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Review Article

A comparison of growth among growth-friendly systems for scoliosis: a systematic review

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Abstract

BACKGROUND CONTEXT: The optimal method for surgical treatment of early onset scoliosis is currently unknown. Although the aim of growth-friendly systems is to reduce the curve and maintain growth, there is no consensus on how to measure spinal growth during and after the treatment. Different measurements of different segments (T1−S1, T1−T12, instrumented length) are used for different time points to evaluate growth. The aim of this review is to assess what measurements are used and to compare the growth-friendly systems based on spinal growth during treatment.

METHODS: The electronic MEDLINE, EMBASE, and Cochrane databases were systematically searched for original articles that reported growth for traditional growing rods (TGR), vertical expandable prosthetic titanium rib expansion technique (VEPTR), Shilla, magnetically controlled growing rods (MCGR), and Luque-trolley systems. All measurements were recorded, and weighted averages calculated in centimeter per year were compared.

RESULTS: We included 52 studies (26 TGR, 12 MCGR, 6 VEPTR, 4 Luque trolley, 1 Shilla, and 3 mixed). Often only one segment was reported (T1−S1 length in 22 studies, T1−T12 length in two studies, and instrumented length in five studies). The remaining 22 studies reported T1−S1 length in combination with T1−T12 length (15 studies) or instrumented length (eight studies). Spinal growth achieved by initial correction only was a considerable 3.9 cm (based on 34 studies) as well as the spinal growth achieved by the final fusion surgery (2.3 cm in four studies). To specifically assess growth achieved with the system, length gain after initial surgery and before final fusion in growth system graduates was considered. Only four TGR studies reported on this "true" spinal growth with 0.6 and 0.3 cm/y in the T1−S1 and T1−T12 segment, respectively.

CONCLUSIONS: Reporting on spinal growth is currently inadequate and does not allow a good comparison of different techniques. However, all systems often report growth similar to Dimeglio's T1−S1 spinal growth of 1 cm/y. It should be recognized though that a considerable portion of the reported spinal growth is the result of the initial and final surgical correction and not due to the growth-friendly implant.

Keywords: Early onset scoliosis; Growing rods; Growth-friendly systems; Instrumentation without fusion; Minimal invasive surgical procedure; Luque; MCGR; TGR; VEPTR.

Level of Evidence: Level III systematic review.

FDA device/drug status: Approved (MACEC Spinal Bracing and Distraction System, DePuy Synthes Spine Vertical Expandable Prosthetic Titanium Rib (VEPTR/VEPTR II), and SHILLA(Tm) Growth Guidance System).

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Introduction

One of the biggest challenges for pediatric spine surgeons is the surgical treatment of early onset scoliosis (EOS). If untreated, progression of the curve is inevitable, cardiopulmonary function may be compromised and long-term mortality can increase [1−3]. When the spine is corrected and fused during growth, a disproportionately short trunk can result in lung and thoracic wall deficiency [4]. Current surgical treatments allow for growth of the spine while correcting the scoliosis. These surgical treatments rely on distraction or growth guidance principles. Distraction-based techniques are the traditional growing rods (TGR), either proximally spine-based or rib-based, the vertical expandable prosthetic titanium rib expansion technique (VEPTR) and magnetically controlled growth rods (MCGR). Growth guidance procedures consist of the Luque trolley and the Shilla. The degree of spinal curve correction and maintenance can be easily reported and compared between individuals. However, comparing results based on the reported spinal growth is difficult because of inconsistent reporting [4]. A major obstacle in comparing studies is the use of many different assessment methods. For example, different segments are reported on T1−S1, T1−T12, and the instrumented segment (segment between the most upper and lower instrumented vertebra). Furthermore, the distance of a segment depends on how it is measured. Finally, the time frame and period used for growth differs considerable and is often unclear. Some articles include the growth achieved with the initial instrumentation, others even include the growth achieved with the final fusion and correction surgery. Although the total length gain is what is important in the end, the growth that is relevant to compare different growth systems is the achieved growth of the instrumented spine after initial and before final surgery. We, therefore, aimed to systematically review all original research reporting on growth in patients with scoliosis who have undergone growth-friendly surgery. The purpose of this systematic review is (1) to assess what growth measurements are used and (2) to identify the growth-friendly system that allows the most spinal growth.

Methods

This systematic review was performed in accordance with the items outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement, the guidelines for reporting of meta-analysis of observational studies in epidemiology, and the Cochrane Handbook for Systematic Reviews of Interventions [5−7]. The search strategy was developed with a health sciences librarian and reviewed by two authors (SW and IT). The electronic MEDLINE, EMBASE, and Cochrane Library databases were systematically searched for articles that reported growth for TGR, VEPTR, Shilla, MCGR, and Luque-trolley systems (Supplementary Material 1). Extensive citation tracking, reference screening, and screening of related articles were performed for potentially missing articles (Pubmed, Google scholar). If research would not be accessible, authors would be contacted.

Eligibility criteria and study selection

Studies were limited to articles published in the English language until April 2017 with no restriction on publication date. Articles were screened by two independent reviewers (SW and IT) in EndNote X8 (Clarivate Analytics, Philadelphia, Pennsylvania, United States). Reference screening and citation tracking were performed to find additional relevant articles. Human, clinical studies that reported on the use of growth-friendly systems for EOS of all etiologies were included. To select patients within the same growth phase, initial surgery had to be between 5 and 10 years. Case series that included <five primary cases and studies with only conversion or revision cases were excluded.

Data collection and study quality evaluation

Data were independently extracted from the articles by two reviewers (SW and IT). If any discrepancy could not be solved, a third reviewer was consulted (MK). Study quality was determined independently by the two reviewers using a standardized grading tool (MINORS criteria) [8]. The MINORS score is used to differentiate between low-to-high quality nonrandomized studies on a scale from 0 to 24 [8−11]. The final MINORS score per article were determined by the two reviews after a consensus meeting. The following data were extracted from each article: author, year of publication, study design, type of growth-friendly system, study size, method of length measurement, Cobb angles, time of follow-up, multi- or single center, and use of existing database for patient selection. All research was available and no authors needed to be contacted. The data extraction of spinal growth is expanded below.

Spinal segments

There are three spinal segments on AP x-rays that are used for measuring spinal growth: T1−S1, T1−T12, and instrumented segment (Fig. 1). The T1−S1 measures the total spinal distance from the superior end plate of the T1 to the superior end plate of the S1. The T1−T12 segment is measured from the superior end plate of T1 to the inferior end plate of T12. The instrumented segment is measured between the superior end plate of the most upper instrumented vertebra and the inferior end plate of the lowest instrumented vertebra. T1−S1 is often used to indicate growth in the entire spine, T1−T12 is a proxy for pulmonary development, and instrumented length is used to indicate the growth of the system. Because all three measurements add different information, all were extracted and analyzed.

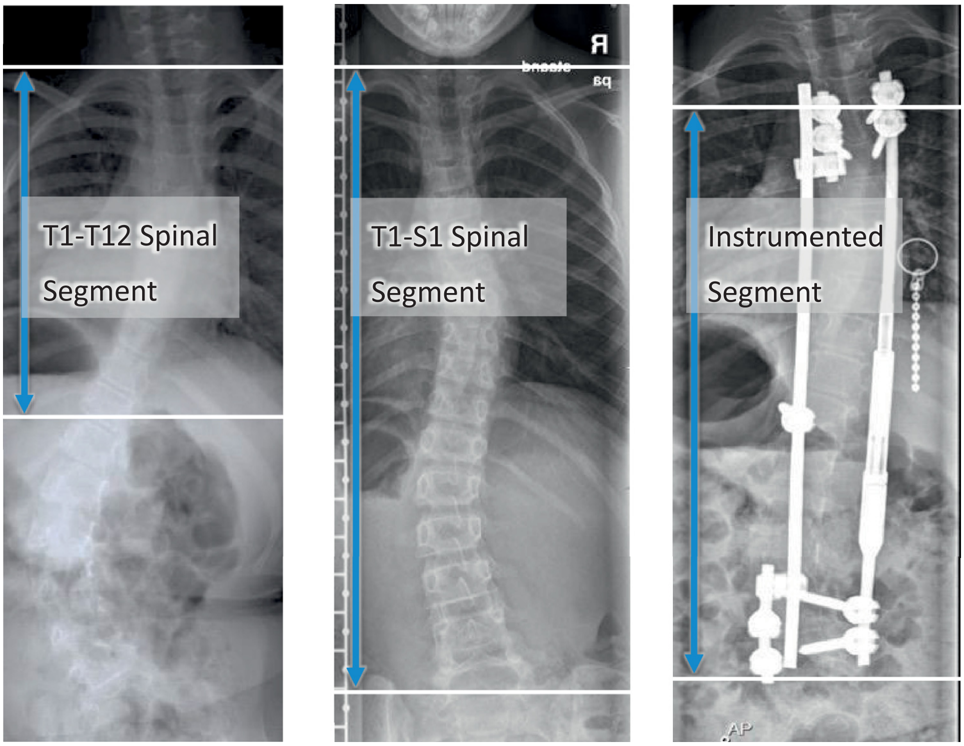

Fig. 1. Different segments for measuring spinal growth. The T1−S1 measures the total spinal length from the superior end plate of the first thoracic vertebrae to the superior end plate of the first sacral level. The T1−T12 segment is measured from the superior end plate of the 1st thoracic vertebrae to the inferior end plate of the 12th thoracic vertebrae. Instrumented length is measured between the superior end plate of the most upper instrumented vertebrae and the inferior end plate of the lowest instrumented vertebrae.

Distance measurements of spinal segments

There are three types of 2D measurements of the spinal segment distances: spinal length, spinal height, and free hand. The spinal length is a direct line that measures from the midpoint of the chosen end plates (eg, superior end plate of T1 to superior end plate of S1). The spinal height is measured as the perpendicular between 2 parallel horizontal lines passing through the centers of the chosen end plates. Finally, the free-hand measurement is made by drawing a line through midline of the spine following the curvature of the scoliosis. The degree and type of spinal curvature can result in three different values for these three methods of measuring spinal segments (Fig. 2). A large reduction in spinal curvature (eg, after initial implantation surgery) would directly increase the spinal height, to a lesser extent increase the spinal length and would not increase the free-hand length as the spine itself did not grow. Unfortunately, clear descriptions on how spinal segments were measured were usually lacking and we accepted this inaccuracy in our pooled results.

Time frames of spinal growth

We defined three time frames for spinal growth assessment based on the initial instrumentation surgery and final correction and fusion surgery (Fig. 3). The most ideal is the *true spinal growth*, which is average growth achieved after initial instrumentation and before final fusion for just growth-friendly graduates. Unfortunately, only very few studies provide this data. Often patients with short follow-up, long follow-up, and growth system graduates (patients who finished growth-friendly treatment) are averaged for one growth measure and these patients are not reported separately. For practical reasons, the following time frames were characterized with the knowledge that different end points are averaged into one outcome. The *follow-up spinal growth* is the average reported growth for all patients without the growth achieved during initial instrumentation. The *total reported spinal growth* is the maximal growth reported for all reported patients including the growth achieved during initial instrumentation. The three time frames were extracted and analyzed separately.

Data summary

Spinal growth was standardized to centimeters per year. The different growth-friendly systems were compared and analyzed for differences. All reported measures in this article (age, growth, Cobb angles, and follow-up) were calculated with weighted means. The inter-rater reliability of the MINORS scores of the two independent observers was analyzed with intraclass correlation. The articles were averaged with weights based on included patients per article.

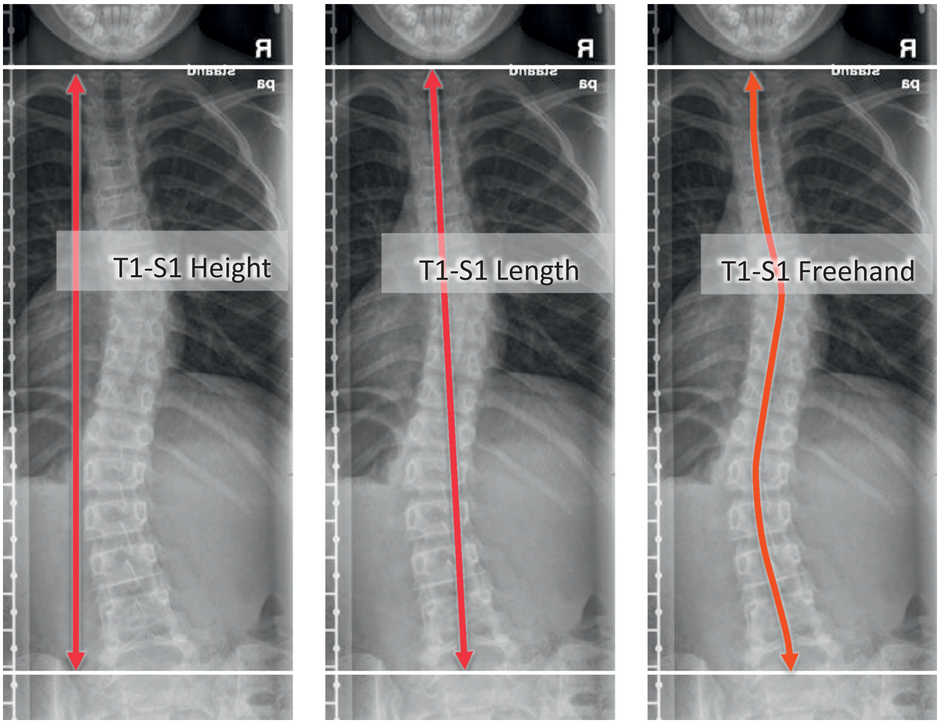

Fig. 2. Different methods of measuring the T1−S1 spinal segment. The spinal height is measured as the perpendicular between 2 parallel lines passing through the centers of the chosen end plates. The spinal length is a direct line that measures from the midpoint of the chosen end plates (eg, superior end plate of T1 to superior end plate of S1). The free-hand measurement is measured by drawing a line through midline of the spine following the curvature of the scoliosis.

Results

Search yield

The search in the MEDLINE, EMBASE, and Cochrane libraries yielded 1,048 articles after removal of duplicates. Total of 922 articles were excluded after title and abstract screening. After full text screening of the remaining 126 articles, 52 articles were included for this review. No extra articles were found after citation tracking, reference screening, and screening of related articles (Pubmed, Google scholar). Complete flow chart with reasons for exclusion is displayed in Supplementary Material 2. All data could be extracted from the 52 articles without the need for a third reviewer. The intraclass correlation of the MINORS scores before consensus from the two independent observers was 0.97. The individual MINOR scores after consensus per included articles are displayed in Table 1. The average MINORS score of the included articles was 10.7 on a scale of 0 to 24 (which is relatively low even for nonrandomized studies).

Included systems

Twenty-six articles reported on single or double TGR. The other included systems were MCGR with 12 articles, VEPTR 6, and Shilla 1. Two articles compared Shilla with TGR and one article compared MCGR with TGR. Three articles used the old Luque-trolley systems with only sublaminar wires [12−14]. One article used a modern construct with hooks and pedicle screws [15]. Twenty-two multicenter studies were included: 15 were from a database of the growing spine study group (13 TGR and 2 comparing TGR with Shilla and TGR and MCGR) and 2 from a database of the children's spine study group (both VEPTR).

Segment measurements

Of the 52 articles, 22 reported on only the T1−S1 distance. Two articles only reported the T1−T12 distance and five only reported on the instrumented segment. Fifteen articles reported on both T1−S1 and T1−T12 distance and eight articles reported on both T1−S1 and instrumented segment. None reported on all three segments.

Time frame measurements

True spinal growth (after initial instrumentation and before finals fusion) was only reported in four articles. The follow-up spinal growth (excluding initial surgery) was extracted from 47 articles. Total reported spinal growth (including initial surgery) could be extracted from 40 articles out of the total 52.

True growth rate

Four studies reported on graduates and the true growth rate in the T1−S1 segment. The average growth rate based

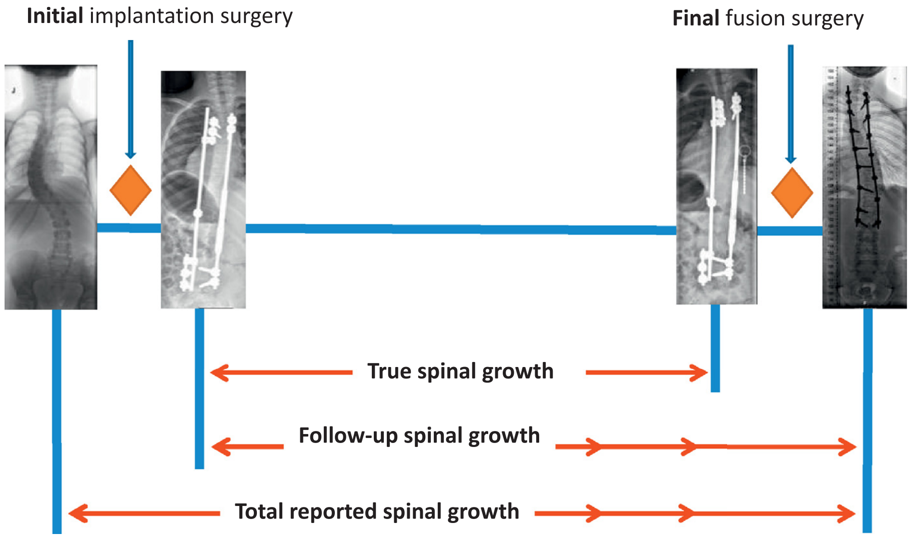

Fig. 3. Different time periods used for measuring spinal growth. The true spinal growth is measured after initial instrumentation and before any final fusion. The follow-up spinal growth excludes the initial surgery. The total reported spinal growth includes the initial surgery. Often articles combine patients with short follow-up, long follow-up, and patients who were already fused in their spinal growth measurement. They do not report on these three groups separately resulting in a nonset end-point for the follow-up and total spinal growth periods.

on four studies with a total of 176 patients was 0.6 cm/y (range 0.4−1.1) [16−19]. The T1−T12 true spinal growth rate was based on one study with 110 graduates and was calculated as 0.3 cm/y (Table 2) [19]. Finally, two studies with a total of 36 patients had a true spinal growth in the instrumented segment of 0.9 cm/y (range 0.9−1.0) [16,17]. The true growth rate could only be extracted from studies published by the growing spine study group [16−19].

Follow-up spinal growth

The most frequently used, but less-accurate measurement was the follow-up spinal growth. When calculated to length gain per year, this showed 1.0 cm/y for TGR, 0.9 cm for MCGR, 0.5 cm for VEPTR, and 0.7 cm for Shilla [16−55]. For the T1−T12 segment, this was 0.7 cm for TGR, 0.6 cm for MCGR, 0.3 cm for VEPTR, and 0.3 cm for Shilla [19,34,39,41,45,46,48,50−52,54−56]. Finally, the instrumented segment could only be extracted for three systems and showed 1.0 cm/y for TGR, 1.1 cm for MCGR, and 0.8 cm for Shilla [12−15,17,24,26,30,31,33,57,58]. We compared the average age at initial surgery and follow-up for the different systems and found that included patients in the MCGR studies were considerably older at initial surgery and had a shorter follow-up (Fig. 4).

Total reported spinal growth

The least accurate measurement was the total reported spinal growth, which may or may not include the effect of the first and final reduction. The MCGR showed the highest growth in T1−S1 segment of 3.4 cm/y [39,41−43,45−50]. The growth for TGR was 1.8 cm, 1.9 cm for VEPTR, 1.8 cm for Luque trolley, and 1.4 cm for Shilla [13,16−21,23,25−29,31,32,35−40,51−55,59−62]. All growth measurements including total T1−T12 growth is displayed in Table 3 [63]. The average follow-up was 1.5 years for MCGR, 3 years for VEPTR, 4.6 years for Shilla, and 4.7 years for TGR and Luque trolley.

Effect of initial and final surgery

In 34 studies, the T1−S1 segment increased an average of 3.9 cm as a result of initial surgery only [16,17,19−21,23,25−29,31−33,35−42,44−50,52−55,60]. Based on 12 studies, this initial surgery resulted in an average T1−T12 segment increase of 2.4 cm [19,39,41,45−48,50,52,54,55,60]. Based on four studies, the average T1−S1 segment increase of just the final fusion surgery was an average of 2.3 cm [16−19]. Based on one study, the T1−T12 segment increased a total of 0.87 cm during final fusion surgery [19]. If we combine these studies, we find that the average total increase in length of T1−S1 is 9.5 cm. This means that 40% of length gain is achieved with initial instrumentation, 36% of length gain during the growth-friendly period, and 24% during the final fusion (Fig. 5).

Discussion

In this review, we made an attempt to compare currently used growth-friendly systems. The research questions seemed straightforward and relevant. However, we found that there were many impediments that made a state of the art meta-analysis to guide clinical decision-making impossible. Some of these impediments would be nonexistent if a more universal way of reporting is used. Of the reported segments, the T1−S1 measurement is most often used.

Table 1
Overview of studies

Year	First author	Country	System	Patients (N)	Female (%)	NM (%)	Pre-op Cobb	Post-op Cobb	Last Cobb measured	Final fusion perfomed (N)	MINORS
1984	Moe	USA	TGR	20	50	30	NM	NM	NM	9	7
2005	Thompson	USA	TGR	28	68	29	NM	NM	NM	28	11
2005	Akbarnia	USA	TGR	23	70	9	82	38	36	23	11
2008	Akbarnia	USA	TGR	13	23	15	81	36	28	13	12
2009	Sponseller (1)	USA	TGR	36	NM	56	86	NM	48	6	11
2009	Sponseller (2)	USA	TGR	10	NM	0	77	NM	36	5	6
2010	Farooq	UK	TGR	88	NM	23	73	42	44	30	11
2011	Sankar	USA	TGR	38	NM	39	74	36	35	0	9
2011	Elsebai	Turkey	TGR	19	63	0	66	45	47	5	12
2011	McElroy	USA	TGR	95	66	16	79	41	45	19	14
2012	Wang	China	TGR	30	67	0	72	35	35	3	12
2012	Uzumcugil	Turkey	TGR	20	75	0	59	35	29	0	14
2012	McElroy	USA	TGR	27	67	100	85	40	49	0	8
2012	Caniklioglu	Turkey	TGR	25	96	4	57	23	25	NM	10
2013	Miladi	France	TGR	23	NM	0	68	33	29	2	12
2013	Johnston	USA	TGR	27	NM	22	67	NM	46	6	8
2014	Wang	China	TGR	7	71	0	81	40	41	NM	12
2014	Enercan	Turkey	TGR	16	56	13	64	21	22	2	11
2014	Paloski	USA	TGR	46	50	17	78	41	48	0	13
2015	Sun	China	TGR	53	74	8	NM	NM	NM	NM	11
2015	Atici	Turkey	TGR	23	78	0	62	37	34	13	8
2016	Brooks	USA	TGR	38	55	68	69	NM	48	NM	12
2016	Chen	China	TGR	40	73	18	72	41	46	NM	11
2016	Jayaswal	India	TGR	13	54	0	79	57	53	0	11
2016	Upasani	USA	TGR	110	55	33	76	43	41	99	9
2017	Jain	USA	TGR	14	71	0	74	30	36	4	11
1982	Luque	Mexico	Luque	47	60	100	72	16	24	0	5
1985	Rinsky	USA	Luque	9	78	100	67	31	45	0	9
1999	Pratt	UK	Luque	7	43	0	48	25	41	1	10
2011	Ouellet	Canada	Luque	5	60	20	60	21	21	5	9
2013	Akbarnia	USA	MCGR	14	50	36	60	34	31	0	10
2013	Dannawi	UK	MCGR	34	62	32	69	47	41	0	9
2014	Yoon	UK	MCGR	6	33	67	87	34	53	0	11
2014	Hickey	UK	MCGR	8	25	0	59	42	43	0	7
2014	Akbarnia	USA	MCGR	12	58	33	59	32	38	0	17
			TGR	12	58	NM	64	35	42	0	
2016	Cheung	China	MCGR	9	56	0	NM	NM	NM	0	13
2016	Heydar	Turkey	MCGR	18	61	22	68	35	35	2	11
2016	Keskinen	Finland	MCGR	50	62	26	56	36	40	NM	16
2016	Lebon	France	MCGR	30	47	37	66	40	44	3	10
2016	Ridderbusch	Germany	MCGR	24	67	21	63	29	26	0	11
2016	Thompson	UK	MCGR	19	47	26	62	45	43	0	13
2016	Hosseini	USA	MCGR	23	70	35	57	38	41	NM	11
2017	La Rosa	Italy	MCGR	10	50	20	65	27	29	0	7
2015	Andras	USA	Shilla	36	NM	36	69	26	45	0	16
			TGR	36	NM	36	72	38	38	0	
2015	McCarthy	USA	Shilla	33	64	NM	69	44	38	0	10
2016	Luhmann	USA	Shilla	19	63	26	70	22	38	0	13
			TGR	6	67	0	68	32	39	1	
2009	Samdani	USA	VEPTR	11	64	45	82	51	58	NM	7
2011	White	USA	VEPTR	14	29	93	74	53	57	1	12
2014	Abol Oyoun	Germany	VEPTR	20	60	100	37	25	36	NM	9
2015	Heflin	USA	VEPTR	12	42	0	66	NM	61	2	10
2016	Murphy	USA	VEPTR	25	52	0	69	56	54	0	9
2017	El Hawary	USA	VEPTR	63	44	57	72	47	57	NM	13

NM, neuromuscular scoliosis; pre-op, preoperative; post-op, postoperative; FFU, final follow-up; TGR, traditional growing rods; MCGR, magnetically controlled growing rods; VEPTR, assess growth achieved with the system, length gain after initial surgery and before final fusion in growth system; Cobb, angle of scoliosis on anterior-posterior radiographs in degrees.

Final fusion: last surgery for growing rod graduates in which the entire spine is fused.

Table 2
True spinal growth in graduates

Segments	System	True spinal growth in cm/y (excluding initial surgery and final fusion surgery)
T1−S1	TGR (174)	0.6 [0.4−1.1]
T1−T12	TGR (110)	0.3
Instrumented	TGR (36)	0.9 [0.9−1.0]

TGR, traditional growing rods.

Average weighted means, (#) total included patients, [#] range of reported values. Initial surgery: first surgery during which the growth-friendly system was implanted; final fusion surgery: last surgery during which the growth-friendly system is removed and the spine is fused.

Although this nicely represents patient length, it does not adequately represent the growth achieved by the growth-friendly system as the T1−S1 measurement often includes spinal growth outside the instrumented segment. The T1−T12 measurement can be a good proxy for thoracic growth and lung growth. However, the T1−T12 measurement also includes spinal growth outside the instrumented segment and excludes the growth achieved in the instrumented lumbar levels. Measuring the growth of the instrumented segment most accurately reflects the growth-friendly system. However, there is variability in the number of vertebrae instrumented in patients making comparisons harder. Ideally, the growth per vertebra per year should be given but this is only very exceptionally the case. The different time (event) points used for follow-up also causes major problems for comparing the studies. Often only the first 1 or 2 years of follow-up were reported, where more length gain can be expected due to the law of diminishing returns [23]. In addition, the effect of initial surgery and final fusion was included or not clearly described. Apparently, these surgeries are responsible for a substantial percentage of final length gain (>60%). Therefore, the true growth rate in growth system graduates (patients who finished their treatment) is the best method to assess growth in juvenile scoliosis. Unfortunately, only four studies included in our review complied to this.

Based on Dimeglio's data for normal growth, the T1−S1 spinal growth between 5 and 10 years is at a relatively low average of 1 cm/y. After the age of 10 years, the growth velocity increases to an average of 1.8 cm/y until skeletal maturity [64]. New data suggest that the first spinal growth spurt ends at the age of 4 years and the second spinal growth spurt starts at age 12, extending the period of the slower growth velocity in the spine [65]. Based on these data, a normal growth of at least 1 cm/y can be expected for the patients included in this review and many of the included papers claim such "normal" growth rates. However, this growth is often only observed in the first years, or largely caused by length gain as a result of initial (3.9 cm) and final surgery (2.3 cm). The true growth rate of 0.6 and 0.3 cm/y that we found for T1−S1 and T1−T12, respectively, in TGR graduates is considerably lower. Actually, it seems that the added value of the repeated lengthening is quite low as it is responsible for only one-third of the final height gain. On the other hand, the lengthening may be needed to maintain a relatively mobile spine. In that case, the growth system is primarily to prevent severe curve progression at the young age and to allow some correction with final fusion later. This would imply that the focus should be less on centimeters, but more on ways to reduce the high costs in terms of material, repeat surgeries, and complications of the current systems [66−68].

Strengths and limitations

This is the first systematic literature review attempting to compare currently used growth-friendly systems. Despite the rarity of surgical treated EOS patients, a relatively large number of studies and patients could be included.

The included studies were of low methodological quality caused by the predominance of retrospective case series and reflected by the MINORS sore of 10.7. Reporting on the

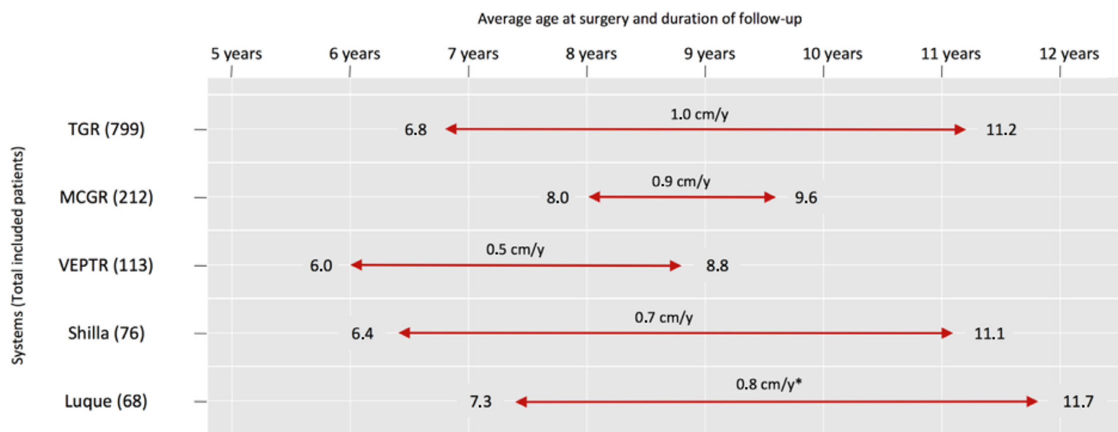

Fig. 4. The average age at surgery and duration of follow-up for the growth-friendly systems. Average weighted means of T1−S1 follow-up growth in centimeter per year displayed with the average weighted means of the reported ages and follow-up. *No T1−S1 growth for Luque was available, the instrumented follow-up length gain is used here.

Table 3
Reported length gains

	Follow-up spinal growth in cm/y (excluding initial surgery)		Total reported spinal growth in cm/y (including initial surgery)	
T1−S1	TGR (845)	1.0 [0.5−2.3]	TGR (687)	1.8 [1.0−2.7]
	MCGR (212)	0.9 [0.3−1.9]	MCGR (207)	3.4 [1.5−5.5]
	VEPTR (113)	0.5 [0.0−1.0]	VEPTR (125)	1.9 [1.0−3.0]
	Shilla (76)	0.7 [0.6−0.8]	Shilla (95)	1.4 [1.4−1.6]
	Luque		Luque (47)	1.8
T1−T12	TGR (175)	0.7 [0.2−1.5]	TGR (128)	0.8 [0.7−1.1]
	MCGR (181)	0.6 [0.2−1.2]	MCGR (116)	2.4 [1.9−3.6]
	VEPTR (99)	0.3 [0.2−0.6]	VEPTR (119)	1.3 [0.6−2.1]
	Shilla (40)	0.6	Shilla (40)	0.9
	Luque		Luque	
Instrumented	TGR (181)	1.0 [0.8−1.1]		
	MCGR (9)	1.1		
	VEPTR			
	Shilla			
	Luque (68)	0.8 [0.3−1.0]		

Average weighted means, (#) total included patients, [#] range of reported values. cm, centimeter.
Initial surgery: the first surgery during which the growth-friendly system was implanted.

achieved growth is inadequate in most studies and the published growth rate periods are often unclear as well as the patient population. Moreover, different measurement methods had to be combined for every segment caused by unclear descriptions in the articles. We included articles that combined patients with short follow-up, long follow-up, and growth-friendly graduates. Often these patient groups were not reported separately and the combined result was used. Consequently, comparisons of outcomes of growth of the different systems should be interpreted with caution.

Implications for future research

Until reporting on growth in the spine is improved, there will be serious limitations in interpreting and comparing the data. Probably many of these reporting and subsequent assessment problems can be mitigated if there would be some minimal requirements and/or rules for publishing on this data. For example, that the methods are clearly described and even better, that at least some kinds of measurement like the instrumented segment length are always reported. Also, it should be clear which time frame is reported on and preferably the results per distinct period are given separately. The mean age and mean follow-up (mean time between the first postoperative radiograph and last measured radiograph) for each group should be clearly mentioned. Finally, the raw data including per patient growth should be made available through on-line Supplementary Material.

Conclusion

This review indicates that reporting on spinal growth is currently inadequate. The reported growth seems comparable to physiological growth, but is substantially overestimated caused by the effects of curve correction at the initial and final surgery. Only TGR reported on true spinal growth, which was considerably below normal spinal growth rates. This true growth appears to be responsible for only one-third of the total length gain.

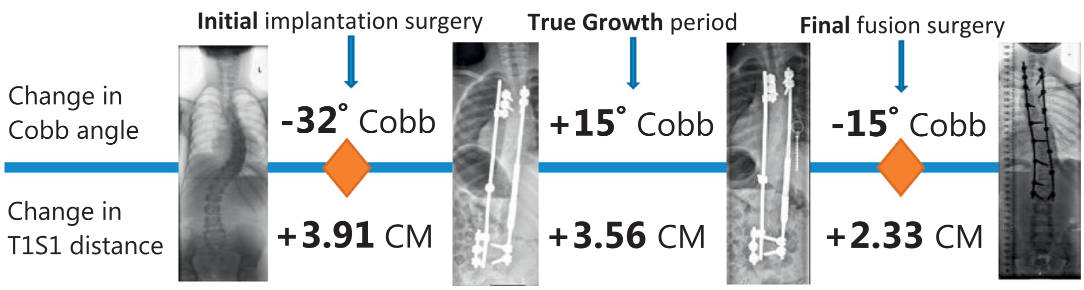

Fig. 5. Effect of initial and final fusion surgery. The average Cobb decrease after initial implantation was based on 42 studies. The change in Cobb angle during the true growth period is based on four studies. The change in Cobb angle because of final fusion surgery is based on four studies. The T1−S1 increase during initial implantation surgery is based on 34 studies. The true growth period is based on four studies. The T1−S1 increase because of final fusion surgery is based on four studies.

Supplementary material

Supplementary material related to this article can be found at http://dx.doi.org/10.1016/j.spinee.2018.08.017.

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