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The primary aim of *World Journal of Orthopedics (WJO, World J Orthop)* is to provide scholars and readers from various fields of orthopedics with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

WJO mainly publishes articles reporting research results and findings obtained in the field of orthopedics and covering a wide range of topics including arthroscopy, bone trauma, bone tumors, hand and foot surgery, joint surgery, orthopedic trauma, osteoarthritis, osteoporosis, pediatric orthopedics, spinal diseases, spine surgery, and sports medicine.

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Complications in growth-friendly spinal surgeries for early-onset scoliosis: Literature review

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Abstract

BACKGROUND

The treatments for early-onset scoliosis (EOS), defined as curvature of the spine with onset before 10 years of age, continue to pose a great challenge for pediatric orthopedics. The treatment goals for EOS include minimizing spinal deformity while maximizing thoracic volume and pulmonary function. Different surgical techniques have different advantages and drawbacks; however, the two major concerns in the management of EOS are repeated surgeries and complications.

AIM

To review the current literature to assess the safety of EOS surgical treatment in terms of the rate of complications and unplanned surgeries.

METHODS

In January 2021 two independent reviewers systematically searched three electronic medical databases (PubMed, the Cochrane Library, and Embase) for relevant articles. Every step of the review was done according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Due to the heterogeneity of articles and topics after data analysis, a descriptive (synthetic) analysis was performed.

RESULTS

A total of 2136 articles were found. Forty articles were included in this systematic review, after applying our inclusion and exclusion criteria. EOS surgery has a varying but high rate of complications. The most frequent complications were categorized as implant (54%), general (17%), wound (15%) and alignment (12%).

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The rate of complications might have been even higher than reported, as some authors do not report all types of complications. About 54% of patients required unplanned surgeries due to complications, which comprised 15% of all surgeries.

CONCLUSION

The literature concerning the definitions, collection, and interpretation of data regarding EOS surgery complications is often difficult to interpret. This creates problems in the comparison, analysis, and improvement of spine surgery practice. Additionally, this observation indicates that data on the incidence of complications can be underestimated, and should be interpreted with caution. Awareness of the high rate of complications of EOS surgery is crucial, and an optimal strategy for prevention should become a priority.

Key Words: Scoliosis; Spine; Growth-friendly implant; Surgery; Complications; Treatment

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Core Tip: Early-onset scoliosis (EOS) is defined as curvature of the spine $\geq 10^\circ$ with onset before 10 years of age, regardless of etiology. The treatment for EOS is still a great challenge for pediatric orthopedics, and surgery is often necessary. Repeated surgeries and complications are two major concerns in EOS management. The literature on the definitions, collection, and interpretation of data regarding EOS surgery complications is often difficult to interpret. This creates problems in the comparison, analysis, and improvement of spine surgery practice. Data on the incidence of complications can be underestimated, and should be interpreted with caution.

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INTRODUCTION

Early-onset scoliosis (EOS) is defined as curvature of the spine $\geq 10^\circ$ in the frontal plane with onset before 10 years of age[1]. EOS is not a diagnosis, but can rather be defined as the age of onset of a coronal plane spinal deformity. As such, EOS includes spinal deformities resulting from congenital malformations, neuromuscular conditions, inherited bone dysplasias and syndromes, and, in idiopathic cases, with no underlying disorder. As EOS has such a wide variety of etiologies, its natural history varies widely, and in many cases is established at the time of the child's diagnosis which reveals the spinal deformity[2]. The natural history of untreated progressive EOS was reported on by Scott and Morgan in 1955[3]. They documented the progression of curves from 30 to 100 degrees. Moreover, 4 patients out of 28 died before the age of 20 years, of cardiorespiratory disease. Relentless curve progression, in the absence of treatment, results in increasing chest wall deformity. Rib rotation and curve progression produce restrictive pulmonary disease, with worsening pulmonary function, as documented by diminishing forced vital capacity and total lung volume. If left untreated, the spinal deformity produces chest wall rotation, which obliterates the space available for the lungs[4]. The treatment for EOS remains a great challenge for pediatric orthopedics. The treatment goals for EOS, regardless of the diagnosis, are the same: minimizing spinal deformity while maximizing thoracic volume and pulmonary function[5]. When conservative treatment is ineffective, the option is surgery[6]. Different techniques have different advantages and drawbacks. Those most often used are traditional growing rods (TGR), vertical expandable prosthetic titanium ribs (VEPTR), magnetically controlled growing rods (MCGR), and the Shilla growth guidance system (SGGS). Repeated surgeries and complications are two major concerns in EOS management. The aim of the study was to review the current

literature to assess the safety of EOS surgical treatment in terms of the rate of complications and unplanned surgeries.

MATERIALS AND METHODS

Literature search strategy

The systematic review was conducted according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[7] (Figure 1). In January 2021, a search of three electronic medical databases (PubMed, the Cochrane Library, and Embase) was performed by three independent authors. We combined the terms: “early-onset scoliosis” OR “eos” OR “juvenile scoliosis” OR “infantile scoliosis” OR “tgr” OR “veptr” OR “MCGR” OR “Shilla” OR “growth-friendly” AND “complication”. The reference lists of all retrieved articles were reviewed for the further identification of potentially relevant studies, and assessed using the inclusion and exclusion criteria.

Selection criteria

The eligible studies for the reference review included those dealing with complications in the operative treatment of EOS. The initial screening of titles and abstracts was made using the following inclusion criteria: studies of any level of evidence, reporting clinical results, published in peer review journals, and dealing with complications in operative EOS treatment. Exclusion criteria were: studies with complications in the non-operative treatment of EOS, in vitro, or animal model studies. We also excluded all the remaining duplicates, articles dealing with other topics, and those with poor scientific methodology, or without an accessible abstract. Reference lists were also manually searched for further relevant studies. Reviews, abstracts, case reports, conference presentations, and expert opinions, were excluded.

All papers were tagged: (1) according to the system used: TGR, VEPTR, MCGR, Shilla (guided growth); (2) the number of cases as a “big group” – more than 30 cases, “medium group” – 10-29 cases, and “small group” – less than 10 cases; and (3) the time of follow-up – “short” – less than 2 years, “minimum” – more than 2 years, and “optimum” – more than 5 years. The final inclusion criteria were primarily limited to “big group” and “optimum follow-up”. During the paper extraction, no papers with VEPTR, and only one with Shilla and MCGR, were found, so that the groups’ extracted papers had to be extended with “medium group” and “minimum” follow-up.

Data extraction and criteria appraisal

Three investigators independently reviewed each article. Discrepancies between the reviewers were resolved by discussion and consensus. All data were extracted from article texts, tables, and figures, and put into tables in an Excel sheet.

Complications were categorized as wound-related, implant-related, alignment-related, and general (surgical or medical). Surgical procedures were classified as planned [implantations, lengthenings, final fusions (FF)], and unplanned (revisions). Implantation procedures were included as equal to the number of patients. Not-given information was calculated using specific formulas based on the known data, *i.e.*, the mean number of operations per patient, the number of patients, and the number of operations. Some data – especially in TGR-group patients – like the number of lengthenings and derived information – were estimated based on the mean duration between lengthenings, using formulas, *i.e.*, the mean duration between lengthenings, and follow-up, *i.e.* the number of lengthenings. The mean durations between lengthenings, if not specified, were taken as the mean value of durations between lengthenings specified in other papers. These data were marked in the table with the symbol “1”. In some papers the number of unplanned surgeries was not provided. In those cases, such complications as deep infections and implant fractures were estimated as an indication of at least one revision/unplanned surgery. Some fields were left empty when there were not enough data to estimate the value. When the data in the main text and the tables did not match, the higher value was taken.

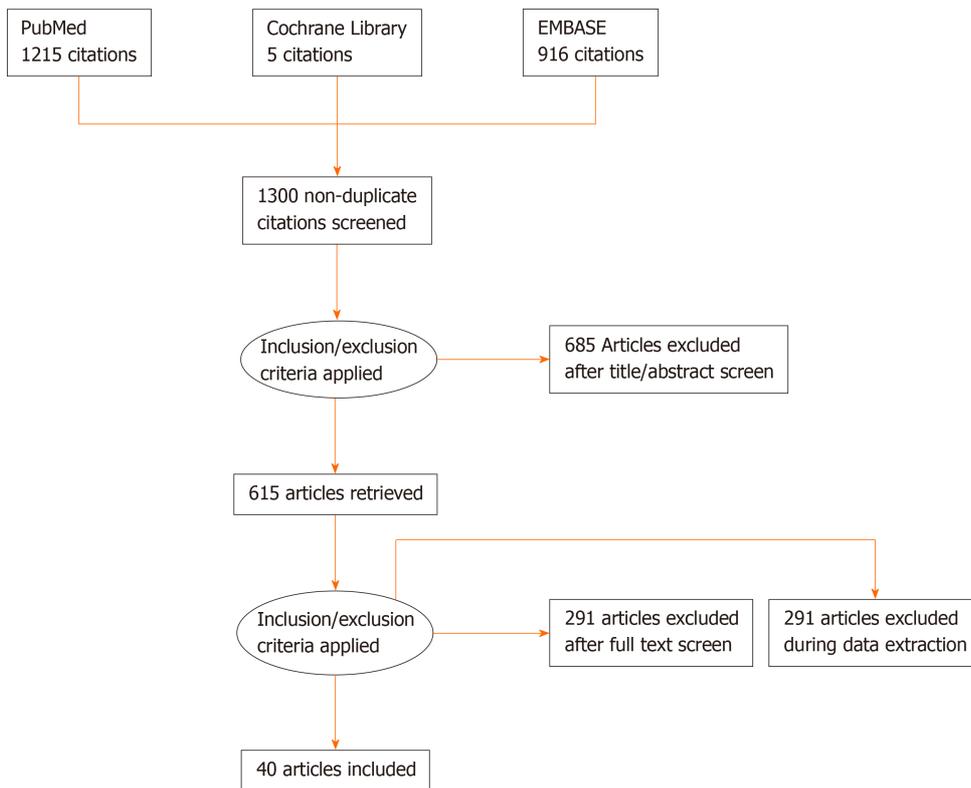


Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart of the method of selection and screening.

RESULTS

Included studies

A total of 2136 articles were found. After the exclusion of duplicates, 1300 articles were selected. At the end of the first screening, following the previously described selection criteria, we selected 615 articles eligible for full-text reading. Ultimately, after full-text reading and reference-list checks, we selected $n = 40$ articles, following previously adopted criteria. A PRISMA flowchart of the method of selection and screening is presented in Figure 1. The included articles focus on complications in the most commonly used systems – TGR (17 papers), VEPTR (13 papers), MCGR (8 papers), and Shilla (guided growth) (7 papers). Data extracted from these papers were assigned to the appropriate system. Harris *et al*[8], 2020, in their paper analyzed the impact of patient and surgical factors on the proximal complications and revision rates of early-onset scoliosis patients using a multicenter database. Total 353 patients met the inclusion criteria: growing rods = 318 and VEPTR = 35. Helenius *et al*[9], 2018, analyzed the outcomes of surgeries using growing rods in patients with severe *vs* moderate early-onset scoliosis. From the group of 214 patients, 198 were treated with TGR and 14 with MCGR. As in the main texts, the data were not separated out, so we included them in the TGR group, as the vast majority were treated with this system. Papers by Akbarnia *et al*[10], Bachabi *et al*[11], Haapala *et al*[12], Andras *et al*[13], and Luhmann *et al*[14], dealt with comparisons between TGR and MCGR, TGR, and VEPTR, Shilla and MCGR, and TGR and Shilla, respectively, so they appear in the table for the applicable system. The demographic findings of the included articles are summarized in Table 1.

Tables 2-5 present the number of surgical procedures (planned and unplanned). The number of patients is re-listed for easier reference to the remaining data. As the quantitative data depends on the number of analyzed patients, the second part of the table presents the percentage data. It shows the percentage of unplanned surgeries, the percentage of unplanned surgeries to all surgeries, the percentage of unplanned surgeries to patients with at least one complication, and the ratio of planned to unplanned surgeries. Eight papers were excluded from these tables, as there were no data on unplanned surgeries. Some fields were left empty if there were insufficient data. From the 40 analyzed papers 12 described all 4 complications (wound and implant-related, alignment, and medical/surgical). These data are marked in the table with the symbol “2”. In the others, some of these complications were not described. It

Table 1 Demographic data from the reviewed articles

Ref.	Construct	Subject	Sex (male/female)	Age at IP	Follow up	Diagnosis	No of patient with final spinal fusion	Comments, kind of complication analyzed	
1	Bess <i>et al</i> [15], 2010	TGR	140	71/59	6	5.0	Neuromuscular (<i>n</i> = 52), idiopathic (<i>n</i> = 40), congenital (<i>n</i> = 24), and other (<i>n</i> = 24)	50	W, I, A, M
2	Du <i>et al</i> [16], 2020		167	69/98	7.2	10.7	Idiopathic (<i>n</i> = 45), neuromuscular (<i>n</i> = 56), syndromic (<i>n</i> = 43), congenital (<i>n</i> = 21), other (<i>n</i> = 2)	167	Analyzed patients who had undergone a FF after growing-rod treatment, W, I, A, M
3	Andras <i>et al</i> [13], 2015		36	nd	6.1	4.3	Syndromal (<i>n</i> = 10), idiopathic (<i>n</i> = 11), congenital (<i>n</i> = 2), neuromuscular (<i>n</i> = 13)	nd	I, M
4	Myung <i>et al</i> [17], 2014		159	nd	5	4.7	Neuromuscular (<i>n</i> = 46), congenital (<i>n</i> = 42), idiopathic (<i>n</i> = 37), syndromal (<i>n</i> = 34)	nd	I
5	Arandi <i>et al</i> [18], 2014		175	78/97	5.9	5.2	Idiopathic (<i>n</i> = 69), syndromal (<i>n</i> = 62), neuromuscular (<i>n</i> = 44)	nd	I
6	Liang <i>et al</i> [19], 2015		55	16/39	6.8	38.4	Congenital (<i>n</i> = 28), idiopathic (<i>n</i> = 6), syndromal (<i>n</i> = 8), neuromuscular (<i>n</i> = 6) and miscellaneous disorders (<i>n</i> = 7)	10	W, I, A, M
7	Ramirez <i>et al</i> [20], 2020		67	32/35	6	4.1	Only non-ambulatory neuromuscular early-onset scoliosis	nd	W, I, M
8	Yamaguchi <i>et al</i> [21], 2014		176	nd	nd	4.7	Congenital (<i>n</i> = 48), neuromuscular (<i>n</i> = 42), syndromal (<i>n</i> = 37), idiopathic scoliosis (<i>n</i> = 32) and miscellaneous (<i>n</i> = 17)	nd	I
9	Poe-Kochert <i>et al</i> [22], 2016		100	42/58	7	4.3	Neuromuscular (<i>n</i> = 38), syndromic (<i>n</i> = 31), idiopathic (<i>n</i> = 22), congenital (<i>n</i> = 9)	100	Analyzed patients who had undergone a FF after growing-rod treatment; W, I
10	Kabirian <i>et al</i> [23], 2014		379	177/202	6.3	5.3	nd	nd	Only deep infection analyzed
11	Hosseini <i>et al</i> [24], 2018		274	114/160	6.7	6.3	Neuromuscular (<i>n</i> = 84), congenital (<i>n</i> = 43), syndromic (<i>n</i> = 89), idiopathic (<i>n</i> = 58)	nd	I
12	Johnston <i>et al</i> [25], 2013		27	nd	5.3	4.5	Neuromuscular (<i>n</i> = 6), idiopathic (<i>n</i> = 11), syndromic (<i>n</i> = 10)	6	Comparing with cast treatment, complications in total
13	Bachabi <i>et al</i> [11], 2020		50	nd	5.5	8.3	nd	nd	W, I, A, M
14	Luhmann <i>et al</i> [14], 2017		18	18	7.7	7.4	Idiopathic (<i>n</i> = 9), neuromuscular (<i>n</i> = 7), syndromic (<i>n</i> = 1), congenital (<i>n</i> = 1)	17	W, I, M
15	Akbarnia <i>et al</i> [10], 2014		12	5	6.5	4.1	Not given	nd	W, I, M
16	Harris <i>et al</i> [8], 2020		353	nd	6	6.0	Not given	nd	I, TGR -318 cases, 35 - VEPTR cases
17	Helenius <i>et al</i> [9], 2018		214	94/120	5.6	6.0	Neuromuscular (<i>n</i> = 68), congenital (<i>n</i> = 28), syndromic (<i>n</i> = 74), idiopathic (<i>n</i> = 44)	49	W, I, M TGR cases 198) MCGR cases 16
18	Gadepalli <i>et al</i> [26], 2011	VEPTR	26	16/10	7.58	7.0	Congenital or infantile scoliosis (<i>n</i> = 12), neuromuscular scoliosis (<i>n</i> = 5), unspecified structural thoracic disorder (<i>n</i> = 7), Jeune syndrome (<i>n</i> = 2)	nd	W, I, M
19	Bachabi <i>et al</i>		22	nd	4.3	7.7	nd	nd	W, I, M

	[11], 2020								
20	Crews <i>et al</i> [27], 2018		151	16/6	7.1	3+	nd	nd	Only SSIs following VEPTR implant or revision surgeries were identified
21	Murphy <i>et al</i> [28], 2016		25	12/13	5.7	4.5	Congenital (<i>n</i> = 25)	nd	W, I, M
22	Berger-Groch <i>et al</i> [29], 2020		13	7/6	2.2	7.6	Congenital (<i>n</i> = 13)	nd	W, I, M
23	Hasler <i>et al</i> [30], 2010		23	8/15	6.5	3.6	Early onset idiopathic scoliosis (<i>n</i> = 1), neuromuscular (<i>n</i> = 11), post-thoracotomy scoliosis (<i>n</i> = 2), Sprengel deformity (<i>n</i> = 1), hyperkyphosis (<i>n</i> = 2), myopathy (<i>n</i> = 1), syndromic (<i>n</i> = 5)	nd	W, I, A, M
24	Latalski <i>et al</i> [31], 2011		12	nd	5.25	2.5	Congenital (<i>n</i> = 3), neuromuscular (<i>n</i> = 9)	0	W, I, A, M
25	Hell <i>et al</i> [32], 2005		15	8/7	6	nd	Congenital (<i>n</i> = 9), neuromuscular (<i>n</i> = 6)	0	W, I, M
26	Garg <i>et al</i> [33], 2014		103	57/46	5.3		Neuromuscular (<i>n</i> = 30), congenital (<i>n</i> = 44), syndromic (<i>n</i> = 18), idiopathic (<i>n</i> = 11)		Only wound complications following VEPTR implant or revision surgeries were identified
27	Waldhausen <i>et al</i> [34], 2016		65	nd	6.9	6.9	Congenital (<i>n</i> = 23), neuromuscular (<i>n</i> = 12), syndromic (<i>n</i> = 14), idiopathic (<i>n</i> = 2), other (<i>n</i> = 14)	28	W, I, M
28	Striano <i>et al</i> [35], 2019		166		6.81		Neuromuscular (<i>n</i> = 61), syndromic (<i>n</i> = 38), congenital (<i>n</i> = 64), idiopathic (<i>n</i> = 3)	nd	Only wound complications following VEPTR implant or revision surgeries were identified
29	Lucas <i>et al</i> [36], 2013		54	21/33	7	2.0	Neuromuscular (<i>n</i> = 19), congenital (<i>n</i> = 30), syndromic (<i>n</i> = 7), idiopathic (<i>n</i> = 3)	nd	W, I, A, M
30	Garg <i>et al</i> [37], 2016		38	22/16	5.51	4.1	Neuromuscular (<i>n</i> = 18), congenital (<i>n</i> = 13), syndromic (<i>n</i> = 5), idiopathic (<i>n</i> = 2)	nd	Only wound complications following VEPTR implant or revision surgeries were identified
31	Subramanian <i>et al</i> [38], 2018	MCGR	31	15/16	7.7	3.9	Neuromuscular (<i>n</i> = 4), syndromic (<i>n</i> = 19), idiopathic (<i>n</i> = 6), congenital (<i>n</i> = 2)	nd	W, I, A, M
32	Urbański <i>et al</i> [39], 2020		47	14/18	8.8	1-2.5	Neuromuscular (<i>n</i> = 10), syndromic (<i>n</i> = 11), idiopathic (<i>n</i> = 20), congenital (<i>n</i> = 6)	0	W, I, A, M
33	Akbarnia <i>et al</i> [10], 2014		12	5/7	6.8	2.5	Neuromuscular (<i>n</i> = 4), syndromic (<i>n</i> = 4), idiopathic (<i>n</i> = 3), congenital (<i>n</i> = 1)	nd	I, M
34	Studer <i>et al</i> [40], 2019		30	10/20	9.4	2.1	Congenital (<i>n</i> = 11), neuromuscular (<i>n</i> = 10), syndromic (<i>n</i> = 4), idiopathic (<i>n</i> = 5)	nd	W, I, A
35	Kwan <i>et al</i> [41], 2017		30	11/19	7.3	3.0	Syndromal (<i>n</i> = 8), idiopathic (<i>n</i> = 8), congenital (<i>n</i> = 6), neuromuscular (<i>n</i> = 8)	5	W, I, A,
36	Obid <i>et al</i> [42], 2020		22	4/18	9.5	4.0	Idiopathic (<i>n</i> = 14), neurofibromatosis (<i>n</i> = 2), neuromuscular and syndromic (<i>n</i> = 6)	9	W, I, A, M
37	Lampe <i>et al</i> [43], 2019		24	7/17	10.5	3.5	Syndromal (<i>n</i> = 4), idiopathic (<i>n</i> = 9), congenital (<i>n</i> = 1), neuromuscular (<i>n</i> = 10)	nd	W, I, A, M

38	Haapala <i>et al</i> [12], 2020		18	11/7	6.8	3.2	Neuromuscular (<i>n</i> = 12) II, syndromic (<i>n</i> = 8) EOS two NFI (<i>n</i> = 2)	5	I, A, M
39	Haapala <i>et al</i> [12], 2020	Shilla	13	8/5	6	4.0	Neuromuscular (<i>n</i> = 11), syndromic (<i>n</i> = 2)	4	W, I, M
40	Andras <i>et al</i> [13], 2015	Shilla	36	nd	6.1	4.6	Syndromal (<i>n</i> = 10), idiopathic (<i>n</i> = 11), congenital (<i>n</i> = 2), neuromuscular (<i>n</i> = 13)	nd	I, M
41	Nazareth <i>et al</i> [44], 2020	Shilla	20	10/10	5.7	5.2	Syndromic (<i>n</i> = 9), neuromuscular (<i>n</i> = 5), idiopathic (<i>n</i> = 3), congenital (<i>n</i> = 3).	7	W, I, M
42	Miękisiak <i>et al</i> [45], 2019	GGs	57	13/44	9.8	2+	Not given	nd	GGs - the same principle as Shilla. System made of Ti. W, I, A, M
43	McCarthy <i>et al</i> [46], 2014	Shilla	10	2/8	7.5	2.0	Idiopathic (<i>n</i> = 3), congenital scoliosis (<i>n</i> = 1), syndromic (<i>n</i> = 2), neuromuscular scoliosis (<i>n</i> = 4)	nd	W, I
44	Luhmann <i>et al</i> [14], 2017	Shilla	18	nd	7.9	6.1	Idiopathic (<i>n</i> = 8), neuromuscular (<i>n</i> = 7), syndromic (<i>n</i> = 3)	15 and 3 implant removals	W, I, M
45	McCarthy <i>et al</i> [47], 2015	Shilla	40	17/23	6.11	5.0	Idiopathic (<i>n</i> = 9), congenital (<i>n</i> = 1), neuromuscular (<i>n</i> = 16), syndromic (<i>n</i> = 14)	15 and 3 Implant removals	W, I, A

Type of complications: Wound (W), implant-related (I), alignment (A), and medical/surgical complications (M). FF: Final fusions; GGS: Growth guidance system; VEPTR: Vertical expandable prosthetic titanium ribs; TGR: Traditional growing rods; MCGR: Magnetically controlled growing rods.

probably means that the number of unplanned surgeries was understated.

Excluded from these tables were papers in which the number of unplanned surgeries was not specified, and were not calculated; some cases referred to final fusion, but it was not specified when, so the total number based on the duration between lengthenings was not possible to estimate.

Unplanned surgeries are due to complications which cannot be resolved conservatively. The total number of complications is much higher. Table 6 presents the total number of complications, the number of patients with a minimum of one complication, the percentage of complications in all patients, the percentage of patients with a minimum of one complication, the number of complications in complicated patients, the complication rate per surgical procedure in percentage terms, and the percentage complications requiring surgical procedures. Some cells in the table are empty because of insufficient data in the corresponding papers.

In Table 7 the total number of complications are divided into wound-related, implant-related, alignment, and surgical/medical-related. Only 12 out of 40 papers include analyses of all these types. The paper by Johnston *et al*[25], 2013, did not differentiate the types of complications, so this reference was excluded from Table 7.

Smith *et al*[48] published in 2015 a New Classification System to Report Complications in Growing Spine Surgery, and only 4 out of 23 papers published in 2016 used this system (Table 8).

DISCUSSION

Currently there is great interest in the concept of the continued growth of the spine and chest while treating spinal deformity in EOS patients. The risk of complications is inherent in correction surgeries, regardless of etiology. Many studies agree that in the case of neuromuscular scoliosis the probability of a complication is 35%, while for EOS the probability increases to 48%[49]. Watanabe *et al*[50] identified risk factors for complications in the treatment of early-onset scoliosis using the dual growing rod technique. Postoperative complications occurred after 119 out of 538 procedures (22%) and affected 50 patients (57%). Complications mostly included implant-related failures (72%), and infections (16%). The authors suggested that independent risk factors for postoperative complications included an increase of every 20° in the proximal thoracic Cobb angle, an increase of every 20° in the thoracic kyphosis angle, and 6 or more rod-

Table 2 The number of planned and unplanned surgical procedures in the traditional growing rods group

Ref.	Subject	Surgical procedures (n)	Planned surgical procedures (n)	Unplanned surgical procedure		% unplanned surgeries to all surgeries	% unplanned surgery to patients with at least one complication	Ratio of planned to unplanned surgery
				n	%			
Bess <i>et al</i> [15], 2010	140	897	823	74	52.9 ²	8.2 ²	91.4 ²	11.12
Du <i>et al</i> [16], 2020	167	199	167	32	19.2 ³	16.1 ³	100.0 ³	5.22
Andras <i>et al</i> [13], 2015	36	288	259	29	80.6	10.1	100.0	8.9
Myung <i>et al</i> [17], 2014	159	1081 ¹	1050 ¹	31 ¹	19.5	2.9	83.8	33.87
Arandi <i>et al</i> [18], 2014	175	1247 ¹	1190	57 ¹	32.6	4.6	71.3	20.88
Liang <i>et al</i> [19], 2015	55	272	263	23 ¹	41.8 ²	8.5 ²	100.0 ²	11.43
Ramirez <i>et al</i> [20], 2020	67	463 ¹	396 ¹	67	100	14.5	163.4	5.91
Poe-Kochert <i>et al</i> [22], 2016	100	157 ¹	100 ¹	57	57 ³	36.3 ³	285.0 ³	1.75
Kabirian <i>e et al</i> [23], 2014	379	2344	2274 ¹	70	18.5	3.0	166.7	32.49
Luhmann <i>et al</i> [14], 2017	18	167	141	26	144.4	15.6		5.42
Akbarnia <i>et al</i> [10], 2014	12	73	68	5	41.7	6.8	45.5	13.6
Harris <i>et al</i> [8], 2020	353	3141 ¹	2895 ¹	246	69.7	7.8	174.5	11.77
Helenius <i>et al</i> [9], 2018	214	1971	1836	133	62.1	6.7	137.1	13.8

¹Data estimated based on the mean values of duration between lengthenings.

²The values of the % of unplanned surgeries in which all four complications were analyzed in the paper.

³Corresponds to the papers in which all the patients were after the final fusion.

lengthening procedures. According to Bess *et al*[15], the patients' early age when carrying out the index surgery influenced the incidence of complications, but Watanabe did not confirm this. He believed that a patient's being young at the time of the index surgery significantly reduced the risk of the child's developing a significant deformity, the degree of which at the start of the treatment significantly affects the risk of its course. However, one should be aware of the inverse relationship between the age of the index surgery and the number of lengthenings in distraction-based methods [4].

Bess, and the Growing Spine Study Group, stated in publications that there was a 24% complication rate each time a growing-rod construct was surgically lengthened, and a 13% decrease in complications for each additional year of age at the time of the initial growing rod implantation[15]. Rod implantation below age 7 years, increasing kyphosis, and more severe major curve magnitude, have been shown to correlate with a higher rate of complications overall[51].

Surgical difficulties, as well as the potentially harmful effect of repeated anesthesia, have led to the adoption of magnetically controlled growing rods, and guided growth systems like Shilla. However, problems with the loss of fixation and failure of the implants in some cases persist[10,47]. Some authors have pointed out an additional problem connected with metal debris which appears in the serum and surrounding tissues[52]. Although it does not directly affect the outcome of the treatment, it is worth considering this occurrence as undesirable/a complication.

The most important issue is that authors define complications in different ways. In Andras *et al*[13], major complications are defined as any neurological injury and any

Table 3 The number of planned and unplanned surgical procedures in the vertical expandable prosthetic titanium ribs group

Ref.	Subject	Surgical procedures (n)	Planned surgical procedures (n)	Unplanned surgical procedure		% unplanned surgeries to all surgeries	% unplanned surgery to patients with at least one complication	Ratio of planned to unplanned surgery
				n	%			
Murphy <i>et al</i> [28], 2016	25	232	188	40	160	17.2	266.7	4.69
Gadepalli <i>et al</i> [26], 2011	26	100	86	14	53.8	14.0		6.14
Berger-Groch <i>et al</i> [29], 2020	13	182	178	5	38.5	2.7		35.6
Hasler <i>et al</i> [30], 2010	23	187	172	15	65.2 ²	8.0 ²	166.7 ²	11.47
Latalski <i>et al</i> [31], 2011	12	44	38	6	50 ²	13.6 ²	75.0 ²	6.33
Striano <i>et al</i> [35], 2019	166	670	560	110	66.3	16.4	275.0	5.09
Lucas <i>et al</i> [36], 2013	54	184	152	30	55.6 ²	16.3 ²	83.3 ²	5.07
Garg <i>et al</i> [37], 2016	38	410	350 ¹	60 ¹	157.9	14.6		5.83

¹Data estimated based on the mean values of duration between lengthenings.

²The values of the % of unplanned surgeries in which all four complications were analyzed in the paper.

Table 4 The number of planned and unplanned surgical procedures in the magnetically controlled growing rods group

Ref.	Subject	Surgical procedures (n)	Planned surgical procedures (n)	Unplanned surgical procedure		% unplanned surgeries to all surgeries	% unplanned surgery to patients with at least one complication	Ratio of planned to unplanned surgery
				n	%			
Subramanian <i>et al</i> [38], 2018	31	53	31	22	71 ²	41.5 ²	104.8	1.41
Urbański <i>et al</i> [39], 2020	47	60	47	13	27.7 ²	21.7 ²	81.3	3.62
Akbarnia <i>et al</i> [10], 2014	12	16	12	4	33.3	25.0	100.0	3
Studer <i>et al</i> [40], 2019	30	43	30	13	43.3	30.2	118.2	2.31
Kwan <i>et al</i> [41], 2017	30	44	30	14	46.7	31.8	100.0	2.14
Obid <i>et al</i> [42], 2020	22	46	19	5	22.7 ²	10.9 ²	41.7 ²	3.8
Lampe <i>et al</i> [43], 2019	24	43	24	19	79.2 ²	44.2 ²	172.7 ²	1.26

²The values of the % of unplanned surgeries in which all four complications were analyzed in the paper.

issue requiring surgery for implant revision or infection. In Ramirez *et al* [20], complications are defined as any change from the normal postoperative course which occurred from the time of the surgery until the most recent follow-up visit. In McCarthy *et al* [47], 2015, complications are defined as any problem requiring a return to the operating room, so all returns to the operating room were considered unanticipated. Some authors report major complications and some report the whole range of general complications.

Table 5 The number of planned and unplanned surgical procedures in guided growth group – the Shilla and growth guidance system groups

Ref.	Subject	Surgical procedures (n)	Planned surgical procedures (n)	Unplanned surgical procedure		% unplanned surgeries to all surgeries	% unplanned surgeries to patients with at least one complication	Ratio of planned to unplanned surgery
				n	%			
Haapala <i>et al</i> [12], 2020	13	19	17	2	15.4	10.5	40.0	8.5
Andras <i>et al</i> [13], 2015	36	101	36	65	180.6	64.4	224.1	0.55
Nazareth <i>et al</i> [44], 2020	20	41	20	21	105	51.2	140.0	0.95
Miękisiak <i>et al</i> [45], 2019	57	82	57	25	43.9 ²	30.5 ²		2.28
McCarthy <i>et al</i> [46], 2014	10	15	10	5	50	33.3	100.0	2
Luhmann <i>et al</i> [14], 2017	18	56	36	20	111.1			1.8
McCarthy <i>et al</i> [47], 2015	40	109	58	51	127.5			1.14

²The values of the % of unplanned surgeries in which all four complications were analyzed in the paper.

For this study, complications were categorized as wound, implant, alignment, or general [surgical or medical]. Wound problems were classified as either superficial or deep infections, and other wound-related problems, such as painful scars. Implant complications included rod breakage, failure of foundation fixation such as hook or screw pullout, and implant prominence. Alignment complications included junctional kyphosis (proximal or distal), curve progression above or below the instrumented levels, and curve progression after definitive fusion. General complications included, but were not limited to, dural tears, hematomas, and postoperative cardiopulmonary and gastrointestinal complications. Unfortunately, not all authors evaluated all these kinds of complications together – 4 out of 17 in TGR, 3 out of 13 in VEPTR, 4 out of 8 in MCGR, and 1 out of 7 in Shilla. Only 16 out of 44 papers (36%) referred to alignment complication in the evaluation – mostly in MCGR (88%), and conversely to VEPTR (23%). Five papers (11%) (TGR) described only implant-related complications, and 5 only wound-related (4 VEPTR and 1 TGR). The most frequently evaluated set of complications were wound, implant, and medical-related – 13 papers (30% of the papers). The original idea of the paper was to evaluate the number of procedures used to treat complications categorized as either planned or unplanned. Planned procedures were defined as procedures which were scheduled as part of the routine growing-rod-treatment protocol. Unplanned procedures were defined as unscheduled surgical procedures performed to manage a complication. Unfortunately, there was no division into such treatments, so the data were simplified and surgical procedures were classified as planned (implantations, lengthenings, final fusions) and unplanned (revisions). In that case, the number of complications requiring surgical treatment could have been greater, as some of them could have been repaired during the planned lengthening procedure. Only 10 papers (23%) (2 TGR, 3 VEPTR, 4 MAGEC, 1 Shilla) included data with unplanned surgeries, and all described complications concurrently. FF significantly influenced the number of surgeries. Despite the number of patients with FFs being known, there were no data about the time of the FFs – so estimated data based on the mean follow-up times and durations between lengthening procedures were understated. Deleting these references from the statements in question leaves 6 papers with no TGR patients. Adding Smith's classification for evaluation as a criterion further reduces the number of papers to only one. That is why the analysis had to be simplified.

TGRs constitute the most commonly applied technique, and are considered the gold standard for EOS with long curves [53]. In the reviewed papers, the complication rate per patient of the growing rod technique was very high and ranged from 19% to 208% (median 84%). Interestingly, Akbarnia *et al* [10], presented a complication rate of 208%

Table 6 Number of complications analyzed in extracted papers

Ref.	Subject	Total No. of complications	No. of patients with a minimum of one complication	% of complications in all patients	% of patients with a minimum one complication	No. of complications in complicated patients	Complication rate per surgical procedure (%)	% complications requiring surgical procedures
TGR								
Bess <i>et al</i> [15], 2010	140	171	81	122.1 ²	57.9 ²	2.1 ²	19.1 ²	43.3 ²
Du <i>et al</i> [16], 2020	167	49	32	29.3 ^{2,3}	19.2 ³	1.5 ³	nd	nd
Andras <i>et al</i> [13], 2015	36	47	29	130.6	80.6	1.6	16.3	61.7
Myung <i>et al</i> [17], 2014	159	64	37	40.3	23.3	1.7	5.9	48.4
Arandi <i>et al</i> [18], 2014	175	146	80	83.4	45.7	1.8	11.7	39.0
Liang <i>et al</i> [19], 2015	55	42	23	76.4 ²	41.8 ²	1.8 ²	15.4 ²	54.8 ²
Ramirez <i>et al</i> [20], 2020	67	92	41	137.3	61.2	2.2	19.9	72.8
Yamaguchi <i>et al</i> [21], 2014	176	44	26	25.0	14.8	1.7		
Poe-Kochert <i>et al</i> [22], 2016	100	30	20	30.0 ³	20.0 ³	1.5 ³	19.1 ³	190.0
Kabirian <i>et al</i> [23], 2014	379	70	42	18.5	11.1	1.7	3.0	
Johnston <i>et al</i> [25], 2013	27	23	12	85.2	44.4	1.9	12.8	
Bachabi <i>et al</i> [11], 2020	50	45	33	90.0 ²	66.0 ²	1.4 ²	9.4 ²	
Luhmann <i>et al</i> [14], 2017	18	26		144.4	nd		15.6	
Akbarnia <i>et al</i> [10], 2014	12	25	11	208.3	91.7	2.3	34.2	
Harris <i>et al</i> [8], 2020	353	264	141	74.8	39.9	1.9	nd	93.2
Helenius <i>et al</i> [9], 2018	214	216	97	100.9	45.3	2.2	11.0	61.6
VEPTR								
Bachabi <i>et al</i> [11], 2020	22	26	18	118.2	81.8	1.4	7.9	
Crews <i>et al</i> [27], 2018	151	26	22	17.2	14.6	1.2	8.0	
Murphy <i>et al</i> [28], 2016	25	41	15	164.0	60.0	2.7	17.7	97.6
Gadepalli <i>et al</i> [26], 2011	26	36	nd	138.5	nd	nd		38.9
Berger-Groch <i>et al</i> [29], 2020	13	21	nd	161.5	nd	nd	11.5	23.8
Hasler <i>et al</i> [30], 2010	23	31	9	134.8 ²	39.1 ²	3.4	16.6 ²	48.4
Latalski <i>et al</i> [31], 2011	12	15	8	125.0 ²	66.7 ²	1.9	34.1 ²	40.0
Hell, <i>et al</i>	15	3	3	20.0	20.0	1.0	10.7	

[32], 2005									
Garg <i>et al</i> [33], 2014	103	33	25	32.0	24.3	1.3	nd		
Waldhausen <i>et al</i> [34], 2016	65	37	22	56.9	33.8	1.7			
Striano <i>et al</i> [35], 2019	166	47	40	28.3	24.1	1.2	7.0	234.0	
Lucas <i>et al</i> [36], 2013	54	74	36	137.0 ²	66.7 ²	2.1 ²	40.2 ²	40.5	
Garg <i>et al</i> [37], 2016	38	86		226.3	nd			69.8	
MCGR									
Subramanian <i>et al</i> [38], 2018	31	25	21	80.6 ²	67.7 ²	1.2 ²	47.2 ²	88.0	
Urbański <i>et al</i> [39], 2020	47	17	16	36.2 ²	34.0 ²	1.1 ²	28.3 ²	76.5	
Akbarnia <i>et al</i> [10], 2014	12	12	4	100.0	33.3	3.0	75.0	33.3	
Studer <i>et al</i> [40], 2019	30	12	11	40.0	36.7	1.1	27.9	108.3	
Kwan <i>et al</i> [41], 2017	30	15	14	50.0	46.7	1.1	34.1	93.3	
Obid <i>et al</i> [42], 2020	22	12	12	54.5 ²	54.5 ²	1.0 ²	26.1 ²	41.7	
Lampe <i>et al</i> [43], 2019	24	20	11	83.3 ²	45.8	1.8	46.5	95.0	
Haapala <i>et al</i> [12], 2020	18	10	6	55.6	33.3	1.7	20.0		
Shilla									
Haapala <i>et al</i> [12], 2020	13	5	5	38.5	38.5	1.0	26.3		
Andras <i>et al</i> [13], 2015	36	69	29	191.7	80.6	2.4	68.3		
Nazareth <i>et al</i> [44], 2020	20	31	15	155.0	75.0	2.1	75.6		
Miękisiak <i>et al</i> [45], 2019	57	57		100.0 ²	0.0		69.5		
McCarthy <i>et al</i> [46], 2014	10	5	5	50.0	50.0	1.0	33.3		
Luhmann <i>et al</i> [14], 2017	18	20		111.1	0.0		35.7		
McCarthy <i>et al</i> [47], 2015	40	59	38	147.5	95.0	1.6	54.1		

²The values of the % of unplanned surgeries in which all four complications were analyzed in the paper.

³Corresponds to the papers in which all patients were after final fusion.

TGR: Traditional growing rods; VEPTR: Vertical expandable prosthetic titanium ribs; MCGR: Magnetically controlled growing rods.

(wound, implant-related and medical) in only 12 patients, whereas the rate for deep infections was 19% in 379 cases[23]. Comparing only implant-related complications, this parameter varied from 25% [21] to 40% [17], to 83% [18] – the authors analyzed a similar group of approximately 160 patients. The complication rate per surgical procedure varied from 3% to 34% (median 15%). There were two complications in complication-affected patients. In the analyzed papers, an average of 946 surgical procedures were performed. The incidence of unplanned surgeries in all patients varied from 19% to 144% (median 53%). The percentage of unplanned surgeries for all surgeries was 8% (3%-36%). The ratio of planned to unplanned surgeries was 11.6% (1.8%-33.9%). The most frequent complications were implant-related (61%) and

Table 7 Total number of complications divided into wound-related, implant-related, alignment and surgical/medical related

Ref.	Total No. of complications	Wound complications total/infection		Implant complications mechanical complication		Alignment complications		Surgical or medical complications	
		<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
TGR									
Bess <i>et al</i> [15], 2010	171	34	20	105	61	10	6	22	13
Du <i>et al</i> [16], 2020	49	19	39	13	27	9	18	8	16
Andras <i>et al</i> [13], 2015	32			24	75			8	25
Myung <i>et al</i> [17], 2014	64			64	100				
Arandi <i>et al</i> [18], 2014	146			146	100				
Liang <i>et al</i> [19], 2015	42	5	12	25	60	4	10	8	19
Ramirez <i>et al</i> [20], 2020	92	49	53	30	33			13	14
Yamaguchi <i>et al</i> [21], 2014	44			44	100				
Poe-Kochert <i>et al</i> [22], 2016	29	16	55	13	45				
Kabirian <i>et al</i> [23], 2014	70	70	100						
Hosseini <i>et al</i> [24], 2018	134			134	100				
Bachabi <i>et al</i> [11], 2020	45	7	16	28	62	2	4	8	18
Luhmann <i>et al</i> [14], 2017	26	9	35	11	42			6	23
Akbarnia <i>et al</i> [10], 2014	25	4	16	13	52			8	32
Harris <i>et al</i> [8], 2020	264			264	100				
Helenius <i>et al</i> [9], 2018	216	40	19	127	59			49	23
VEPTR									
Bachabi <i>et al</i> [11], 2020	26	9	35	15	58			2	8
Crews <i>et al</i> [27], 2018	26	26	100						
Murphy <i>et al</i> [28], 2016	57	16	28	28	49			13	23
Gadepalli <i>et al</i> [26], 2011	25	6	24	3	12			16	64
Berger-Groch <i>et al</i> [29], 2020	24	1	4			2	8	21	88
Hasler <i>et al</i> [30], 2010	31	16	52	7	23	7	23	1	3
Latalski <i>et al</i> [31], 2011	15	1	7	7	47	1	7	6	40
Hell, <i>et al</i> [32], 2005	3	1	33	1	33			1	33
Garg <i>et al</i> [33], 2014	34	34	100						
Waldhausen <i>et al</i> [34], 2016	37	12	32	21	57			4	11
Striano <i>et al</i> [35],	47	47	100						

2019									
Lucas <i>et al</i> [36], 2013	49	11	22	28	57	7	14	3	6
Garg <i>et al</i> [37], 2016	86	86	100						
MCGR									
Subramanian <i>et al</i> [38], 2018	24	6	25	16	67	1	4	1	4
Urbański <i>et al</i> [39], 2020	16	2	13	8	50	1	6	5	31
Akbarnia <i>et al</i> [10], 2014	12			8	67			4	33
Studer <i>et al</i> [40], 2019	12	3	25	6	50	3	25		
Kwan <i>et al</i> [41], 2017	15	2	13	12	80	1	7		
Obid <i>et al</i> [42], 2020	12	1	8	3	25	7	58	1	8
Lampe <i>et al</i> [43], 2019	20	3	15	7	35	6	30	4	20
Haapala <i>et al</i> [12], 2020	10			6	60	1	10	3	30
Shilla									
Haapala <i>et al</i> [12], 2020	5	1	20	3	60			1	20
Andras <i>et al</i> [13], 2015	56			55	98			1	2
Nazareth <i>et al</i> [44], 2020	31	4	13	26	84			1	3
Miękisiak <i>et al</i> [45], 2019	57	3	5	34	60	10	18	10	18
McCarthy <i>et al</i> [46], 2014	5	2	40	3	60				
Luhmann <i>et al</i> [14], 2017	20	6	30	13	65			1	5
McCarthy <i>et al</i> [47], 2015	59	6	10	42	71	11	19		

TGR: Traditional growing rods; VEPTR: Vertical expandable prosthetic titanium ribs; MCGR: Magnetically controlled growing rods.

wound-related (27%), while medical complications and alignments accounted for 19% and 8%, respectively. The most concerning problem related to TGRs is the high complication rate. The risks for implant failure, infections, and wound healing problems are significantly increased as a consequence of the repeated lengthening procedures and an unfused spine. If rod breakage or screw displacement occurs, revision surgeries are indicated to change the rod or extend the instrumented segments. Additionally, repeated general anesthesia can pose a threat to mental health. Adequate informed consent and close follow-ups are necessary.

VEPTR was developed for patients with thoracic insufficiency syndrome (TIS), but it is sometimes indicated for individuals with EOS who are at risk of secondary TIS[54, 55]. The complication rate per patient was as high as 125% (17%-226%) with a 9% rate per surgical procedure (7%-18%). Such a discrepancy is very confusing. Garg *et al*[37] identified only wound complications following VEPTR implant or revision surgeries. If so, adding implant, alignment, and medical-related complications, the final percentage of complications should be expected at a much higher level. On the other hand, Crews *et al*[27] analyzed wound, implant, and general complications at the level of 17%. The most frequent complications were implant-related 48%, and wound-related 33%, while medical complications and alignments accounted for 23% and 11%, respectively. which limits their applications. In the analyzed papers, an average of 251 surgical procedures were performed. The percentage of unplanned surgeries in all patients varied from 39% to 160% (median 60%). The percentage of unplanned

Table 8 Complication grades according to Smith

Ref.	Total No. of complications	Related to disease				Related to device				
		Complication grade I	Complication grade II	Complication grade III	Complication grade IV	Complication grade I	Complication grade IIA	Complication grade IIB	Complication grade III	Complication grade IV
Ramirez <i>et al</i> [20], 2020	92					8	8	17	4	4
Murphy <i>et al</i> [28], 2016	57	5	6	2	1	13	8	3	4	
Studer <i>et al</i> [40], 2019	12					2	7			
Miękisiak <i>et al</i> [45], 2019	57	32	17	8	0					

surgeries to all surgeries was 14% (3%-17%). The proportion of planned to unplanned surgeries was 6% (4.7%-35.6%).

MCGRs were introduced by Takaso *et al*[56] in 1998 as remote-controlled growing-rod spinal instrumentation. The system did not require open lengthening as TGRs did, and the effect could instead be achieved by external remote control without repeated anesthesia. The complication rate of the magnetically controlled growing rod technique per patient varied from 36% to 100% (median 55%). In this group of patients, the distribution of complications is fairly homogeneous. Only Akbarnia *et al* [10] described such a high level of complications while omitting wound-related and alignment problems. The complication rate per surgical procedure varied from 20% to 75% (median 31%). In the analyzed papers, an average of 44 surgical procedures were performed. The percentage of unplanned surgeries in all patients varied from 23% to 79% (median 43%). The percentage of unplanned surgeries in all surgeries was 30% (11%-34%). The ratio of planned to unplanned surgeries was 2.3 (1.3-3.8). The most frequently occurring complication was implant-related – 55%, then general (25%), wound (14%), and alignment (10%). La Rosa *et al*[57] stated that MCGRs can prevent surgical scarring, surgical site infections, and psychological distress, which occur in patients with TGRs and VEPTR due to the multiple surgeries. The decreased rate of infections and wound healing problems in patients who received MCGRs is of great benefit to patients. However, Aslan *et al*[58] used psychosocial tools to compare the mental state of patients receiving MCGRs and TGRs. He affirmed that if the patient noticed benefit from the growing rods, and did not experience major complications, the non-invasiveness of the lengthening procedures did not show an advantage on the patients’ psychosocial state. Besides, although MCGRs were associated with a lower rate of infections [both deep and superficial], they were associated with a significantly increased risk of metalwork problems and unplanned revisions[59].

The Shilla technique guides spinal growth towards a normal alignment[60]. The technique first corrects the apical deformity towards a neutral alignment. Then the upper and lower growth guidance portions extend into the distal and proximal areas of the curve, using special screws and caps, allowing the rod to slide with growth in a longitudinal direction. Multiple open lengthening surgeries are avoided, as in MCGRs. The complication rate was as high as 111% of the patients (39%-192%), and the complication rate per surgical procedure was 54%. Haapala *et al*[12] showed the fewest complications - 39%. The remaining authors assessed the number of complications at a similar level. The most frequently appearing complications were implant-related (65%). Wound-related and alignment problems were 16% and 18%, respectively. General complications were only 5%. The percentage of unplanned surgeries in all patients varied from 15% to 181% (median 105%). The percentage of unplanned surgeries to all surgeries was 33% (11%-64%). The ratio of planned to unplanned surgeries was 1.8 (0.6-8.5). Luhmann *et al*[14] found that the Shilla growth guidance system compared favorably with TGRs in terms of the degree of correction of the major curve, spinal length, and growth, and the maintenance of the sagittal alignment. Looking at these data the benefits are not so obvious. Similar to MCGR and TGR, the SGGS is associated with a very high rate of implant-related complications, which usually results in revision surgery. Additionally, for patients with great growth potential, the distal and proximal screws can slide off the rod, requiring the rods to be changed.

EOS surgery has a varying but high rate of complications. Based on this review of 40 papers, 3249 cases, and 15037 surgical procedures, the most-frequent implant complications (total 54%), the general, wound, and alignment were 17%, 15%, and 12%, respectively. These data are simplified and certainly underestimated, because of the reasons described earlier. The rate of complications might have been higher than reported, as some authors did not report every type of complication. Due to complications, 54% of the patients required unplanned surgeries, which equated to 15% of all surgeries.

The long-term risks of EOS surgery have not yet been reported on in research. There is a lack of papers with homogenous cases, long-term follow-up, all revision surgeries, and complication data.

One would expect that successful treatment which encourages the growth of the spine and chest would lead to favorable outcomes in patients with early-onset idiopathic scoliosis. But it is not unambiguous with patients with, *e.g.*, progressive neuromuscular conditions such as congenital muscular dystrophies and spinal muscular atrophy. Surgery can effect spinal growth with expandable instrumentation, but worsening muscle weakness can negate the positive effects of growth-friendly procedures[2]. Tsirikos *et al*[61] showed that the life expectancy of patients with cerebral palsy and other neurogenic deformities subjected to deformation correction does not change, but only an additional source of data such as the number of days in the intensive care unit after surgery, and the presence of severe preoperative thoracic hyperkyphosis, were the only factors affecting survival rates.

As highlighted by Hawes[62], the complexity of spinal surgery is reflected in the diversity of complications which might occur months or even years later. Given the time delay and difficulty in diagnosis, it is likely that some of the events are not recognized as surgical complications. Therefore, clear uniformity of definitions and the carefulness of the surgeon are important in assessing patient follow-up and treatment outcomes.

CONCLUSION

The literature concerning the definitions, collection, and interpretation of data regarding EOS surgery complications is often difficult to interpret. This causes problems in the comparison, analysis, and improvement of spine surgery practice. Additionally, this observation indicates that data on the incidence of complications can be underestimated and should be interpreted with caution. Awareness of the high rate of complications of EOS surgery is crucial, and an optimal strategy for prevention should become a priority.

ARTICLE HIGHLIGHTS

Research background

The treatment for early-onset scoliosis (EOS) remains a great challenge for pediatric orthopedics. The treatment goals for EOS, regardless of the diagnosis, are the same: minimizing spinal deformity while maximizing thoracic volume and pulmonary function. When conservative treatment is ineffective, the option is surgery.

Research motivation

Different surgical techniques have different advantages and drawbacks. Those most often used are traditional growing rods (TGR), vertical expandable prosthetic titanium ribs (VEPTR), magnetically controlled growing rods (MCGR), and the Shilla growth guidance system (SGGS). Repeated surgeries and complications are two major concerns in EOS management.

Research objectives

The aim of the study was to review the current literature to assess the safety of EOS surgical treatment in terms of the rate of complications and unplanned surgeries.

Research methods

The systematic review was conducted according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. In January 2021, a search of three electronic medical databases (PubMed, the Cochrane Library, and Embase) was performed by three independent authors. We combined the terms: “early-onset scoliosis” OR “eos” OR “juvenile scoliosis” OR “infantile scoliosis” OR “tgr” OR “veptr” OR “MCGR” OR “Shilla” OR “growth-friendly” AND “complication”.

Research results

EOS surgery has a varying but high rate of complications. The most frequent complications were categorized as implant, general, wound and alignment. The rate of complications might have been even higher than reported, as some authors do not report all types of complications.

Research conclusions

The literature concerning the definitions, collection, and interpretation of data regarding EOS surgery complications is often difficult to interpret. This creates problems in the comparison, analysis, and improvement of spine surgery practice. Awareness of the high rate of complications of EOS surgery is crucial, and an optimal strategy for prevention should become a priority.

Research perspectives

This observation indicates that data on the incidence of complications can be underestimated, and should be interpreted with caution. Further studies are needed to confirm the study results, especially concerning longitudinal data.

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