



## Clinical Study

# Traditional versus magnetically controlled growing rods for idiopathic early-onset scoliosis: outcomes at 5-year follow-up

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Received 16 February 2025; revised 24 May 2025; accepted 4 July 2025

## Abstract

**BACKGROUND CONTEXT:** Growing rods are the most common surgical treatment for EOS. However, in children with idiopathic EOS, it is unclear how clinical, radiographic, and HRQoL outcomes differ between those treated with MCGRs versus TGRs.

**PURPOSE:** To investigate how clinical, radiographic, and health-related quality-of-life (HRQoL) outcomes differ between children with idiopathic early-onset scoliosis (EOS) treated with magnetically controlled growing rods (MCGRs) versus traditional growing rods (TGRs).

**STUDY DESIGN:** A retrospective review.

**PATIENT SAMPLE:** Children with idiopathic EOS who have undergone treatment with MCGR.

**OUTCOME MEASURES:** A disease-specific Early Onset Scoliosis Questionnaire 24, radiographic measurements, and complications.

**METHODS:** Using an international database, we identified 92 children aged  $\leq 9$  years with idiopathic EOS (major curve  $>30^\circ$ ) treated with TGRs ( $n=54$ ) or MCGRs ( $n=38$ ) from 2002 to 2018. Mean age at index surgery was 6.4 years for both groups. The mean preoperative major coronal curve was  $77^\circ$  in the TGR group and  $67^\circ$  in the MCGR group ( $p=.04$ ).

**RESULTS:** At 5-year follow-up, mean ( $\pm$  standard deviation) major curves were  $46^\circ \pm 18^\circ$  in the TGR group and  $38^\circ \pm 15^\circ$  in the MCGR group ( $p=.03$ ). Median annual thoracic growth (T1-T12) was 4.1 mm (interquartile range, 4.7 mm) in the TGR group and 3.2 mm (interquartile range, 5.6 mm) in the MCGR group ( $p=.29$ ). More complications occurred in the TGR group (mean 2.1 per patient) than in the MCGR group (mean 1.0 per patient) (risk ratio, 2.1; 95% confidence interval: 1.3–3.2). More revisions occurred in the TGR group (2.0 per patient) than in the MCGR group

Investigation performed at the Helsinki University Hospital, Helsinki, Finland, on behalf of the Pediatric Spine Study Group.

FDA device/drug status: Not applicable.

Author disclosures: **AJS:** Grant: Paivikki and Sakari Sohlberg Foundation, Vappu Uuspaa Foundation (None). **JMF:** Nothing to disclose. **GHT:** Royalties: Wolters Kluwer Orthopaedics (None); Stock Ownership: Orthopaedics (None); Trips/Travel: Orthopaedics (None); Board of Directors: Growing Spine foundation JPO, SRS, Shriner's, Societe Internationale de Chirurgie (None). **JBE:** Nothing to disclose. **PFS:** Scientific Advisory Board/Other Office: Nuvasive, Green Sun Medical (None). **PDS:** Royalties: Globus (None); Consulting: Orthopaedics, J&J (none).

**IJJ:** Grant: Finnish Paediatric Research Foundation (D); Consulting: Medtronic (D); Trips/Travel: Stryker (B); Grants: Medtronic International (F), Stryker (D), University of Helsinki Research Foundation for Injuries and Rehabilitation (D). AJS relationships B. All other relationships are D.

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Abbreviations: EOS, early onset scoliosis; MCGR, magnetically controlled growing rods

(0.9 per patient) (risk ratio, 2.2; 95% confidence interval: 1.4–3.4). Both groups achieved maximum scores in HRQoL domains of pulmonary function, transfer, physical function, daily living, and financial impact; no other measured domains differed between groups.

**CONCLUSIONS:** The risks of complications and revision surgery in children with idiopathic EOS were lower for those treated with MCGRs than for those treated with TGRs. HRQoL scores were similar and high in both groups at 5-year follow-up. MCGRs provide safe, effective surgical treatment for idiopathic EOS.

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**Keywords:** Growth-friendly treatment; Idiopathic early-onset scoliosis; Magnetically controlled growing rods; Spinal deformity correction; Traditional growing rods

## Introduction

Early-onset scoliosis (EOS) is a spinal deformity diagnosed before the age of 10 years and is classified according to etiology as idiopathic, congenital, syndromic, or neuromuscular [1]. These categories are the most important predictor of a patient's health-related quality of life (HRQoL) [2]. EOS can progress during childhood and cause severe deformity, disability, and cardiopulmonary insufficiency [3,4]. Treatment options include serial casting, bracing, and for patients with severe, progressive deformities, surgical treatment [3–5].

Spinal deformity can be corrected through surgical spinal fusion. However, spinal fusion before the age of 8 years may lead to pulmonary impairment in children with EOS [3,6]. To avoid early spinal fusion, “growth-friendly” surgical management can be used to control the deformity while allowing continued spinal growth [7,8]. Since its development in the 1980s, “growing rod” treatment has become the most common surgical method to address EOS. Growing rod treatment uses serial distractions, which are performed surgically in the case of traditional growing rods (TGRs) or noninvasively in the case of magnetically controlled growing rods (MCGRs). However, TGRs are associated with a complication rate as high as 58% during the course of treatment, which typically lasts until the child reaches skeletal maturity [9–11]. Complications can be wound-related, implant-related, or neurological. As an alternative to TGRs, MCGRs were developed to allow noninvasive lengthening on an outpatient basis to reduce the risk of deep surgical site infection [12,13]. Metallosis has often been observed around the MCGR actuator. As the clinical relevance of the metallosis is not fully understood, MCGRs are typically removed at the end of the treatment, and final fusion is performed [14].

The long-term outcomes of growing-rod treatment for patients with idiopathic EOS are unclear. In a study of 50 patients with idiopathic EOS, TGRs provided greater curve correction and spinal height gain with fewer complications than did treatment with a vertical expandable prosthetic titanium rib [15]. To address the lack of apical control and the subsequent risk of crankshaft phenomenon with growing rods, the apical control technique has recently been

described [16]. However, the large actuator prevents the use of apical screw in the MCGR instrumentation. Residual curve of at least 50 degrees is associated with decreased pulmonary function in nonneuromuscular patients with early-onset scoliosis [17]. Increased spinal height has been associated with improved HRQoL in EOS [18]. In another study of 88 patients with severe EOS (major curve >90°), MCGRs provided better curve correction at 2-year follow-up with fewer unplanned revision surgeries than TGRs, but only 14% of patients in that study had idiopathic EOS [8]. Additionally, the amount of lengthening achieved with MCGRs has been shown to decline over time in patients with idiopathic EOS compared with the more sustained lengthening observed in patients with syndromic EOS [19]. The long-term impact of growth-friendly management on HRQoL in patients with idiopathic EOS remains unclear, and comparisons of radiographic and HRQoL outcomes between TGRs and MCGRs in these patients have not been well established.

The purpose of this study was to compare radiographic outcomes, incidence of complications and revision surgery, and HRQoL in children with idiopathic EOS 5 years after growth-friendly instrumentation with TGRs or MCGRs. We hypothesized that major coronal curve correction and spinal height gains would be similar between groups, but that the incidence of revision surgery would be lower in patients treated with MCGRs than in those treated with TGRs. We also hypothesized that HRQoL scores at 5-year follow-up would be better in the MCGR group than in the TGR group.

## Materials and methods

### Patient selection

Institutional review board approval was received from the University of California, San Diego, USA (no. 150962 R). We performed a retrospective review of prospectively collected data from 11 countries. We included patients who 1) were diagnosed with idiopathic EOS according to Scoliosis Research Society criteria [1]; 2) underwent primary intervention using dual TGRs or MCGRs from 2002 through 2018, at age 9 years or younger; 3) had a major

Table 1

Characteristics of children with idiopathic early-onset scoliosis treated with MCGRs or TGRs, 2002-2018

Characteristic	MCGR <i>n</i> =38		TGR <i>n</i> =54		P
	N (%)	Median (IQR)	N (%)	Median (IQR)	
Age at surgery, years		6.4±1.7 <sup>†</sup>		6.4±2.1 <sup>†</sup>	.83
Female gender	24 (63)		37 (69)		
Growth-friendly treatment period, years		5.1 (0.8)		5.7 (2.9)	.004
Preoperative height, cm		111±14 <sup>‡</sup>		110±17 <sup>‡</sup>	.81
Preoperative weight, kg		20±6.6 <sup>‡</sup>		21±9.3 <sup>‡</sup>	.53
Preoperative bracing	15 (39)		28 (52)		
No. of lengthenings <sup>§</sup>		15 (7)		5 (3.5)	<.005
Lengthenings per year <sup>§</sup>		2.9 (1.4)		1.0 (0.5)	<.005
No. of surgical procedures <sup>§,  </sup>		2 (2)		7 (5)	<.001
Achieved final fusion within 5 years	20 (53)		32 (59)		

<sup>†</sup> Expressed as mean±standard deviation.<sup>‡</sup> During the first 5 years of treatment.<sup>||</sup> Initial surgery and final fusion excluded.

coronal curve of 30° or greater at the index procedure; and 4) had at least 3 lengthenings and at least 5 years of follow-up. We excluded patients treated with vertically expandable prosthetic titanium ribs or other devices. Of the 124 patients who had idiopathic EOS and at least 5-year follow-up, 38 were treated with dual MCGRs and 55 with dual TGRs. These 93 patients comprised our analytic sample.

#### Patient characteristics

Preoperative characteristics were similar between the 2 groups (Table 1). The median number of lengthenings was 15±7 in the MCGR group and 5±3.5 in the TGR group (*p*<.001). Twenty patients (53%) in the MCGR group and 32 patients (58%) in the TGR group underwent final fusion during follow-up. The median duration of growth-friendly treatment was 5.4 (interquartile range [IQR], 2.8) years in the MCGR and 5.7 (IQR, 2.9) years in the TGR group (*p*=.004). In patients who underwent final fusion, the median total follow-up time was 6.3 (IQR, 1.7) years in the MCGR group and 9.4 (IQR, 3.0) in the TGR group (*p*<.001).

#### Surgical technique

The surgical technique for placement of dual TGRs was as described by Akbarnia et al. [4]. A midline incision is used for exposure, with subperiosteal dissection limited to the planned proximal upper thoracic and distal mid-lumbar foundations to prevent premature fusion. Alternatively, 2 midline skin incisions can be used, with preservation of a central skin bridge. Hooks and/or pedicle screws are used as the foundations to secure the rods to the spine. The number and location of the anchors are based on the curve location, curve type, and patient age. Typically, 4 anchors (hooks or screws) in 2 levels are used for each foundation (a minimum of 8 fixation points). Construct lengthening is scheduled approximately every 6 months. None of the patients had an anterior procedure. MCGRs were used in a

similar fashion during the index surgery. Their lengthening interval was determined by the treating surgeon and ranged between 1 and 6 months.

The “final” fusion was performed using different techniques by different surgeons, including osteotomies for patients who required rebalancing or additional anchors and bone grafts for patients in whom consolidation of the fusion was the major goal.

#### Study design

Patient data were collected prospectively using a standardized multicenter protocol. We extracted data from the following timepoints: preoperatively, immediately after the index procedure, and at 5-year follow-up. Patients who underwent final fusion were additionally evaluated at the last visit before final fusion. We extracted data on patient age, height, number of lengthening procedures, complications, operative time, levels of instrumentation, and type of instrumentation. We also analyzed complications, which were categorized as wound-related, implant-related, neurological, or “other.” Revision surgery was defined as any unplanned procedure or complication treated with surgery. Surgical TGR lengthenings were not considered revision procedures.

#### Radiographic data

Standing posteroanterior and lateral radiographs were obtained before and after the index surgery, before and after final fusion, and at 5-year follow-up. We used radiographs to measure the major coronal curve using the Cobb technique [20]; thoracic height from the upper endplate of T1 to the lower endplate of T12; and spinal height from the upper endplate of T1 to the upper endplate of S1. Maximal thoracic kyphosis was measured using lateral radiographs and the Cobb technique. Radiographs were evaluated for implant-related complications. Spinal growth during the distraction period was also measured.

### HRQoL scores

The Early-Onset Scoliosis 24-Item Questionnaire (EOSQ-24) is a validated patient-reported outcome measure developed to assess the quality of life of patients with EOS [21]. Each of the 24 items is scored on a 5-point Likert scale, with higher scores indicating better HRQoL. The questions assess 12 HRQoL domains, family burden, and satisfaction, with a scaled maximum score of 100. We analyzed EOSQ-24 scores at the latest available timepoint, with a maximum follow-up period of 5 years.

### Statistical analysis

Categorical parameters were analyzed using chi-squared tests. Continuous parameters were analyzed using independent-samples t-tests. Mann-Whitney U tests were used to compare EOSQ-24 scores between groups. A mixed-effects Poisson regression model was used to analyze differences in the incidence of complications and revisions between groups. Poisson regression model results were reported using risk ratios (RRs) with 95% confidence intervals (CIs). Significance was set at  $p < .05$ .

## Results

### Radiographic outcomes

#### Major curve

Preoperatively, the mean ( $\pm$  standard deviation) major coronal curve was  $67^\circ \pm 22^\circ$  in the MCGR group and  $77^\circ \pm 22^\circ$  in the TGR group ( $p = .04$ ; Table 2). At the last growth-friendly follow-up visit, the mean major coronal curve was  $42^\circ \pm 16^\circ$  in the MCGR group and  $50^\circ \pm 22^\circ$  in the TGR group ( $p = .03$ ). At 5-year follow-up, mean major curves

were  $38^\circ \pm 15^\circ$  in the MCGR group and  $46^\circ \pm 18^\circ$  in the TGR group ( $p = .03$ ). Median correction of the major curve was 43% (IQR, 31%) in the MCGR group and 43% (IQR, 31%) in the TGR group at 5-year follow-up ( $p = .73$ ). In patients who underwent final fusion, the mean major coronal curve was  $36^\circ \pm 15^\circ$  in the MCGR group and  $42^\circ \pm 16^\circ$  in the TGR group ( $p = .24$ ). The median major coronal curve correction gained at the final fusion was  $19\% \pm 21\%$  in the MCGR group and  $15\% \pm 36\%$  in the TGR group ( $p = .73$ ). Five patients (13%) in the MCGR group and ten (19%) in the TGR group had a residual major curve of at least 50 degrees at the 5-year follow-up (RR, 0.86, 95% CI, 0.57–1.29).

#### Thoracic height

Preoperatively, mean T1-T12 height was  $164 \pm 26$  mm in the MCGR group and  $160 \pm 29$  mm in the TGR group ( $p = .53$ ). At the last growth-friendly follow-up visit, mean T1-T12 height was  $209 \pm 30$  mm in the MCGR group and  $215 \pm 50$  mm in the TGR group and ( $p = .53$ ). Median annual thoracic height increase (T1-T12) during the growth-friendly treatment period was 3.2 mm (IQR, 5.6 mm) in the MCGR group and 4.1 mm (IQR, 4.7 mm) in the TGR group ( $p = .29$ ). In patients who underwent final fusion, T1-T12 height was  $233 \pm 25$  mm in the MCGR group and  $233 \pm 41$  mm in the TGR group ( $p = .91$ ). The median T1-T12 height gain was 9.6 mm (IQR, 38 mm) in the MCGR group and 8 mm (IQR, 15 mm) in the TGR group ( $p = .45$ ).

#### Complications and unplanned revisions

There were 39 complications in the MCGR group (mean, 1.0 per patient) and 114 in the TGR group (mean, 2.1 per patient) (RR, 2.1; 95% CI, 1.3–3.2,  $p = .001$ ) during 5-year follow-up. The most frequent complications were implant-related complications (mean, 0.6 per patient in the MCGR group and 1.3 per patient in the TGR group) (RR, 2.1; 95% CI, 1.3–3.6,  $p = .005$ ). There were 5 wound-related complications in the MCGR group and 6 in the TGR group (RR, 1.1; 95% CI, 0.07–17,  $p = .94$ ). After the final fusion, there was 1 implant-related complication in each group and 1 deep surgical site infection in the TGR group.

There were 35 unplanned surgical revisions (0.9 per patient) in the MCGR group and 107 (2.0 per patient) in the TGR group (RR, 2.2; 95% CI, 1.4–3.4,  $p < .001$ ). Four patients underwent 6 revisions because of MCGR lengthening failure. Two patients with MCGRs had neurologic complications: 1 patient presented with dural lesion, and 1 had an unspecified neurologic complication.

#### HRQoL outcomes

EOSQ-24 scores were available for 30 patients in the MCGR group and 25 patients in the TGR group at final follow-up. There were no differences in scores for any of the EOSQ-24 domains between the groups (Table 3). EOSQ-24 domains for pulmonary function, transfer, physical function, daily living, and financial impact reached a maximum

Table 2  
Radiographic outcomes of children with idiopathic early-onset scoliosis treated with MCGRs or TGRs, 2002–2018

Outcome measure by time point	Mean $\pm$ standard deviation		p
	MCGR (n=38)	TGR (n=54)	
Major coronal curve, °			
Preoperative	67 $\pm$ 22	77 $\pm$ 22	.04
After initial surgery	33 $\pm$ 12	47 $\pm$ 15	<.001
Last growth-friendly follow-up	42 $\pm$ 16	50 $\pm$ 17	.03
After final fusion	36 $\pm$ 15	42 $\pm$ 16	.24
Thoracic height (T1-T12), mm			
Preoperative	164 $\pm$ 26	160 $\pm$ 29	.53
After initial surgery	188 $\pm$ 25	188 $\pm$ 35	.94
Last growth-friendly follow-up	210 $\pm$ 30	215 $\pm$ 50	.53
After final fusion	234 $\pm$ 25	233 $\pm$ 41	.91
Maximum thoracic kyphosis, °			
Preoperative	47 $\pm$ 21	53 $\pm$ 22	.28
After initial surgery	37 $\pm$ 15	37 $\pm$ 14	.88
Last growth-friendly follow-up	50 $\pm$ 19	58 $\pm$ 22	.06
After final fusion	52 $\pm$ 14	52 $\pm$ 16	.95

MCGR, magnetically controlled growing rods; TGR, traditional growing rods.

Table 3

Scores of children with idiopathic early-onset scoliosis treated with MCGRs or TGRs from 2002 to 2018 on the early-onset scoliosis 24-item questionnaire at the last available follow-up

Domain	Median (interquartile range)		P
	MCGR ( <i>n</i> =30)	TGR ( <i>n</i> =25)	
General health	75.0 (37.5)	75.0 (12.5)	.82
Pain discomfort	75.0 (37.5)	75.0 (50.0)	.73
Pulmonary function	100.0 (12.5)	100.0 (12.5)	.43
Transfer	100.0 (25.0)	100.0 (25.0)	.42
Physical function	100.0 (16.7)	100.0 (8.3)	.67
Daily living	100.0 (37.5)	100.0 (25.0)	.46
Fatigue/energy level	87.5 (37.5)	87.5 (37.5)	>.99
Emotion	87.5 (25.0)	87.5 (25.0)	.81
Parental impact	95.0 (25.0)	90.0 (20.0)	.76
Financial impact	100.0 (25.0)	100.0 (25.0)	.58
Child satisfaction	75.0 (25.0)	75.0 (25.0)	.87
Parent satisfaction	75.0 (25.0)	75.0 (25.0)	.49

MCGR, magnetically controlled growing rods; TGR, traditional growing rods.

score in both groups. Scores for family burden and satisfaction did not differ between the groups.

## Discussion

MCGRs provided similar correction of scoliosis with fewer complications and unplanned revisions than TGRs in the treatment of idiopathic EOS at 5-year follow-up. Despite the lower incidence of complications, HRQoL scores were similar and high in both groups. These findings support the use of MCGRs as an effective growth-friendly surgical treatment for patients with idiopathic EOS.

In the current study, the median annual gains in thoracic height were similar between treatment groups. Recently, Heyer et al. [19] investigated the lengthening behavior of MCGRs. They noted a decline in the lengthening observed over time in children with idiopathic EOS compared with those with syndromic EOS.

We found that the risk of complications was twice as high in the TGR group as in the MCGR group, which agrees with findings of previous research [8]. The risk of complications can be reduced by 13% for every year that surgery is postponed (eg, through serial casting or bracing) [9]. The need for surgical lengthenings with the use of TGRs increases the risk of deep surgical site infection and revision surgery. In our study, the risk of revision surgery was more than twice as high in the TGR group as in the MCGR group. This finding is similar to those of previous studies that have shown greater risk of revision surgery in patients treated with TGRs [8,22].

Despite multiple surgical procedures and outpatient lengthenings, patients in our study reported excellent HRQoL. In fact, EOSQ-24 domains for pulmonary function, transfer, physical function, daily living, and financial impact reached a maximum score. We found no difference in patient and parent satisfaction between the TGR and

MCGR groups, despite fewer complications and surgical procedures in the MCGR group. This might be explained by the maximum score in 5 EOSQ-24 domains, but also by higher expectations in these otherwise healthy children who also may tolerate better the complications than those with other comorbidities. Additionally, larger gains in spinal height have been associated with improved EOSQ-24 outcomes and the mean annual spinal growth tended to be higher in the TGR group during the distraction period [23].

A previous case-control study comparing psychosocial outcomes between TGR and MCGR patients found no clear advantage for MCGRs, despite fewer surgeries [24]. Baseline EOSQ-24 scores have been reported to be better in patients with idiopathic EOS than in those with syndromic or neuromuscular EOS [2]. In a previous study that included 44 patients with all causes of EOS, EOSQ-24 domain scores were generally lower than those in the current study, with no differences between patients treated with MCGRs versus TGRs when adjusted for length of follow-up [25]. Saarinen et al. [8] observed better major curve correction of severe EOS with lower risk of unplanned surgery and better EOSQ-24 scores when using MCGRs over TGRs at 2-year follow-up. However, only 6 of 44 patients in either group had idiopathic EOS.

## Limitations

Our study has several limitations that should be considered. First, because surgical treatment of idiopathic EOS is rare, our sample sizes were small despite using an international multicenter database. Second, the use of multicenter data introduces heterogenous clinical practices, including different lengthening protocols and preferences in terms of spinal instrumentation (eg, pedicle screws vs. hooks). Information on the upper and lower instrumented vertebrae was not available. Consequently, growth per segment could not be assessed due to the lack of data on instrumented levels. Third, changes in care during the long study period may have affected the outcomes in ways that are unaccounted for. Exact information on patient-specific implant selection was not available. Patients with TGRs were generally operated earlier than those with MCGRs, reflecting changes in practice over time and potentially affecting comparability. Fourth, the EOSQ-24 questionnaire, which was published and validated in 2018, was used in only 83% of the MCGR group and 45% of the TGR groups. Fifth, because of the unavailability of pulmonary function data, we were unable to assess the effect of the treatment on pulmonary function. These limitations are countered by our homogeneous patient sample that included only patients with idiopathic EOS followed for at least 5 years. All patients had spine-based dual growing rods, and patients with previous growth-friendly instrumentation were excluded.

## Conclusions

The risks of complications and revision surgery were lower in our sample of children with idiopathic EOS treated with MCGRs than for those treated with TGRs. Deformity correction and thoracic height gain did not differ between treatment groups. HRQoL outcomes were excellent in both groups and did not differ between the study groups.

## Ethical review statement

Institutional review board approval was received from the University of California, San Diego, USA (no. 150962R).

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## CRedit authorship contribution statement

**Antti J. Saarinen:** Writing – review & editing, Formal analysis, Software, Visualization, Writing – original draft, Data curation, Validation. **John M. Flynn:** Supervision, Writing – review & editing. **George H. Thompson:** Supervision, Writing – review & editing. **John B. Emans:** Supervision, Writing – review & editing. **Peter F. Sturm:** Writing – review & editing, Supervision. **Paul D. Sponseller:** Writing – review & editing, Supervision. **Ilkka J. Helenius:** Conceptualization, Writing – review & editing, Supervision.

## Acknowledgments

For editorial assistance, we thank Rachel Walden, MS, in the Editorial Services group of The Johns Hopkins Department of Orthopaedic Surgery. The authors disclose receipt of the following financial or material support for the research, authorship, and/or publication of this article: Dr. Saarinen has received research funding from Vappu Uuspää Foundation and Päivikki and Sakari Sohlberg Foundation.

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