Eur Spine J (2010) 19:400–408
DOI 10.1007/s00586-009-1253-9

ORIGINAL ARTICLE

Efficacy and safety of VEPTR instrumentation for progressive spine deformities in young children without rib fusions

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Received: 9 August 2009 / Revised: 1 November 2009 / Accepted: 10 December 2009 / Published online: 31 December 2009

Abstract This retrospective study analyses 23 children treated with vertical expandable prosthetic titanium rib (VEPTR) for correction of non-congenital early onset spine deformities. After the index procedure (IP), the device was lengthened at 6-month intervals. The average (av) age at the time of IP was 6.5 years (1.11–10.5). The av follow-up time was 3.6 years (2–5.8). Diagnosis included 1 early onset idiopathic scoliosis, 11 neuromuscular, 2 post-thoracotomy scoliosis, 1 Sprengel deformity, 2 hyperkyphosis, 1 myopathy and 5 syndromic. Surgeries (187) included 23 IPs, av 6.5 (4–10) device expansions per patient (149) and 15 unplanned surgeries. 23 complications (0.13 per surgery) included 10 skin sloughs, 5 implant dislocations, 2 rod breakages and 6 infections. Coronal Cobb angle was av 68° (11°–111°), at follow-up av 54° (0°–105°). Pelvic obliquity was av 33° (13°–60°), at follow-up av 16° (0°–42°). T1 tilt was av 29° (5°–84°), two remained unchanged, the remainder improved 10°–68°. Sagittal plane: All but two had stable profiles, two hyperkyphosis of 110°/124° improved to 56°/86°. Space available for lung ratio was less than 90% in ten before the IP, improved in nine and deteriorated in one. Originally designed for thoracic insufficiency syndromes related to rib and vertebral anomalies, VEPTR proved to be a valuable alternative to dual growing rods for non-congenital early onset spine deformities. The complication rate was lower, the control of the sagittal plane and the pelvic obliquity was as good, but the correction of the coronal plane deformity was less than growing rods. However, VEPTR's spine-sparing approach might provoke less spontaneous spinal fusion and ease the final correction at maturity.

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Keywords VEPTR · Early onset scoliosis · Non-congenital scoliosis · Correction · Instrumentation

Introduction

The vertical expandable prosthetic titanium rib (VEPTR) procedure has set standards for young children with thoracic insufficiency syndromes related to congenital spine and rib anomalies [1–3]. The concomitant control of complex spinal deformities by force transmission from the ribs to the spine and pelvis [2–4] stimulates surgeons to expand the indications beyond the primary scope to early onset deformities of idiopathic, neuromuscular and syndromic origin [5, 6]. The growth-promoting lengthening strategy and the polyaxial anchor points may overcome post-fusion issues such as short and stiff trunk, small thorax, poor pulmonary function and crankshaft phenomenon [4, 7, 8]. However, VEPTR's safety and efficacy remains still to be shown for non-congenital deformities. It thereby competes with a variety of established or evolving growth respecting methods such as serial casting [9], growing rods [10–16] and growth guiding implants [12, 17, 18].

Our purpose is to delineate the effectiveness, associated risks and potential benefits of VEPTR in a retrospective cohort of children with progressive non-congenital early onset spine deformities.

Materials and methods

After approval of the local ethical committee, we studied patients who had undergone VEPTR instrumentation at our institution with a minimum follow-up of 2 years (index surgery and at least four expansion procedures at 6 months

intervals). Patients with rib fusions or congenital vertebral anomalies as the main deforming causes as well as patients with stiff chest walls were excluded [19]. The index procedure (IP) was performed as described by Campbell [1] but without rib osteotomies. Our protocol included pre- and postoperative anteroposterior and lateral standing or—in non-ambulatory patients—sitting radiographs and clinical photographs at the time of IP and at very expansion procedure. We used spinal cord monitoring (motor evoked potentials) during the IP but for expansions only in case of initial signal changes. Biplanar Cobb angles and pelvic obliquity were digitally measured (AxioVision Rel.4.4 Carl Zeiss, Jena, Germany) by one of us (C.H.) on all radiographs. T1 tilt and space available for lungs (SALs) ratios [20] were assessed on pre- and post-IP radiographs and at follow-up. SAL ratios of less than 90% and pelvic obliquity and T1 tilt $> 10°$ were rated pathologic [20]. Diagnosis, pattern of spine deformities, type of construct, changes of strategy, complications and extra-surgeries were recorded. Dislodgment and breakages of implants parts were rated as complication if they led to extra-surgery.

Statistical analysis was performed by one of the authors (C.H.) using SPSS version 13.0 for Windows. We used Student's *t* tests (paired, two-tailed) to compare pre- to post-IP, post-IP to last follow-up and pre-IP to last follow-up values for coronal deformities, sagittal profiles, SALs, as well as for cervical and pelvic tilts. Statistical significance was defined as $p < 0.05$.

Results

Demographic data (Table 1)

Twenty-three patients (8 boys, 15 girls) fulfilled the inclusion criteria: 1 early onset idiopathic scoliosis, 11 neuromuscular (9 myelomeningocele, 1 tetraparesis, 1 cerebral palsy), 2 post-thoracotomy scoliosis, 1 Sprengel deformity, 2 hyperkyphosis, 1 congenital muscular dystrophy, 5 syndromic. All neuromuscular patients were non-ambulatory. The av age at the time of the IP was 6.5 years (1.11–10.5 years). Thirteen patients had a history of failed brace treatment. The av follow-up time was 3.6 years (2–5.8 years).

Surgeries

We performed 23 IPs, an av of 6.5 (4–10) expansion surgeries per patient (total 149) and 15 unplanned surgeries. Routine interventions included 110 lengthenings and 39 changes to longer components (25), changes of type of constructs (8) and repositioning of upper cradles (8), laminar hooks (1) and pelvic hooks (5). Eighteen implant-related events required seven unplanned interventions due to pain, skin slough or apparent loss of correction.

Changes of strategy

In eight patients, we modified the construct during routine surgery. Five times we extended to the pelvis to counteract junctional kyphosis (3) and pelvic obliquity with loss of balance (2). We added additional constructs to unload a dislodging cradle (1) and to treat an emerging compensatory upper thoracic curve (1). One rib-to-rib construct was removed for interference with scapular motion (1).

Coronal plane deformity (Table 2)

The main *Cobb angle* before the IP averaged 68° (11°–111°), thereafter 48° (10°–86°; $p < 0.005$), and at follow-up 54° (0°–105°; $p < 0.005$ compared to initial angle; $p = 0.04$ compared to post-IP angle). The av correction after IP was 30% (7°–54°), at follow-up 25% (26% increase to maximal 100% correction). Two patients (Nos. 4, 20) had a more than 10° worse Cobb angle at follow-up than before the IP (14° and 17°, respectively), 16 improved more than 10°.

Effect of expansion procedures on main deformity:

After the IP, 6 curves (Nos. 3, 4, 7, 18, 23, 29) progressed more than 10° until the last follow-up, 3 (Nos. 8, 12, 17) improved 10° or more (10°, 16°, 17°) with subsequent lengthenings and 14 patients remained within 0°–9° of the post-IP value. Between distractions, the curve deteriorated on an av of 9.7° (7°–13°) and improved with subsequent distractions: av 8.6° (6°–13°). Loss of fixation caused curve progression of more than 15°.

Pelvic obliquity

More than half (13 of 23), including nine non-ambulatory patients, had a pelvic obliquity of more than 10°: 33° (13°–60°), after IP 14° (1°–41°; $p < 0.005$) and at follow-up 16° (0°–42°; $p < 0.005$ compared to initial angle; $p = 0.2$ compared to post-IP angle). The initial correction averaged 64% (15–96%). From there to the last follow-up, five patients showed further improvement (1°–5°), two had no change and six a moderate reoccurrence (range 4°–11°). Four patients (Nos. 2, 4, 7, 11)—all neuromuscular—had a pelvic obliquity of 30°–40° at follow-up. In a MMC patient (No. 4) with a rigid pelvic obliquity (51°), the polyaxiality of the ala hooks allowed trunk sweeping.

Cervical tilt

Fifteen patients had a T1 tilt: av 29° (5°–85°). Two remained unchanged; all the others improved between 10° and 68°. At the last follow-up, six patients had normal

Table 1 Demographic data and VEPTR strategies

Patient no.	Diagnosis	Age[a]	Curve pattern[b]	VEPTR construct[c]				Reasons for change of strategy
				Initial		Follow-up		
				Left	Right	Left	Right	
1	Infantile scoliosis	6.4	LL RT	RR RP	RP	RR RP	RP	
2	Myelomeningocele	8.4	LL		RP		RP	
3	Myelomeningocele	4.4	RL	RR RP		RR RP		
4	Myelomeningocele	8.6	LL		RP	RP	RP	Increasing pelvic obliquity
5	Myelomeningocele	9.0	RT	RR	RR	RR	RR	
6	Myelomeningocele	2.0	LTL		RP		RP	
7	Myelomeningocele	9.9	LTL		RP		RP	
8	Myelomeningocele	8.11	LTL	RR	RR	RP	RP	Junctional kyphosis
9	Myelomeningocele	2.0	LTL	RP	RR	RP	RR	
10	Myelomeningocele	5.2	LTL	RP	RP	RP	RP	
11	Tetraparesis	5.4	LTL RT		RP		RP	
12	Cerebral paresis	5.0	LT		RP		RL RP	Load-sharing for dislodging upper cradle
13	Post-thoracotomy	1.11	RT	RR RL		RR RL		
14	Post-thoracotomy	10.11	LT		RL		RL	
15	Sprengel deformity	7.4	LT	RR	RL		RL	Interference with scapular motion
16	Kyphosis	7.7	RTL	RP	RP	RP	RP	
17	Kyphosis	7.0	RL LT	RP	RP RL	RP	RP RL	
18	Myopathy	5.11	RTL	RP RL		RP RL	RR	Compensatory high thoracic countercurve
19	Sotos syndrome	6.4	RTL	RL	RP	RP	RP	Loss of balance
20	Sotos syndrome	10.5	LT	RR	RR RL	RR	RR RL	
21	Incontinentia pigmenti	2.5	RL	RP	RP	RP	RP	
22	Dysostosis cleidocranialis	1.8	LT	RR	RR	RR RP	RR RP	Junctional kyphosis, upper cradle cut-through
23	Unknown syndrome	5.1	LTL	RP		RP	RP RL	Junctional kyphosis

[a] At index procedure: years.months

[b] *L* left, *R* right; curve pattern: *LT* left thoracic, *RT* right thoracic, *LL* left lumbar, *RL* right lumbar, *LTL* left thoracolumbar, *RTL* right thoracolumbar

[c] *RL* VEPTR construct rib to lumbar spine, *RR* VEPTR construct rib-to-rib, *RP* VEPTR construct rib to iliac crest by Dunn-McCarthy hooks

values (<10° tilt), five between 10° and 20° and four between 21° and 30°.

The initial and overall corrections were significant ($p < 0.005$), but there was no further improvement between the initial correction and the last follow-up ($p = 0.2$).

Sagittal plane (+kyphosis, −lordosis) deformity

The *thoracic* Cobb angle before the IP averaged 55° (−44° to −128°), after the IP 46° (−33° to −107°; $p = 0.03$) and at follow-up 55° (−33° to −94°; $p < 0.9$ compared to initial angle; $p = 0.04$ compared to post-IP angle). The sagittal profile was significantly flattened with the initial procedure but returned to the initial value with repetitive expansions. Ten patients (Nos. 2, 8, 9, 12, 16, 17, 18, 20, 22, 23) showed a thoracic hyperkyphosis (68°–128°). Six patients were corrected and four stabilised. The latter (Nos. 12, 20, 22, 23) and one with abnormal profile (No. 14) developed a high thoracic junctional kyphosis. The overall kyphosis remained stable. A mild, beneficial kyphogenic effect was observed in two MMC patients (Nos. 1, 6) and one tetraparetic patient (No. 11) with lordotic thoracic spines. One MMC patient (No. 7) and one with a Sprengel deformity (No. 15) developed thoracolumbar and high thoracic kyphosis, respectively. Two patients (Nos. 16, 17) with thoracic hyperkyphosis of 110° and 124°, respectively, had a stable correction of 52 and 33%.

Space available for lung

Prior to VEPTR, ten patients had a SAL ratio of less than 90% which improved to normal in five, partially improved in four and deteriorated in one.

Table 2 Deformity parameters

Patient no.	Main coronal Cobb angle (°)				Sagittal Cobb angle (°)[a]				Pelvic obliquity (>10°)				T1 tilt (>10°)				SAL (<90%)			
	Pre $p < 0.005$	Post	f/up $p = 0.04$	Δ[b] $p < 0.005$	Pre $p = 0.03$	Post	f/up $p = 0.04$	Δ $p = 0.9$	Pre $p < 0.005$	Post	f/up $p = 0.2$	Δ $p < 0.005$	Pre $p < 0.005$	Post	f/up $p = 0.2$	Δ $p < 0.005$	Pre $p = 0.08$	Post	f/up $p = 0.9$	Δ $p = 0.06$
1	71	43	47	−24	19	23	30	11												
2	102	63	69	−33	99	81	71	−28	60	40	36	−24	13	3	4	−9	81	84	95	14
3	71	44	65	−6	−44	−33	−33	11	23	5	0	−23	54	24	21	−33	100	95	84	−16
4	72	58	86	14	22	17	22	0	51	31	42	−9	12	2	3	−9				
5	27	29	34	7	39	33	30	−9					32	26	12	−20	90	81	82	−7
6	73	52	57	−16	−21	−28	15	36	22	1	5	−17	13	13	11	−2	76	93	90	15
7	76	61	75	−1	25	44	90	65	48	41	39	−9	28	11	14	−14	58	79	86	28
8	11	10	0	−11	76	81	59	−17					54	29	24	−30				
9	87	79	82	−5	128	97	81	−47	18	1	1	−17					69	88	81	12
10	50	26	24	26	25	25	25	0	22	8	8	−14								
11	93	59	77	−16	−15	−18	7	22	33	24	31	−2	30	15	13	−17				
12	100	86	70	−30	88	84	94	6	27	13	12	−15	85	53	30	−55	61	91	87	26
13	63	29	34	−29	49	52	58	9					12	2	1	−11				
14	61	41	43	−18	42	45	46	4					20	24	18	−2	79	78	84	5
15	85	43	66	−19	49	48	81	32					5	10	10	5				
16	42	21	23	−19	110	53	56	−54					7	4	2	−5				
17	63	57	40	−23	124	83	86	−38	16	5	15	−1	6	0	0	−6	79	81	70	−9
18	76	48	52	−24	68	71	69	1	53	2	10	−43	35	−20	−9	−44	89	82	92	3
19	63	42	47	−16	42	28	59	17												
20	88	76	105	17	105	107	93	−12									84	82	92	7
21	56	42	42	−14	36	24	27	−9												
22	30	16	21	−9	72	55	70	−2	13	1	5	−8	17	3	3	−14				
23	111	63	58	−53	98	69	93	−5	48	11	6	−42	71	4	5	−66	54	100	96	42

SAL space available for lungs

[a] Saggital profile: lordosis, negative values; kyphosis, positive values

[b] Difference between follow-up value and preoperative value

Complications

Nine patients (40%) (Nos. 2, 7, 9, 11, 12, 13, 16, 22, 23) sustained 23 complications: 10 skin sloughs, 7 implant dislocations/breakages and 6 deep infections (5 patients). The risk of complication was 22% (5/23) per IP and 12% (18/149) per expansion procedure. Fifteen unplanned surgeries included 8 wound debridements (5 patients) and 2 temporary implant removals for infections, 4 myocutaneous local flaps and 7 changes/refixations of implants. One lumbar extension rod and one ala hook broke (No. 7). Nine of 47 upper cradles, 0/10 lower cradles, 1/8 laminar hooks were dislodged. 5/29 ala hooks migrated and were repositioned. One hook was dislodged posteriorly in a kyphotic MMC patient (No. 9). Ten stable ala hooks showed moderate caudal migration with some reoccurrence of pelvic obliquity.

Some neuromuscular patients ossified along the implant (Nos. 3, 4, 7, 11). One girl (No. 20) with Sotos syndrome and severe funnel chest died at the age of 10.5 years from an acute pneumonia which was unrelated to surgery. Temporary loss of motor evoked potentials' during the IP was observed in one patient (No. 23) but quickly resolved after partial release of distraction.

We did not observe any postoperative pulmonary problems. One patient with congenital muscular dystrophy (No. 1, Selenoprotein N1-defect) and a restrictive respiratory syndrome needed a tracheostoma and home ventilation due to acute deterioration of her respiratory function. However, this occurred between two VEPTR expansions and was therefore unrelated to a perioperative period.

Discussion

Early spinal fusion, unilateral growing rods and Luque trolley systems are predictably disappointing in controlling non-congenital early onset spinal deformities and in preserving growth [17]. The dilemma of simultaneously providing three-dimensional stability and enhancing growth in a mixed population of idiopathic, neuromuscular and syndromic disorders seems to be best challenged by *dual growing rods* [14, 21]. However, the risk of placement and pull-out of pedicle screws in patients with small anatomy, repetitive surgery, the rigidity of fixation and a complication rate of 20% per surgery [10] promotes the search for alternatives. The *Shilla system* is based on a single intervention with periapical pedicle screw fixation, local fusion as well as pedicle screw anchoring at both ends of the curve. Those screw heads provide slide-through of the rods with further growth [12]. Since even more pedicles are instrumented as compared to growing rods and the apex is fused, we acknowledged *VEPTR* as a spine-sparing alternative in 23 patients with non-congenital early onset deformities. VEPTR was primarily designed for children with thoracic insufficiency syndrome related to spinal and thoracic abnormalities [1, 4, 20]. Successful control of severe deformities extended its use to non-congenital deformities. However, the database for this entity is still small. Recently, VEPTR was found to be effective in groups of 11 neuromuscular, non-ambulatory and 17 neuromuscular and idiopathic cases, respectively [5, 6]. *Campbell* constrains its indication in syndromic patients to stiff chest walls [22].

The rarity of EOS also limits studies on widely used growing rods to 12–36 patients [11, 15, 16, 23], except multicenter group comparisons which include up to 143 patients [10, 24]. The *Shilla system* is represented by a small series of nine patients with non-congenital deformities [12].

Demographic data

The av *age* of 5.4–7.6 years at first surgery is consistent between methods [5, 6, 11, 12, 14–18, 23, 24]. This compares well to our study and reflects the patient's history of conservative measures and the lack of early emerging respiratory problems. In contrast, patients with stiff chest walls [22] or patients with congenital progressive scoliosis require growth-promoting interventions as early as 0.6 years and at an av age of 3.2–6 years [2, 3].

Though VEPTR and periodic expansions are feasible in very young children, one should initially take advantage of serial plasters and/or bracing in patients with progressive deformities but without rib abnormalities and respiratory issues. In case of failure of this non-invasive approach, the soft tissues and the ribs have at least further developed with growth, which renders any growth-promoting instrumentation less complication-prone.

Coronal plane deformity

The initial av Cobb angle was 68°, which is within the range of 58°–92° in other studies [5, 6, 12, 14, 16, 18, 22, 23, 25]. Neuromuscular patients have more severe curves [11, 15]. Force transmission from ribs to the spine with normal rib–vertebral joints may lessen the resulting corrective forces. VEPTR corrected 30% (Fig. 1) of the initial deformity, which is slightly less than in other VEPTR studies [5, 6, 22] and less than 50–60% yielded by growing rods [12, 14, 16, 25]. VEPTR [6, 22], dual growing rods [11, 14, 23] and Shilla [12] keep the initial correction, whereas single growing rods [15] and Luque trolleys [17, 18] are at risk to completely loose it. During 3.5 years follow-up time and 7.5 surgeries per patient, we did not observe stiffening of the spine and thorax. The stable relation between loss of correction with ongoing growth and re-gain with subsequent expansions caused undulating Cobb angle changes of 8°–10°.

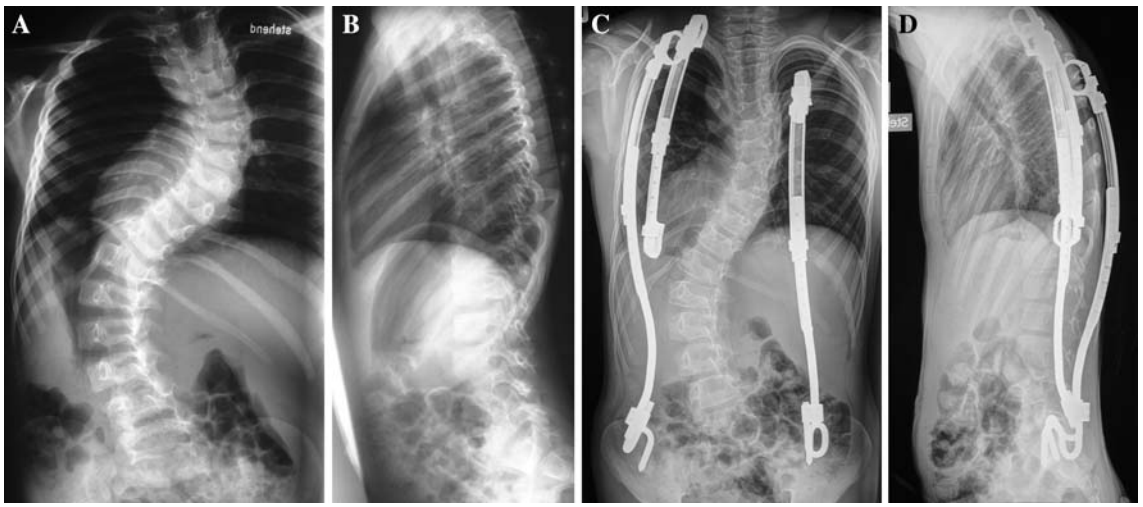

Fig. 1 **a**, **b** Preoperative spine pa/lateral standing. 6.4-Year-old boy (No. 1) with an infantile S-shaped scoliosis which progressed to 71° Cobb angle at the lumbar main curve despite full time bracing. Physiologic sagittal profile. **c**, **d** 3-Year follow-up after five expansion procedures. Brace free after treatment without restriction of physical activity led to a hitherto uneventful course with an actual Cobb angle of 47° (34% correction) and a maintained physiologic profile

Statistically, there was a significant deterioration of the Cobb angle between the IP and the last follow-up ($p = 0.04$). However, the av loss was 5°, which is within the error of radiographic measurements.

T1 tilt

All 11 neuromuscular patients presented with a *T1 tilt or pelvic obliquity*, which promotes cervical scoliosis, shoulder imbalance and loss of sitting balance (Fig. 2). More than half of all patients (15/23) showed T1 tilting which improved from 30° to 10° at follow-up. The initial T1 tilt was comparable but the correction was better than in a VEPTR series on stiffer congenital deformities [20].

Pelvic obliquity

It averaged 33° (13°–60°) with a stable 50% correction over time. This equals sacral and iliac fixations of growing rods [11, 15]. Patients with initial obliquities of less than 30° reached 80° correction, whereas more than 30° only improved by 20%. The VEPTR S-hook acts as polyaxial implant which might limit correction in severe cases. Load sharing by bilateral rib-to-pelvis constructs (Eiffel tower) is recommended. Caudad hook migration leads to tilt recurrence which is resolved by hook repositioning over the iliac crest.

Sagittal profile

There is some concern that expansions of curved VEPTR bars are kyphogenic. We have not observed that in normal or hyperkyphotic sagittal profiles [5, 22]. In flat thoracic spines, mild beneficial kyphogenesis occurred. Well-known from growing rods, flattening of the profile within the instrumented area may lead to kyphogenic "catch-up" at the upper thoracic spine. This was seen in 5 of our 23 patients, 4 of them with initial hyperkyphosis, as described in an earlier VEPTR series [22]. The influence of upper thoracic pedicle screw fixation in growing rod constructs [16] on junctional kyphosis development remains to be studied. VEPTR cradle's intrinsic polyaxiality provides less sagittal control but offers a smooth transition to uninstrumented levels. VEPTR and growing rods keep the av sagittal profile stable [14, 16, 23–25]. Erratic improvement or deterioration is possible [5, 23]: Two patients (Nos. 7, 15) had an unexplained increase. In contrast, two patients (Nos. 16, 17) with thoracic hyperkyphosis of 110° and 124° had a stable correction of 52 and 33%, an experience we share with other VEPTR users [5].

Space available for lungs

Since all our patients were asymptomatic and many also too young or uncooperative, we relinquished pulmonary function tests. SAL ratios [19] show the relation between spine straightening and unfolding of the concave lung space. Nine of 10 patients with a pathologic SAL ratio (<0.9) improved (+13%) in accordance with other growth sparing implants [22, 23].

However, this change was not statistically significant ($p = 0.06$).

Complications

Repetitive surgeries summon risks from age of 6 to 7 years at the time of first surgery until a definitive procedure at maturity. Presumably, the av EOS patient treated with a

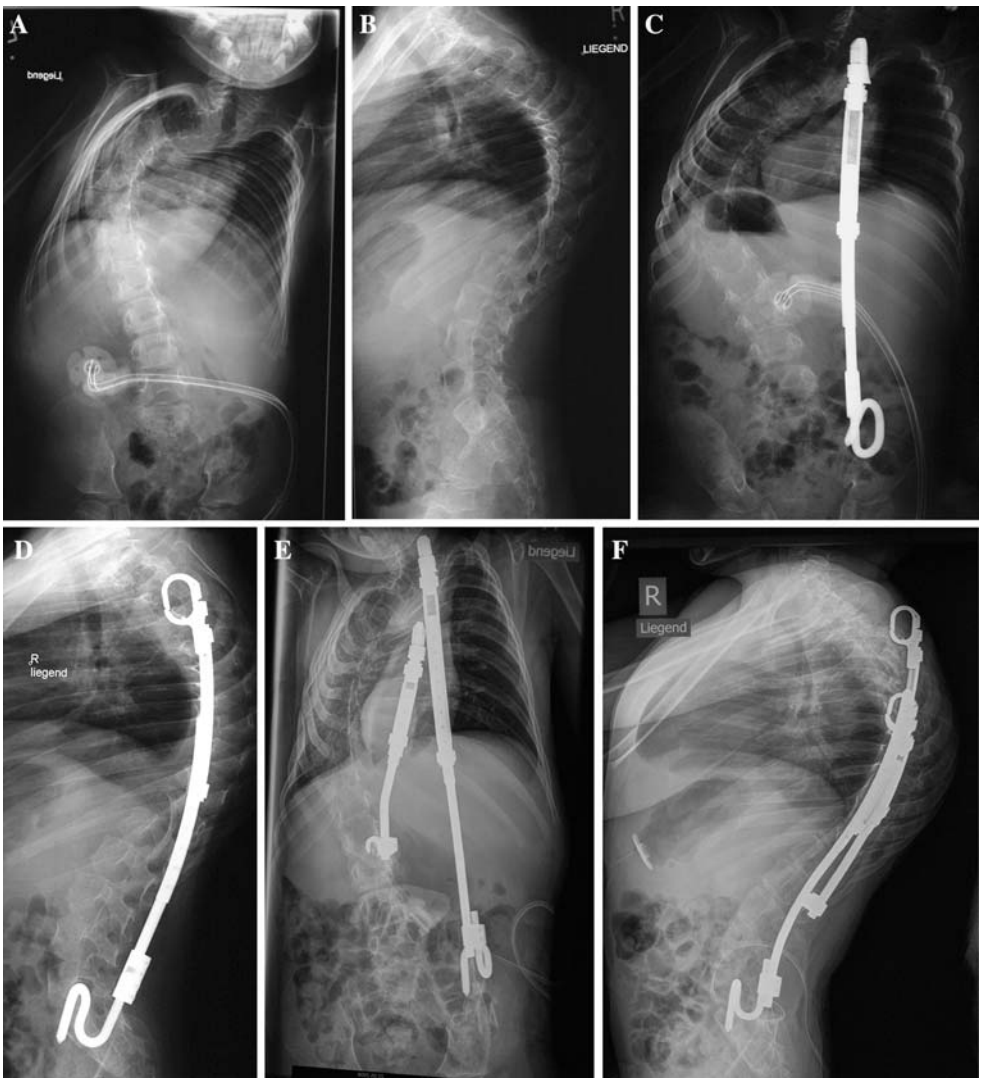

Fig. 2 **a**, **b** Preoperative spine ap/lateral in a supine position. 5-Year-old boy (No. 12) with severe cerebral palsy with loss of sitting ability due to progressive kyphoscoliosis. Brace intolerance. **c**, **d** 1-Year follow-up after two expansions. Progression is halted with one rib-to-pelvis construct. Since the upper cradle shows cutting-through the very soft ribs and there is an imminent skin slough, it is decided to share loads with a second construct. **e**, **f** 4-Year follow-up after 7 and 1 change of construct. The coronal plane deformity has improved from initial 100° scoliosis to 70°, the sagittal profile is kept stable, pelvic obliquity and T1 tilt are significantly better. The boy is able to sit brace free in the wheelchair

growing implant will undergo a total of 10–14 lengthenings. The overall number of complications pro-surgery was 0.13 in our series and compares favourably to the latest study on 143 patients with growing rods: 0.21 for single and 0.18 for dual-rod use [10]. Most of our patients (14/23) never faced a problem. However, 9 patients shared the burden of 23 complications (2.6 per patient).

There is a complex multitude of patient- and surgeon-specific factors influencing the outcome. We were not able to identify particular underlying risk factors in the patients with complications. However, poor soft tissue status and small, fragile ribs may account for most of the problems but were not objectifiable. Bone and soft tissue biopsies in those cases have never revealed a specific pathology.

None of the adverse events let us abandon the VEPTR strategy. The infection rate of 22% was similar to growing rods and the Shilla method [12, 23]. Even in the absence of postoperative bracing, implant breakage is extremely rare in VEPTR [2, 3] but is described in up to 10% with Shilla and dual growing rods and in more than 10% with single growing rods [23]. As with other techniques, we recorded loosening of anchor points as the most common problem [12, 23, 25]. Overall, it occurred in 16% (15/94 fixations) and particularly in 19% of all upper cradles (9/47). Since VEPTR does not involve the spine, this is easily manageable, usually during routine lengthenings. Caution at the time of surgery and parent's awareness between surgeries may anticipate the occurrence of skin sloughs and prevent infections.

Conclusion

Vertical expandable prosthetic titanium rib proved to be a valuable alternative to dual growing rods as treatment for non-congenital early onset spine deformities. The complication rate was lower and the control of the sagittal plane and pelvic obliquities was good, but the correction of the coronal plane deformity was less than growing rods. However, the constructs were placed laterally to span the thorax as experienced for congenital deformities. Placement closer to the spine and use of new VEPTR generation multipoint fixations presumably adds to the corrective power. The spine-sparing approach potentially preserves the flexibility and growth potential of the spine and thus supports the final correction at maturity which might be beneficial compared to spine-based techniques such as growing rods and the Shilla technique.

However, those benefits are—though plausible—hypothetical and need to be weighed out against potential stiffening of the thorax which itself has so far been only an assumption. Spine mobility and thoracic motion after VEPTR implantation and after spine-based procedures remain to be investigated, as well as VEPTR's ability to control rotation. Both were not subject of our study.

With the ongoing development of new methods and implants, the treatment of progressive spine deformities in young children has become more differentiated. VEPTR represents the gold standard for congenital deformities with rib fusions. Though spine motion is sacrificed at multiple levels by fusion, the Shilla technique is a valuable option in cases where repetitive surgery and anaesthesia are deemed contraindicated. However, in most of the cases without concomitant thoracic pathologies, repetitive expansions are feasible. Flexible curves may still be best treated with a combination of serial casting and bracing as it preserves the biology and anatomy best. Brace intolerance and/or progression of the deformity as well as stiff curves are indications for either double growing rods or VEPTR. Since the latter leaves the spine untouched, which is a potential advantage both in terms of motion preservation and in case of pull-out of anchor points, and the corrective power has proved to be efficient, we give it the preference. Multiple anchor points and additional, bigger implant radius with the recently released new generation VEPTR will add efficiency and hopefully further diminish the complication rate.

Conflict of interest statement None.

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