Is the Vertebral Expandable Prosthetic Titanium Rib a Surgical Alternative in Patients with Spina Bifida?

John M. Flynn MD, Norman Ramirez MD,
John B. Emans MD, John T. Smith MD,
Mary Jane Mulcahey PhD, Randal R. Betz MD

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Abstract

Background Nonambulatory children with myelodysplasia are most likely to develop spinal deformity. As the deformity progresses, the overall health of the patient deteriorates. Traditional management of the deformity with fusion results in a short trunk, crankshaft deformity, and spine and lung growth inhibition. One alternative that potentially minimizes these problems is the vertebral expandable prosthetic titanium rib (VEPTR).

Questions/purposes We therefore asked whether the use of the VEPTR in immature nonambulating children with myelodysplasia with spinal deformity would (1) correct deformity; (2) allow growth; and (3) allow adequate respiratory function.

Patients and Methods We identified 20 nonambulatory patients with myelodysplasia who were part of a multicenter Investigational Device Exemption study of

214 patients treated with the VEPTR system. Demographics, standard radiographic measurements, pulmonary function parameters, and complications in 16 patients were analyzed. Average age at first surgery was 48.6 months. The minimum followup was 25 months (mean, 59 months; range, 25–164 months).

Results The Cobb angle decreased postoperatively in nine patients, increased less than 10° in five patients, and increased less than 20° in two patients. The mean increase in thoracic spinal length (growth) by year after the initial procedure with lengthening was 0.48 cm. Ventilatory function improved in 11 patients and deteriorated in five patients. Intraoperative complications occurred in two patients. Complications directly related to the implant were seven infections and five implant migrations.

Conclusions Our observations suggest VEPTR is a reasonable treatment option for spinal deformity in the immature, nonambulatory myelodysplasia population correcting the spinal deformity, allowing spinal growth, and maintaining adequate respiratory function. The rate of complications is within the range reported for spinal fusion using standard approaches.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

One or more of the authors (JBE, JTS, RRB) are consultants to Synthes Spine.

Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

J. M. Flynn (✉), N. Ramirez
Department of Pediatric Orthopaedic Surgery, Hospital La
Concepcion, Carr #2 Km 173.4, San German, PR 00683, USA
e-mail: jmflynmd@aol.com

J. B. Emans
Children's Hospital Harvard Medical School, Boston, MA, USA

J. T. Smith
Primary Children's Hospital, Salt Lake City, UT, USA

M. J. Mulcahey, R. R. Betz
Shriners Hospital for Children, Philadelphia, PA, USA

Introduction

Nonambulatory children with low thoracic-high lumbar myelodysplasia are at high risk to develop progressive spinal deformity [13]. As the deformity progresses, the overall health of the patient commonly deteriorates [12]. The dysplastic anatomy of the vertebral column and truncal weakness in myelodysplasia together often cause

progressive spine and chest wall deformity in a paralytic spine leading to thoracic insufficiency. Primary thoracic insufficiency syndrome (TIS) is defined by Campbell and Smith as the inability of the thorax to support normal respiration or lung growth and may be the result of thoracic spine and chest wall deformity adversely affecting lung function and growth [2–5]. Secondary TIS is commonly encountered in nonambulatory patients with myelodysplasia as a result of decreased space available for the lung and decreased tidal volume as the diaphragm is forced cephalad by a collapsing spinal deformity or short trunk. Crowding of the abdominal or visceral contents resulting from the deformity further inhibits diaphragm effectiveness and affects pulmonary function [4, 5, 9]. A clinical manifestation is the “marionette sign” in which the head and torso bob in synchrony with respiration with the diaphragm doing a push up against body weight [4, 5, 9]. The decrease in pulmonary capacity may go unnoticed as a result of the child’s limited physical activities. The patients must use their upper extremities to extend their torso for adequate breathing and to maintain sitting balance [5]. The achievement of a functional sitting height is essential in nonambulatory patients with myelodysplasia to allow for efficient pulmonary function and to avoid abdominal crowding.

Deformities in this patient population are complex as a result of several factors: (1) the lack of posterior elements that make the spine unstable in all planes; (2) the lack of muscle support of the spine and soft tissue contractures; (3) poor pulmonary function; (4) congenital defects above or below the last intact posterior element; and (5) central nervous system anomalies such as hydrocephalus, Arnold-Chiari malformation, and intrathecal anomalies. Little is known about the natural history of the untreated spinal deformity [10]. Marchesi et al. separated the deformity into congenital and developmental curves [11]. All congenital forms showed rapid progression despite brace treatment, often to curvatures in excess of 100°. Among the developmental type(s), curves detected before 10 years of age were rapidly progressive beyond 70°. Curves detected after 10 years never exceeded 30°. Carstens et al. evaluated 13 patients with spina bifida and detected restrictive changes in pulmonary function preoperatively [6]. Treatment for immature children with myelodysplasia and spinal deformity is complex with scanty information in the literature to guide treatment [10].

The vertical expandable prosthetic titanium rib (VEPTR) has the mechanical ability to control spinal deformity and allow for continued vertebral column lengthening and lung parenchymal growth [2–4]. VEPTR instrumentation allows for fixation lateral from the scar midline incision and absent or abnormal posterior elements of the myelodysplastic spine, potentially decreasing the

risk of infection and increasing the corrective moment arm. Scheduled expansions of the VEPTR implants enable continuous growth of the spine. Therefore, VEPTR should be considered as an alternative operative technique to address the pathology in the skeletally immature nonambulatory myelodysplastic population [2–4].

We therefore asked whether the use of the VEPTR in immature nonambulating children with myelodysplasia with spinal deformity would (1) correct deformity; (2) allow growth; and (3) allow adequate respiratory function.

Patients and Methods

Twenty patients of a multicenter Investigational Device Exemption study of 214 patients treated with the VEPTR growing spinal system were nonambulatory patients with myelodysplasia. The VEPTR device is indicated for the treatment of TIS in skeletally immature patients. The indication for the VEPTR in this patient population is progressive scoliosis of congenital or neurogenic origin. Contraindications for use of the VEPTR are: (1) stiff thoracic kyphosis greater than 50°; (2) spinal cord syrinx, tethered spinal cord, or other spinal cord abnormality; (3) inadequate soft tissue coverage for the VEPTR; (4) absence of proximal ribs for attachment of the VEPTR; (5) inability to tolerate repetitive episodes of general anesthesia; (6) absence of diaphragm function; and (7) active pulmonary infection.

Subjects were considered for the study if they (1) had a primary diagnosis of TIS with a thoracic malformation. Subjects had to have (2) a thoracic condition that was not effectively treated with approved conventional methods such as bracing or spinal fusion. Subjects needed to (3) be between 6 months of age and skeletal maturity. Subjects also needed to have both (4) adequate natural ribs for VEPTR attachment and (5) adequate soft tissue coverage of the hemithorax. Finally, subjects needed to be (6) medically stable to undergo a major surgical procedure such as a thoracostomy; (7) willing to participate in followup studies; and (8) able to provide parental provision of written, informed consent. Subjects were excluded if they were unable to meet any of these criteria. We also excluded four patients who had less than 2 years followup. This left 16 patients. Eight patients were male and eight female. The mean age at the initial procedure was 48.6 months (range, 15–168 months). The older patient who underwent the surgical procedure at 14 years of age was a male who was referred late with congenital scoliosis, rib fusion, and thoracic insufficiency syndrome. The minimum followup was 25 months (mean, 59 months; range, 25–164 months). The cohort was included in the request for approval of Humanitarian Device Exemption for the VEPTR indicated

for the treatment of TIS in children. The research protocol was approved by our Institutional Review Board to evaluate the Investigational Device Exemption study data.

The universal health concerns in these patients are numerous and substantially influence the care of the spinal deformity. The patients presented with multiple associated medical conditions: hydrocephalus with ventriculoperitoneal shunt in 12 patients, seizure disorder in four patients, tethered cord surgery in one patient, rib fusions in four patients, clubfeet postsurgery in five patients, cardiac problems in three patients, respiratory problems in seven patients, a gastrostomy tube in four patients, an absent kidney in one patient, chronic urinary tract infection in 16 patients, vescicostomy in four patients, a cleft lip in one patient, and chronic skin ulcers in four patients.

Data collection protocols were standardized across sites and consisted of a clinical history, including gender, age at surgery, number of procedures, estimated blood loss, length of stay, and surgical time. Physical examination included preoperative and postoperative respiratory rate, heart rate, and blood pressure. Pulmonary function by pulmonary function tests (subjects 7 years or older), radiographic measurements, and complications were recorded. Data were recorded on case report forms and collected at baseline and repeated within 10 days of the initial VEPTR procedure.

Although pulmonary function tests (PFTs) were required pre- and postoperatively for all cooperative subjects older than age 7 years, 12 of the 16 patients were unable to comply. As an alternative to PFTs, preoperative and postoperative assisted ventilation rating (AVR) scores [4] and capillary blood gas measurements were chosen to measure patients' pulmonary function. AVR scores reflect an ordinal rating scale anchored between 0 (room air) and 4 (full mechanical ventilation) of subjects' need for respiratory support.

Sitting AP and lateral whole spine radiographs were performed preoperatively and postoperatively to evaluate the cervical, thoracic, and lumbar spine and rib cage anatomy. A scanogram ruler was used on the lateral border of the chest for measurement. Measurements were obtained by trained individuals at each patient's site. Because central measurement was not used, some intraobserver variability is expected. Radiographic measures included thoracic spinal height, hemithoracic height (both sides), hemithoracic width (both sides), and Cobb angle [7]. Using an AP radiograph, hemithoracic height was measured from the top of the lung apex at the center of the upper most rib to the inferior rib one or two levels below the dome of the hemidiaphragm [2, 5]. The ratio of the height of the concave hemithorax compared with that of the convex hemithorax, expressed as a percentage, is considered to be the space available for the lung [5]. The thoracic spinal

height was calculated by measuring from the top of the first thoracic vertebrae to the bottom of the T-12 equivalent vertebrae [2].

The VEPTR implant (Synthes Spine, West Chester, PA) is inserted superiorly in the thoracic area through a midline incision with lateral flaps. Inferiorly it is placed through lateral incisions, parallel, off the midline avoiding scarred tissue from the neurosurgical repair. Transverse osteotomies are performed through any fused ribs, and the hemithorax is lengthened by distraction. The majority of patients require one rib osteotomy; however, in some cases, two are performed to lengthen the hemithorax. In children older than 6 months but younger than 18 months of age, a rib-to-rib VEPTR construct is placed medially to stabilize the reconstruction. In children older than age 18 months, a rib-to-spine VEPTR construct is placed and a second construct is placed on the posterior axillary line, rib to rib. The cephalad hook engages one or two ribs; the caudal hook may engage a lower rib, lamina, or iliac crest. For those with lumbar spine abnormalities or myelomeningocele precluding posterior anchoring devices, rib-to-pelvis constructs are commonly used. These are placed unilaterally or bilaterally depending on the patient's anatomy (Fig. 1A-B). The system allows for expansion. The lengthening occurs approximately every 6 months to maintain correction and growth of the vertebral column as well as the chest wall [2]. Sixteen initial implantation surgeries were performed with a mean surgical time of 241 minutes (range, 141–593 minutes). The mean estimated blood loss was 73.2 mL (range, 17–220 mL). The mean number of device lengthening procedures was eight (range, 3–15 procedures). The mean number of device replacements was one (range, 0–6).

Patients were hospitalized for 11 days (range, 5–29 days). During the postoperative period, patients were placed on prophylactic antibiotics. Mobilization out of bed into a chair was at the first or second day as tolerated. Intensive respiratory therapy was started preoperatively and continued until discharge. Physical therapy consisted of ROM of the extremities and increasing sitting tolerance. No spinal or lower extremities orthotics were prescribed.

Followup intervals typically coincided with subjects' expansion surgeries or occurred at 4, 8, 12, 16, 20, and 24 months after the initial VEPTR implant with followup evaluations thereafter every 6 months. Preoperative radiographic measurements were made on all patients, immediately postoperatively, and at 24 months postoperatively.

Distributions of variables were given as means and ranges. We determined correction of spinal deformity comparing differences between preoperative and postoperative Cobb angle [7]. Spinal growth was determined comparing the difference between the preoperative and

Fig. 1A-B (A) A preoperative sitting AP radiograph in a 4-year 7-month-old boy with spina bifida is shown. (B) The same patient is shown with a postoperative AP and lateral views after the initial implantation. Bilateral rib-to-pelvis construct with S rods.

Table 1. Preoperative and postoperative variables

Measurement	Preoperative (range)	Postoperative (range)	Last followup (range)	p Value
Respiratory rate (breaths/min)	30 (18–44)		27 (14–46)	0.3283
Heart rate (beats/min)	132 (103–176)		117 (78–153)	0.1422
Capillary O ₂	71 (25–126)		75 (57.6–98)	0.5906
Capillary pCO ₂	40 (31–61)		42 (26–64)	0.3609
Serum HCO ₃	25 (21–33)		25 (21–38.5)	0.6677
Cobb angle (scoliosis)	47 (20–72)		47 (19–84)	0.8054
Thoracic spine height increase		1 cm (–0.1 to 3.1 cm)	3 cm (–1.4 to 7.5 cm)	0.0491
Thoracic spinal length increase per year (not including original procedure)			0.48 cm (–0.1 to 1.96 cm) per year	

postoperative thoracic spine lengths. The respiratory function was evaluated comparing the difference between preoperative and postoperative AVR scores. All statistical comparisons were performed using the Student's two-tailed t-test.

Results

Spinal deformity decreased over the course of followup in 56% (nine of 16) of patients. In five patients, the increase in Cobb angle to final followup was less than 10°. In two patients, the increase was 18° and 20°. The mean preoperative Cobb angle was similar ($p = 0.81$) to that at last evaluation: 47° (range, 20°–72°) versus 47° (range, 19°–84°), respectively. The patient who underwent the surgical procedure with 20° degrees of scoliosis was a 3 year old boy patient with a congenital scoliosis, multiple rib fusions, and ventilator support.

Throughout treatment, the thoracic spine length increased. After the initial surgical procedure, the mean thoracic spine length increased by 1.0 cm (range, –0.1 to 3.1 cm). The length of the thoracic spine increase ($p = 0.049$) at final evaluation was 3 cm (range, –1.4 to 7.5 cm). The mean thoracic spinal length (growth) by year after the initial procedures with the programmed lengthening every 6 months was 0.48 cm (range, –0.1 to 1.96 cm). The mean concave hemithoracic height increased ($p = 0.013$) from preoperative to last followup from 12.1 cm (range, 7.8–18.6 cm) to 16.1 cm (range, 10.1–20.7 cm).

We found no differences between the preoperative and postoperative PO₂, PCO₂, and HCO₃ levels and no differences in the preoperative and postoperative respiratory rate and heart rate (Table 1). The AVR scores of 11 of 16 patients either improved or remained the same. At preoperative and last evaluation, AVR scores showed two patients improved, one from full-time ventilation to room

air and one patient from supplemental oxygen ventilation to room air. Nine patients had no change in their AVR score. Deterioration in AVR scores occurred in five patients, two patients from room air to nighttime ventilation, one patient from supplemental oxygen to part-time ventilation, one patient from room air to nighttime ventilation, and one patient from nighttime ventilation to full-time ventilation.

Death occurred in two patients, at 20.2 months after the initial surgery as a result of cardiorespiratory arrest and at 65.2 months after the initial surgery as a result of cor pulmonale and cardiac arrest. One hundred eleven surgical procedures (initial implant, lengthening, and exchanges) were performed with intraoperative complications occurring in two patients; one patient developed hypotension, which resolved, and the other patient had a pleural tear that required repair. Complications that did not occur intraoperatively were divided into implant-related complications and no implant-related complications. Implant-related complications were five soft tissue superficial wound infections treated with nutritional support, local débridement and antibiotics, and two deep wound infections requiring removal of the implant. There were five implant migrations: two superior migrations of the rib cradle, one superior migration of the rib cradle with a brachial plexus palsy, one migration of the Dunn-McCarthy hook, and one fracture of the Dunn-McCarthy rod. Complications not related to the implant but requiring or extending the hospital stay were two urinary tract infections, one urinary tract infection with sepsis, two pneumonias, one abdominal distension, and one patient with seizures.

Discussion

Nonambulatory, low thoracic-high lumbar myelodysplastic children are at high risk to develop progressive spinal deformity [13]. As the deformity progresses, the overall health of the patient commonly deteriorates [12]. The dysplastic anatomy of the vertebral column and truncal weakness in myelodysplasia together often cause progressive spine and chest wall deformity in a paralytic spine leading to secondary thoracic insufficiency. Secondary TIS is commonly encountered in nonambulatory patients with myelodysplasia as a result of decreased space available for the lung and decreased tidal volume as the diaphragm is forced cephalad by a collapsing spinal deformity or short trunk. The achievement of a functional sitting height is essential in nonambulatory patients with myelodysplasia to allow for efficient pulmonary function and to avoid abdominal crowding. The VEPTR has the mechanical ability to control spinal deformity and allow for continued vertebral column lengthening and lung parenchymal

growth [2–4]. Since 1989, the VEPTR system has been used in a select group of patients [2–4]. This is the earliest series of uniformly surgically treated spinal deformity in patients with spina bifida treated with VEPTR insertion followed by regular device lengthening. The purpose of treatment was to optimize spine alignment and maximize thoracic volume while maintaining thoracic and spine growth [2, 5]. Without treatment, increase in spinal deformity with loss of spine alignment and increased functional impairment and deterioration of respiratory function would be expected [10]. We therefore asked whether the use of the VEPTR in immature nonambulating children with myelodysplasia with spinal deformity would (1) correct deformity; (2) allow growth; and (3) allow adequate respiratory function.

The study is not without limitations: (1) the selective use of this device; (2) the absence of a control or comparative group; and (3) the natural history of untreated spinal deformity and the development of thoracic insufficiency syndrome in the spina bifida population are not well studied. We recognized this is a very limited population in which a novel surgical technique had been used, without treatment, increase in spinal deformity with loss of spine alignment, and increased functional impairment and deterioration of respiratory function would be expected. Therefore, it is difficult to quantify the impact VEPTR implantation has had on the natural history of the patients. Ours was a retrospective multicenter review of a small group of patients in a large IDE data base. Variables now known to be relevant with current knowledge were not considered at the time of recording of the data. Sagittal measurements are an example of one of these variables.

Establishing absolute criteria for surgical correction of spinal deformity in patients with spina bifida is unclear because the long-term natural history of untreated deformity is limited [10]. Muller et al. established that progression in patients with spina bifida was related to the size of the curve: curves less than 20° progressed slowly and curves greater than 40° progressed at a rate of 13° per year [13]. Nonambulatory patients had a greater rate of progression [13]. Marchesi et al. separated the deformity into congenital and developmental curves [11]. All congenital forms showed rapid progression despite brace treatment, often to curvatures in excess of 100°. Among the developmental type(s), curves detected before 10 years of age were rapidly progressive beyond 70°. Curves detected after 10 years never exceeded 30°. At the time of initial VEPTR implantation, one patient had a deformity of less than 20°, five patients were between 20° and 40°, and 10 patients were over 40° of deformity. With no treatment we should expect a progression of 13° per year in 62% (10 of 16) patients. However, on final followup, there was a decrease in the magnitude of the spinal deformity in 56%

(nine of 16) of patients. Only five patients had an increase of less than 10° and two patients had an increase in Cobb angle of over 10°. These findings support the hypothesis that VEPTR may positively affect the natural history of spine deformity progression.

DiMeglio and Bonnel established thoracic spinal growth of 1.4 cm per year in normal children during the first 5 years of age and 0.6 cm per year from age 5 to 10 years [8]. In the spina bifida population, spinal growth prediction has not been studied. In our series, the mean thoracic spinal length (growth) by year after the initial procedures with the programmed lengthening every 6 months was 0.48 cm (range, -0.1 to 1.96 cm). The VEPTR maintained growth of the thoracic vertebral column in 81% (13 of 16) of patients.

Carstens et al. evaluated 13 patients with spina bifida and detected restrictive changes in pulmonary function preoperatively [6]. The dilemma arises when a skeletally immature child has a large progressive curve that is interfering with activities of daily living. Sherman et al. in a randomly selected cohort of 12 subjects (10 to 17 years of age) with myelomeningocele compared with 12 control subjects found the mean total lung capacity and fractional lung volumes were lower in case subjects than control subjects [14]. Although we found no difference in pO₂, pCO₂, HCO₃, or respiratory rate, these values did not deteriorate. A beneficial effect on the natural history of TIS in this population was an improvement in the AVR scores in 12.5% (two of 16) of patients. There was no change in AVR score in 56% (nine of 16) of patients and deterioration in AVR score in 31% (five of 16) of patients.

Mortality and complication rates appear acceptable in this high-risk population of patients with spina bifida [1, 10, 12, 15]. In previous series, wound infection has been reported to occur in up to half of the patients. Midline incisional necrosis (commonly seen when a triradiate incision is used) is also a reported complication [12]. In our series, there were five of 16 (31%) soft tissue superficial wound infections treated with local débridement and antibiotics and two of 16 (12%) deep wound infections requiring removal of implant. By avoiding midline incisions, there were no patients with incisional necrosis.

Within the limitations of this study, VEPTR implantation in patients with spina bifida allows continued thoracic spine growth while controlling progressive spine deformity. The data suggest VEPTR surgery maintains or improves ventilatory status in this patient population. Therefore, VEPTR treatment can be used to manage both

spinal deformity and respiratory function while allowing spinal growth in the immature nonambulating child with myelodysplasia.

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References

1. Banta JV. Combined anterior and posterior fusion for spinal deformity in myelomeningocele. *Spine*. 1990;15:946–952.
2. Campbell R, Smith M, Mayes T, Mangos JA, Willey-Courand DB, Kose N, Pinero RF, Alder ME, Duong HL, Surber JL. The effect of opening wedge thoracostomy on thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis. *J Bone Joint Surg Am*. 2004;86:1659–1674.
3. Campbell RM, Hell-Vocke AK. Growth of the thoracic spine in congenital scoliosis after expansion thoracoplasty. *J Bone Joint Surg Am*. 2003;85:409–420.
4. Campbell RM, Smith M. Thoracic insufficiency syndrome and exotics scoliosis. *J Bone Joint Surg Am*. 2007;89:108–122.
5. Campbell RM, Smith MD, Mayes TC, Mangos JA, Willey-Courand DB, Kose N, Pinero RF, Alder ME, Duong HL, Surber JL. The characteristics of thoracic insufficiency syndrome associated with fused rib and congenital scoliosis. *J Bone Joint Surg Am*. 2003;85:399–408.
6. Carstens C, Paul K, Niethard F, Pfiel J. Effect of scoliosis surgery on pulmonary function in patients with myelomeningocele. *J Pediatr Orthop*. 1991;11:459–464.
7. Cobb JR. Outline for the study of scoliosis. In: Edwards JW, ed. *Instructional Course Lectures*. Vol 5. Ann Arbor: American Academy of Orthopaedic Surgeons; 1948:261–275.
8. DiMeglio A, Bonnel F. *The Growing Spine*. Paris, France: Springer; 1990.
9. Emans J, Caubet J, Ordonez C, Lee EY, Ciarlo M. The treatment of spine and chest wall deformities with fused ribs by expansion thoracostomy and insertion of vertical expandable prosthetic titanium rib: growth of thoracic spine and improvement of lung volumes. *Spine (Phila Pa 1976)*. 2005;30(Suppl):S58–68.
10. Guille JT, Sarwark JF, Sherk H, Kumar SJ. Congenital and developmental deformities of the spine in children with myelomeningocele. *J Am Acad Orthop Surg*. 2006;14:294–302.
11. Marchesi D, Rudeberg A, Aebi M. Development in conservatively treated scoliosis in patients with myelomeningocele (patients of the years 1964–1977). *Acta Orthop Belg*. 1991;57:390–398.
12. McMaster MJ. Anterior and posterior instrumentation and fusion of thoracolumbar scoliosis due to myelomeningocele. *J Bone Joint Surg Br*. 1987;69:20–25.
13. Muller EB, Nordwall A, Oden A. Progression of scoliosis in children with myelomeningocele. *Spine*. 1994;19:147–150.
14. Sherman MS, Kaplan JM, Effgen S, Campbell D, Dold F. Pulmonary dysfunction and reduced exercise capacity in patients with myelomeningocele. *J Pediatr*. 1997;131:413–418.
15. Ward WT, Wenger DR, Roach JW. Surgical correction of myelomeningocele scoliosis: a critical appraisal of various spinal instrumentation systems. *J Pediatr Orthop*. 1989;9:262–268.