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REVIEW

Systematic review of the complications associated with magnetically controlled growing rods for the treatment of early onset scoliosis

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Abstract

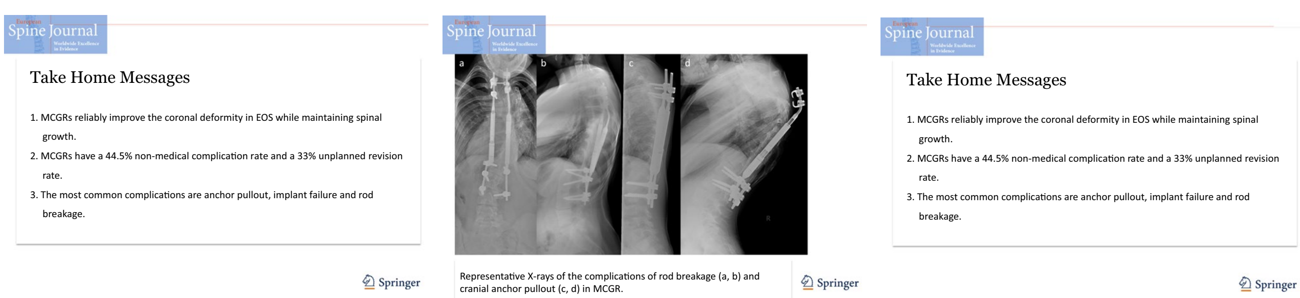
Purpose To analyse the complication profile of magnetically controlled growing rods (MCGRs) in early onset scoliosis (EOS).

Methods This is a systematic review using PUBMED, Medline, Embase, Google Scholar and the Cochrane Library (keywords: MAGEC, Magnetically controlled growing rods and EOS) of all studies written in English with a minimum of five patients and a 1-year follow-up. We evaluated coronal correction, growth progression (T1–S1, T1–T12) and complications.

Results Fifteen studies (336 patients) were included (42.5% male, mean age 7.9 years, average follow-up 29.7 months). Coronal improvement was achieved in all studies (pre-operative 64.8°, latest follow-up 34.9° $p=0.000$), as was growth progression ($p=0.001$). Mean complication rate was 44.5%, excluding the 50.8% medical complication rate. The unplanned revision rate was 33%. The most common complications were anchor pull-out (11.8%), implant failure (11.7%) and rod breakage (10.6%). There was no significant difference between primary (39.8%) and conversion (33.3%) procedures ($p=0.462$). There was a non-statistically significant increased complication rate with single rods (40 vs. 27% $p=0.588$).

Conclusions MCGRs improve coronal deformity and maintain spinal growth, but carry a 44.5% complication and 33% unplanned revision rate. Conversion procedures do not increase this risk. Single rods should be avoided.

Graphical abstract These slides can be retrieved under Electronic Supplementary material.



Keywords Magnetically controlled growing rods · MCGR · Early onset scoliosis · EOS · Complications

Introduction

Early onset scoliosis (EOS) is an uncommon condition that has been defined as the onset of scoliosis before the age of 10 years. This condition has a potentially poor prognosis with curve progression increasing the morbidity and mortality risk [1–3]. Therefore, adequate control of small curves

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or correction of larger curves is essential to optimise the child's well-being.

Some children with EOS can be treated non-operatively with observation or serial casting/bracing. However, in other children, the curve severity or progression necessitates operative intervention. Because these children often retain significant growth potential, corrective procedures with growth preservation are favoured.

The objective of any growing device is to support the growth of the spine while controlling curve progression. Historically, this has involved Traditional Growing Rods (TGRs) with multiple repeated operations to distract the respective growing system. However, these patients commonly have complex medical comorbidities and every operation increases their morbidity and mortality risk [4–6]. Furthermore, these repeat procedures carry a significant socio-economic burden to the family and health care provider [5, 7, 8].

Magnetically controlled growing rods (MCGRs) offer a solution to managing EOS, without the need for repeated surgery [9, 10]. This is achieved through the use of an externally placed device to distract the rod non-invasively via a magnetically driven linear actuator. Following the initial publication of its use by Cheung and colleagues, a number of studies, including those from our institution, have reported the successful use of MCGR in EOS, with few implant-related failures [11–17]. We have also reported on the cost savings associated with the use of MCGR in contrast to TGR for the surgical treatment of EOS as supported by the National Institute for Health and Clinical Excellence (NICE) [18].

In contrast, other studies have reported high complication rates, with high rates of implant failure [19–22]. In view of these concerns about MCGR and the varying results from different studies, we sought to undertake a systematic review evaluating studies that reported the outcomes of MCGR in the treatment of EOS.

Methods

We performed a comprehensive search of all publications up to 10 October 2017 using PubMed, Medline, Embase, Google Scholar and the Cochrane Library. The MeSH term early onset scoliosis (EOS) and keywords (magnetically controlled growing rods, magnetic growing rods, magnetic rods, MCGR and MAGEC) connected by the Boolean operators "AND" and "OR" were used to identify all possible studies. This was followed by an analysis of the text words contained in the title and abstract, and of the index terms used to describe articles. Secondly, a search using all identified keywords and index terms was undertaken across all of the included databases. Finally, a manual search was conducted of the reference lists of identified articles and relevant reviews for additional studies.

All studies written in English reporting on the use of MCGR in the treatment of EOS with a cohort size greater than five patients and a minimum of a 1-year follow-up were initially identified. Studies were subsequently included if they had also evaluated complications. Studies not written in English, review articles and animal studies were excluded. Studies reporting the use of MCGR as part of a hybrid growing system were also excluded.

The primary outcome measures were overall complication rates and unplanned re-operation rates. Secondary outcome measures were the degree of curve correction and the improvement in T1–S1 and T1–T12 heights, respectively.

The key papers identified were reviewed independently by two of the authors (CT and DK) with the data from each paper collated to answer our selected outcome measures.

Patient age, follow-up and pre-operative Cobb ranges are described as the individual patient ranges, because all studies documented these parameters. All other ranges are described as the range of averages, based on each study average for each parameter described.

Some studies failed to report whether a specific complication did not occur. In this situation, we did not presume that the complication did not occur, but instead excluded their results for the specific complication of interest. Equally, some articles failed to define whether a complication underwent revision. In these cases, only when revision was stipulated were they included in the reported revision rate. Furthermore, some publications used MCGR in patients over the age of 10 years. Many of these studies stated that a diagnosis of EOS had been made prior to the age of 10 years and in some of the cases patients had been previously treated with TGR or had delayed treatment due to failed non-operative measures. We therefore included these patients.

We defined implant failure as a permanent loss of distraction or failure to distract. A temporary loss of distraction with subsequent lengthening without operative intervention was defined as temporary loss of distraction and not implant failure. Rod and rod foundation breakage were combined and not described as implant failure. Similarly, screw or hook pull-out were combined and not described as implant failure.

A non-medical-related complication included complications directly related to the spine. Infections and wound dehiscence were included in this category. Systemic illness and anaesthetic complications were categorised as medical complications and were not the focus of this review. The unplanned re-operation rate was defined as an unexpected revision rather than a planned re-operation and included wound debridement, revision of fixation, premature rod exchange and early definitive fusion.

Statistical analysis

Comparison between the average pre-operative and post-operative radiographic parameters of each study was performed with a two-tailed homoscedastic t test.

A meta-analytic approach was used to determine a difference in complication rates between primary and conversion procedures as well as single and double rods. Because of the high number of articles that discuss primary or conversion procedures, as well as those that discuss both, data were extracted from all papers where this was stipulated. However, all articles discussing the number of rods included both single and double rods except one article [23] which only discussed dual rods. Therefore, for accurate statistical analysis, only papers discussing both single and double rods were included in the statistical analysis of single vs. double rods.

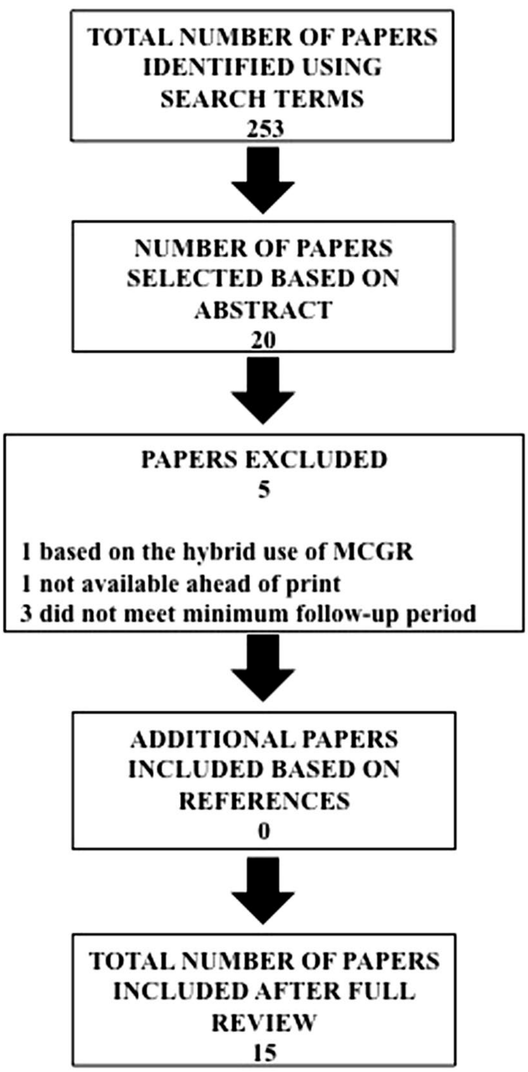

Fig. 1 Flow diagram for the identification of relevant papers

Statistical significance was defined as a p value less than 0.05.

Results

The initial literature search identified a total of 253 articles. On reviewing the abstracts, 20 publications were initially identified that fulfilled our search criteria. No further relevant studies were identified from the references of the included studies (Fig. 1).

After exclusion criteria, a total of 15 publications and 336 patients were included in this review [12, 13, 16, 19, 21, 23–32] (Tables 1, 2). All publications were published between 2013 and 2017 and ranged from a level of evidence of 3–4. The average number of patients per publication was 22.4 (range 8–54 patients) and age at operation was 7.9 years (range 2.4–14.3 years). Of those recording gender 42.5% were male. The average follow-up was 29.7 months (range 12–76 months).

In those describing the underlying condition (263/336), 93 were idiopathic, 66 were neuromuscular, 44 were congenital and 60 were syndromic. Two articles (24 patients) reported the use of all pedicle screw constructs [23, 26], three further articles (68 patients) described the use of hybrid constructs (pedicle screws and proximal hooks) [12, 30, 32] and one article used a combination (1 all screw and 29 hybrid procedures) [29].

The average time from the operation until the first distraction was 79.5 days (range 42–120) and the mean interval between distractions was 80.2 days (range 49–120) in those articles that described their distraction timing [12, 13, 23, 29, 30, 32]. The average recorded distraction per month was 2.3 mm (range 0.7–6.8) and the average number of distractions in articles recording this aspect was 8.6 (range 1–26) [12, 13, 16, 23, 29, 30].

The pre-operative characteristics and post-operative radiographic outcomes are shown in Table 1. Choi and colleagues did not report these outcomes, Yilmaz and colleagues did not present their pre-operative values and Hosseini et al. reported these separately for primary and conversion cases; therefore, their results are not displayed in Table 1 [19, 23, 24].

The average pre-operative Cobb was reported as 64.8° with an individual patient range of 31°–108°. This improved to 36.4° (range from 22.9° to 50°) immediately post-operatively ($p=0.000$) and 34.9° (12.1°–44°) at latest follow-up ($p=0.000$). Similarly, the pre-operative main thoracic kyphosis changed from 38.0° (range 22.9°–50°) to 28.6° (range 22.7°–35°) immediately post-operatively ($p=0.015$) and 29.6° (range 4°–50°) at final follow-up ($p=0.205$).

The average reported pre-operative T1-T12 height was 174 mm (range 158–187.9 mm) and improved to

Table 1 Radiological parameters of the articles reviewed

Study name	Preop cobb	Postopp cobb	Latest cobb	Main thoracic kyphosis preop	Main thoracic kyphosis immediate postop	Main thoracic kyphosis final follow-up	T1–12 preop	T1–T12 immediate postop	T1–T12 final follow-up	T1–S1 preop	T1–S1 immediate postop	T1–S1 final follow-up	Average annual T1–S1 growth (mm)
Akbarnia 2014 [16]	59	33.6	40.1	34	30	43	158	186	189	270	295	307	8.1
Dannawi 2013 [12]	69	47	41	33	29	4				304	335	348	35.2
Doany 2017 [25]	58.5		32.5										
Heydar 2017 [26]	62	29.4	28	38.9	27.4	11.6	187.9	207.4	229.1	321.9	345.8	373.2	9
Hickey 2014 [13]	60	42	43							261	301	307	6
Keskinen 2016 [27]	56.2	35	40	50		50	170	189	195	269	296	301	31.5
Kwan 2017 [28]	100	33.5	36.5	22.9	22.7								
La Rosa 2017 [32]	64.7	26.7	28.5	42.9	28.8	29.6	162		206	271		338	10.8
Lebon 2017 [29]	66	40	44	39	35	42	184	218	220	290	349	355	42.4
Riddersbusch 2016 [30]	63	29	26	43	27	32	182	203	217	296	331	350	30.7
Teoh 2016 (S34) [21]	59.5	42	40.5										4.3
Teoh 2016 (S40) [31]	60	42	41										
Total	64.8	36.4	34.9	38.0	28.6	29.6	174.0	200.7	209.4	285.4	321.9	334.9	19.8

Table 2 Summary of articles studied, including their non-medical complications and unplanned re-revision rates

Study name	Number of patients	Average age (months)	Sex *M*:*F*	Primary or conversion	Follow-up average	Number of non-medical recorded complication	Complication rates (%)	Unplanned re-operations	Unplanned re-operation rate (%)
Akbarnia 2014 [16]	12	81.6	7:5	Primary	30	8	66.7	4	33.3
Choi 2016 [24]	54	87.6	22:32	Both	19.4	23	42.6	15	27.8
Dannawi 2013 [12]	34	96	13:21	Both	15	13	38.2	3	8.8
Doany 2017 [25]	19	80.4	6:13	Primary	34.3	N/A	N/A	7	36.8
Heydar 2017 [26]	16	94		Primary	37	1	6.3	N/A	N/A
Hickey 2014 [13]	8	88	6:2	Both	28	4	50.0	N/A	N/A
Hosseini 2016 [19]	23	89.4	7:16	Both	N/A	14	60.9	13	56.5
Keskinen 2016 [27]	50	87.9	19:31	Both	N/A	15	30.0	10	20.0
Kwan 2017 [28]	30	86.4	11:19	Primary	37	16	53.3	14	46.7
LaRosa 2017 [32]	10	84	5:5	Primary	27	3	30	3	30
Lebon 2017 [29]	30	109.2	16:14	Both	18.4	22	73.3	13	43.3
Ridderbusch 2016 [30]	24	106.8	8:16	Primary	21.3	5	20.8	5	20.1
Teoh 2016 (S34) [21]	8	98.4	6:2	Both	48	8	100.0	8	100.0
Teoh 2016 (S40) [31]	10	104.4	8:2	Unknown	34	9	90.0	8	80.0
Yilmaz 2016 [23]	8	127.2	2:6	Both	36.6	0	0	0	0
Total	336	94.8	136:184	N/A	29.7	141	44.5	103	33.0

Table 3 Breakdown of most commonly reported complications

Complication	Number of events	Number of patients analysed	Percentage (%)
Superficial skin infection or dehiscence	4	180	2.2
Deep infection	8	244	3.3
Prominent metalware	6	155	3.9
Temporary loss of distraction	10	150	6.7
Implant failure	31	283	11.7
Rod or rod foundation breakage	32	301	10.6
Pull-out	26	221	11.8
Proximal junctional kyphosis	6	158	3.8
Other	18	336	5.4
Medical complications	33	65	50.8

200.1 mm (range 186–218 mm) immediately post-operatively ($p=0.007$) and 209.4 mm (range 189–229.1 mm) at final follow-up ($p=0.001$). The average pre-operative T1–S1 height was 285.4 mm (range 261–321.9 mm) and improved to 321.8 mm (range 295.0–349.0 mm) immediately post-operatively ($p=0.008$) and 334.9 mm (range 301–373.2 mm) at final follow-up ($p=0.001$). The average annual T1–S1 growth, including those reported by Hosseini and colleagues, was 21.2 mm (range 4.3–42.4 mm).

The use of a post-operative orthosis was described by Heydar et al. and was only used in non-idiopathic cases and continued until the anchor point was fused [26]. No other articles described their post-operative bracing protocol.

A summary of the articles reviewed and their non-medical related complication rate and unplanned re-operation rate are shown in Table 2.

The number and rate of the most commonly reported complications are summarised in Table 3. In total, there were 174 complications reported including 33 medical complications. Only three articles (65 patients) specifically discussed medical complications, which included nausea, vomiting, anaemia, dermatitis, fever of unknown origin and cough [16, 19, 29].

Implant failure occurred in 11.7% of cases. In those describing the timing of implant failure, one-third occur within 6 months and the rest after 6 months [24]. In 6.7% of cases, a temporary loss of distraction occurred, but subsequently resolved without further intervention [12, 27]. One patient was described to have skin problems related to the lengthening [19]. No patients developed a neurological injury.

Six articles only included primary procedures [16, 25, 26, 28, 30, 32], while eight included primary and conversion procedures [12, 13, 19, 21, 23, 24, 27, 29]. One article did not define whether their cases were primary or conversion procedures [31]. In total, the results of 196 primary procedures and 66 conversion procedures were reviewed (Table 4).

There was no significant difference in the overall rate of complications between primary and conversion procedures ($p=0.462$). Rod breakage was lower in primary (9.4%) than conversion (22.1%) cases, but failed to reach statistical significance (12.7% difference 95% CI − 27.1 to 6.3%). Implant failure rates were similar between primary (16.6%) and conversion (14.0%) cases (2.5% higher in primary cases 95% CI − 10 to 21.3%).

Dual rods were used in 69.2% (157/235) of cases in those who described the number of rods used. There was a higher, but not statistically significant difference, total complication rate between those using single- (40%) and double-rod constructs (27%) ($p=0.588$). Figure 2 illustrates the forest plot of this result.

The complication profile associated with single and double rods is shown in Table 5.

A large difference was noted in the rate of rod breakage between single (20%) and double (7.1%) rods; however, this failed to reach statistical significance ($p=0.077$). Figure 3 illustrates the forest plot of this result.

None of the other complications reached statistical significance.

A subset analysis of complications based on the underlying condition, fixation type and distraction timing or amount was not possible, because complications were not reported

Table 4 Comparison between primary and conversion groups

Type	Number of patients	Average age (years)	Percentage male (%)	Follow-up	Non-medical complications	Complication rate
Primary	196	7.0	37.7	39.9	78	39.8
Conversion	66	8.7	43.5	23.2	22	33.3

Study or Subgroup	Single Events	Single Total	Double Events	Double Total	Weight	Odds Ratio M-H, Random, 95% CI
Dannawi	4	12	4	22	27.4%	2.25 [0.45, 11.33]
Hosseini 2016	3	8	10	15	24.5%	0.30 [0.05, 1.80]
Keskinen 2016	3	13	7	37	28.9%	1.29 [0.28, 5.94]
La Rosa	3	4	0	6	9.7%	30.33 [0.96, 959.66]
Teoh 2016	3	3	4	5	9.5%	2.33 [0.07, 76.67]
Total (95% CI)		**40**		**85**	**100.0%**	**1.51 [0.46, 4.90]**
Total events	16		25			

Heterogeneity: Tau² = 0.64; Chi² = 6.34, df = 4 (P = 0.18); I² = 37%
Test for overall effect: Z = 0.68 (P = 0.50)

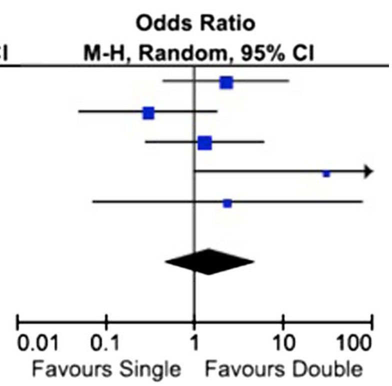

Fig. 2 Forest plot comparing the published literature on the total complications of single vs. double rods. Note the favourable results of dual rods in all except the publication by Hosseini and colleagues. However, overall this finding did not reach statistical significance ($p=0.5$)

Table 5 Complication profile of single vs. double rods

	Number of patients	Prominent metalware	Rod slippage	Distraction failure	Rod breakage	Pull-out
Single	40	1 (2.5%)	5 (12.5%)	3 (7.5%)	8 (20%)	1 (2.5%)
Double	85	3 (3.5%)	5 (5.9%)	5 (5.9%)	6 (7.1%)	3 (3.5%)
Total	125	4 (3.2%)	10 (8.0%)	8 (6.4%)	14 (11.2%)	4 (3.2%)

Study or Subgroup	Single Events	Single Total	Double Events	Double Total	Weight	Odds Ratio M-H, Random, 95% CI
Dannawi	1	12	1	22	16.3%	1.91 [0.11, 33.54]
Hosseini 2016	2	8	2	15	28.0%	2.17 [0.24, 19.28]
Keskinen 2016	2	13	2	37	31.2%	3.18 [0.40, 25.31]
La Rosa	2	4	0	6	11.8%	13.00 [0.45, 377.47]
Teoh 2016	1	3	1	5	12.7%	2.00 [0.08, 51.59]
Total (95% CI)		**40**		**85**	**100.0%**	**2.93 [0.92, 9.31]**
Total events	8		6			

Heterogeneity: Tau² = 0.00; Chi² = 0.97, df = 4 (P = 0.91); I² = 0%
Test for overall effect: Z = 1.82 (P = 0.07)

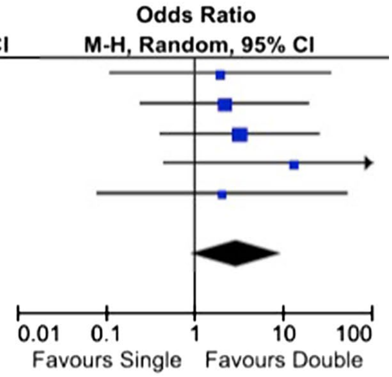

Fig. 3 Forest plot comparing the published literature on rod breakage rates between single- and double-rod constructs. Note the favourable results of dual rods in all publications ($p = 0.07$)

according to these parameters in the initial articles. Due to the low numbers, a multi-variate analysis of the risk factors of patient demographics, conversion and number of rods was not attainable.

Discussion

The surgical management of EOS remains challenging, but the introduction of MCGR provides an attractive alternative to TGRs because of the reduced need for repeated surgeries. All studies included in this review support the notion that MCGRs successfully control curve progression and aid spinal growth. However, MCGRs are not without risk and therefore it is imperative to define its complications' profile. To our knowledge, this is the first comprehensive review of the use of MCGR evaluating the complications and risk factors associated with its use.

We found a 44.5% cumulative non-medical complication risk in studies with a minimum of 1-year follow-up (average 2.4 years) and a 33% unplanned re-operation rate. The three most common complications identified were screw or hook pull-out (11.8%), implant failure (11.7%) and rod or rod foundation breakage (10.6%).

Unfortunately, the articles analysed did not report implant pull-out according to the fixation type and therefore we cannot determine whether hooks, screws or hybrids are superior. Most commonly the fixation technique depends on the local anatomy and therefore surgeon discretion and variable fixation strategies are required.

In our review, implant failure most commonly resulted from breakage of the actuator pin or rod slippage. Implant failure and slippage is well reported by Cheung and colleagues [33]. In their study of 22 patients, they found increased body mass index (BMI), older age, greater preoperative and post-operative T1–12 and T1–S1 heights and reduced distances between the internal magnets as significant risk factors for slippage. Unfortunately, the articles included in our review did not sub-analyse complications according to BMI, age, degree of correction or distances between magnets. Therefore, we cannot confirm the results of Cheung and colleagues [33]. However, Dannawi and colleagues noted an increased rate of slippage in single-rod constructs when compared to double rods [12]. Our results suggest that rod slippage (12.5% in single rods vs. 5.9% in dual rods) and distraction failure occurs more commonly in single-rod constructs (7.5 vs. 5.9%, respectively), but due to low numbers these findings failed to reach statistical significance.

We also found rod breakage to be more common in single-rod constructs (20 vs. 7.1%, respectively), although not statistically significant ($p = 0.077$). The evidence to support the use of a single- or double-rod construct remains unclear. Previous authors discuss the use of a single rod to prevent prominent metalware [12]. But other authors have documented similar rates of this complication with single and dual rods (1/8 in single rods in contrast to 2/15 in dual-rod constructs) [19]. We found a 1% lower rate of metalware prominence in single rods (2.5%) compared to dual rods (3.5%). However, single rods were affected by higher rates of rod slippage, distraction failure and rod breakage. In addition, Dannawi and colleagues found a significantly improved coronal correction with dual rods (19° in single rods and 24° correction in dual rods $p = 0.04$), a factor integral to the decision making on the number of rods [12]. Therefore, we believe that surgeons should balance the increased risks of rod slippage, implant failure and rod breakage as well as a reduced coronal correction, against the benefit of reduced prominent metalware when using single rods.

Rod breakage is a common problem with this implant and we feel its rate is under reported in this series. Within this review, a number of rods broke during their removal for other reasons, suggesting impending rod breakage. These were not included as complications but suggest a higher rate with longer follow-up. Although intuitive, the evidence supporting larger rod sizes to reduce rod fracture rates is limited. Both Choi et al. and La Rosa et al. found similar rates of rod fracture in those with 4.5-mm and 5.5-mm rods [24, 32]. Our review was unable to elucidate a risk for rod fracture based on size, due to the underreporting of rod size used. Therefore, we cannot provide guidance on rod size. However, the factors determining the rod diameter required include the patient size, surgical correction, number of rods and the risk of metalware prominence.

Hosseini and colleagues showed improved correction in primary cases compared to conversion cases [19]. We had anticipated also finding a higher complication profile in these patients; however, the reported literature does not support such an association (total complication rate of 39.8% for primary procedures in contrast to 33.3% in conversion procedures, $p = 0.462$). Surgeons should be aware of the challenges of conversion procedures, but should not be put off by a potentially higher complication rate in these cases.

Teoh et al. and Rushton et al. have recently raised concerns about metallosis in MCGR [20, 22]. Within our review, the article by Hosseini and colleagues was the only article to describe metallosis in a case that required revision for rod collapse (1 case out of 54 total cases and 9 revisions) [19]. Therefore, our review cannot discern the rate of this complication, but we feel further investigation into the rate of metallosis and its clinical significance is warranted.

Similarly, we were unable to determine the risk factors associated with proximal junctional kyphosis (PJK) in this review because of the limited reporting of this complication. However, Inaparthy et al. specifically reviewed PJK in MCGR in EOS and found a 28.6% incidence in their cohort of 21 patients [34]. All patients with PJK were syndromic with a higher percentage of males and equal numbers of primary and conversion cases. A negative correlation between age and PJK angle was also identified. However, none of their cohort required revision surgery and therefore the clinical effect of PJK remains uncertain.

Within this review, only Kwan and colleagues assessed the complication profile depending on the rate of distraction [28]. They identified more frequent distractions (1 week–2 months) were associated with a higher re-operation rate than less frequent distractions (3–6 months). Further research into the risk of accelerated distractions is necessary.

Three articles assessed the timing of when MCGR revisions were required and found that on average this was at 88.9 months post-operative [21, 28, 29]. They also attributed the majority of revisions to be due to implant failure or rod fracture. While we were unable to statistically analyse these results due to the low numbers, we would advocate close monitoring of patients after 2 years to identify implant-related complications.

This study has multiple limitations. Firstly is its heterogeneity and reliance on reported data. This review includes 9 studies with less than 25 patients and none of which report their power to identify complications. We chose to include these studies to increase the total number of cases in our review in order to provide a broader overview of the complications expected with MCGR. Furthermore, this review includes the results of multiple surgeons and geographic locations with variable indications. However, we feel that the accumulation of these data offers treating surgeons a greater understanding of the risks associated with MCGR. We also recognise that the implant itself has gone through a series of “generational” developments with none of the papers stating which generation of implant they were using.

Secondly, articles reporting on the complications of MCGR often fail to describe the specifics of each case, making it impossible to include these patients in our analysis. We therefore excluded cases in the subset analyses if their specific risk factors were not described.

Thirdly, the pooling of data in repeat studies from the same institution has the potential to include the same patients in multiple publications. We analysed each study independently and therefore cannot exclude crossover of patients in this review.

Fourthly, multiple complications can occur within the same individual. For example, screw pull-out can occur in the setting of PJK and be classified as two separate complications. However, screw pull-out can also occur without PJK and PJK can occur without screw pull-out. Because the individual patient results are rarely presented in the published literature, our study cannot determine whether these complications are mutually occurring or independent.

Lastly, this study reports the complication risks of MCGR, but does not specifically compare this outcome to other surgical techniques. While we feel that further comparison to alternative options within the same patient group is necessary to allow a greater understanding of the perceived risks and benefits afforded by this specific technique, we believe that this review offers surgeons greater insight into the risk profile of MCGRs.

An important consideration not included in this review is the patient-reported quality of life (QoL). Doany and colleagues assessed the health-related quality of life between MCGRs and TGRs and found that MCGR improved overall QoL [25]. However, these improvements were limited when controlled for length of follow-up and therefore the positive effects of MCGR remain to be definitively proven. We advocate further research into the patients’ perceived QoL.

Conclusions

MCGR offers a successful alternative for controlling curve progression and spinal growth. However, this technique has a 44.5% average reported surgical-related complication rate and a 33% unplanned revision rate. The three most common complications identified were screw or hook pull-out (11.8%), implant failure (11.7%) and rod or rod foundation breakage (10.6%). Single rods confer an increased risk of these complications, but reduce metalware prominence. While conversion procedures do not appear to increase the risk of this procedure.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interest.

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