosis (°), Follow-up Mean	Pelvic Obliquity % Correction	Major Complications (% of patients)	Minor Complications (% of patients)	Mean Follow-up Length (mo)
Current study, cohort data	37	32	47	10.7	16.1	53
Benson et al[6]	Unknown	Unknown	75	14	28	40
Bridwell et al[5]	9 (thoracolumbar)	Unknown	57	7.3	1.8	92
Sarwahi et al[11]	unknown	Unknown	Unknown	21.6	22.5	Unknown
Tsirikos et al,[12] cohort data	41	40	75	43.3	50	38

the single exception of the above-referenced study on flaccid NMS patients.[5] A lower complication rate possibly resulted from improved preoperative assessment, intraoperative management, and postoperative care compared with previous reports. Major complications were equally distributed among patients treated with the three different procedures, although deep wound infections were observed only in the group of patients treated with posterior-only procedures. In the current authors' practice, deep wound infections tend to affect NMS patients treated with any procedure. The pseudoarthrosis rate detected at an average follow-up of 4 years (1 of 56 patients or 1.8%) in the present series is in the lower range compared with previous reports on second-generation ISF (1.5–10%).[3,5,6,11,12,14,15] The low pseudoarthrosis rate, possibly due to the increased stability provided by third-generation instrumentation, is reflected in a minimal loss of correction of scoliosis, kyphosis, and lordosis angles (0–6% in the different groups) observed at follow-up (Table 4). Nevertheless, we noted that in the group of patients treated with posterior-only procedures, loss of correction of lordosis was noticeable at

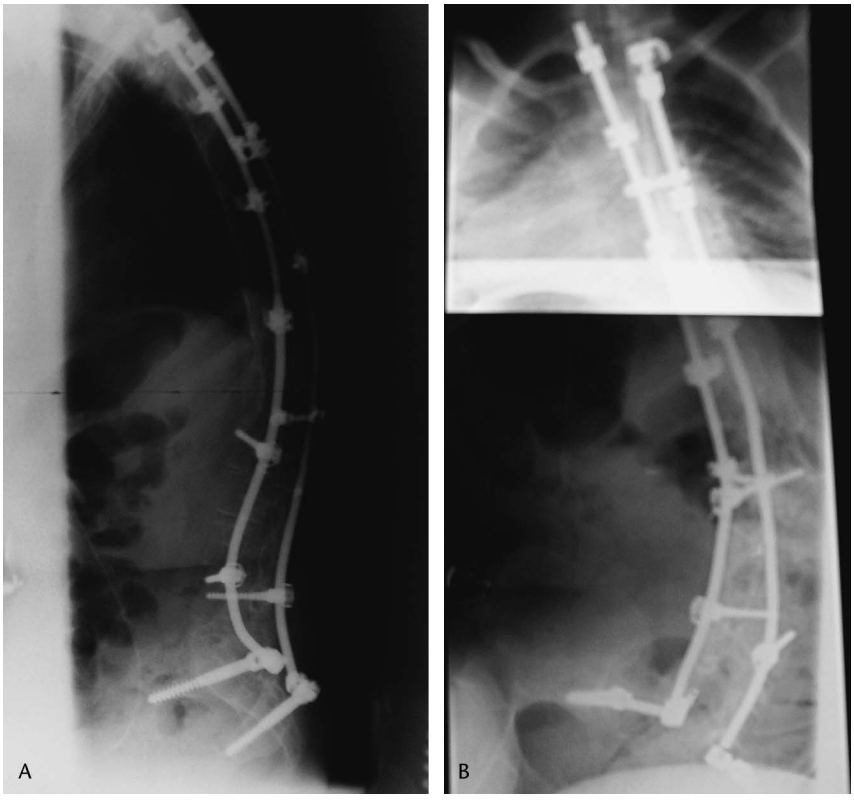

FIGURE 2. A–B, Posteroanterior and lateral preoperative and follow-up films in a 15-year-old boy with DMD. There are adequate lumbar fixation points following posterior-only instrumentation.

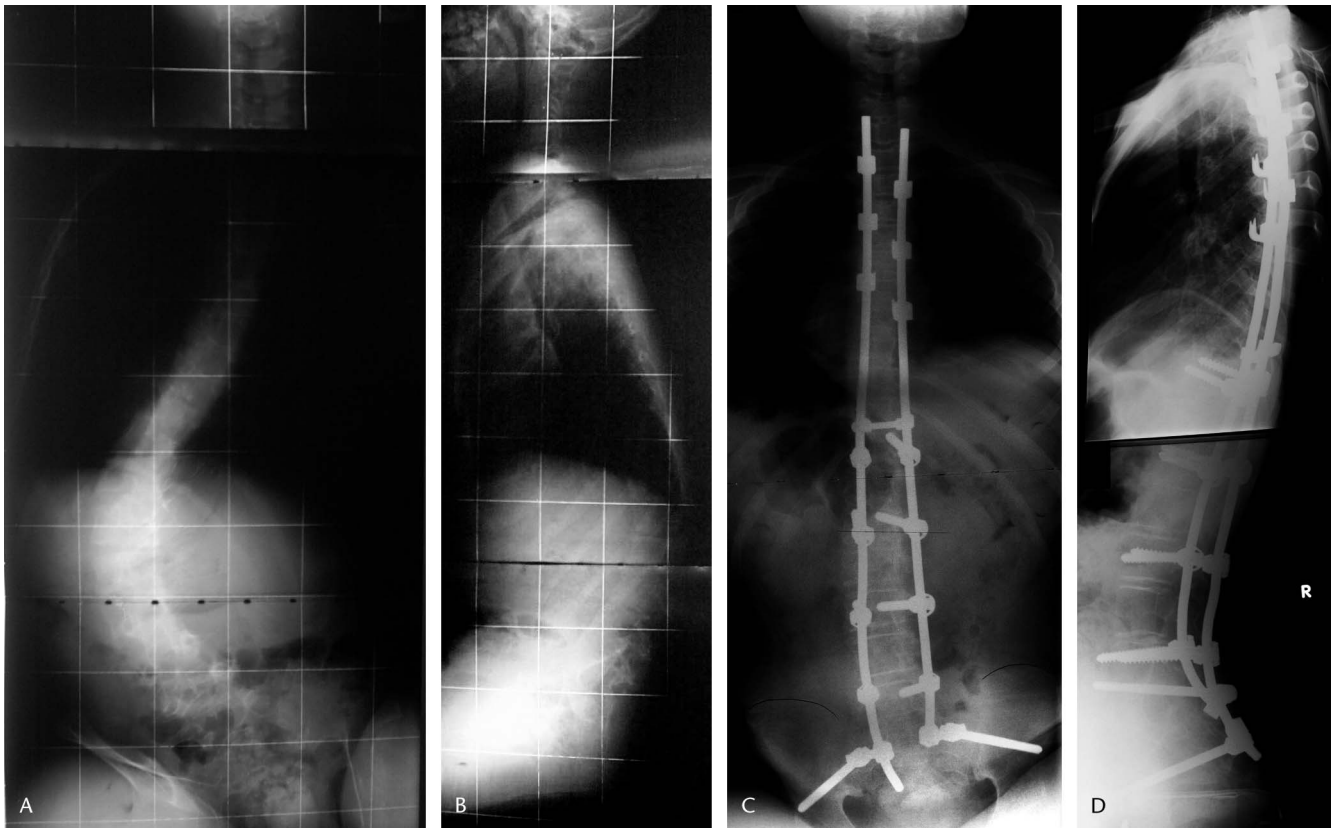

FIGURE 3. A–D, Posteroanterior and lateral follow-up films in a 13-year-old boy with spastic quadriplegic CP. Note the paucity of lumbar fixation points following anterior release/fusion and posterior-only instrumentation. The right rod has disengaged from the iliac bolt, indicating local motion and possibly lumbosacral pseudoarthrosis.

follow-up. Also, correction of pelvic obliquity and loss of correction of the same at follow-up were worse in the group of patients treated with posterior-only procedures than in patients treated with anteroposterior combined and staged procedures, a finding that could lead to deterioration of the patients' conditions at a later date. During the review of the postoperative and follow-up films, it became apparent that in a number of early patients, posterior instrumentation was not applied segmentally (Fig. 2). The paucity of fixation points at the apex of coronal and sagittal curves might cause loss of correction through failure of instrumentation and pseudoarthrosis at a later date. Therefore, we suggest that a strictly segmental concept of fixation should be applied to posterior third-generation instrumentation in neuromuscular deformities (Fig. 3).

The administration of an outcome questionnaire[5] for the evaluation of results of NMS treatment was an effort to move on from the subjective evaluation models that previous authors have reported. This questionnaire was used for evaluation of spastic cases too because no validated questionnaires exist for these patients to date. The designers of the adopted questionnaire[5] validated it only for evaluation of flaccid cases (DMD and SMA) treated with second-generation instrumentation, reporting an average cumulative total of 17.5 points in their patients (Table 5). We recorded a 26.3-point mean score in our flaccid NMS patients and, for descriptive purposes only, 20.9-point mean score in our spastic NMS patients. Still, dissatisfaction might have been expressed by the parents/caregivers who could not receive the outcome questionnaire. Scores in the specific areas of cosmesis and quality of life (Table 3) of our flaccid NMS patients were remarkably similar to those reported for flaccid NMS patients treated with second-generation instrumentation.[5] In both our spastic and flaccid patients, "major improvements" were recorded on average in the areas of satisfaction, cosmesis, function, and quality of life, although higher scores were recorded in flaccid than in spastic patients in the specific areas of satisfaction and function. This finding might be explained by the fact that flaccid cases were treated when functional deterioration was starting to be significant. On the other hand, it might suggest that the course of this deterioration was altered by surgical intervention.

Based on the results of this study, we conclude that segmental third-generation ISF is able to offer NMS patients improved quality of life through satisfactory and lasting correction of their spinal deformity, at the expense of a lower complication rate than that generally reported for second-generation ISF.

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