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Citation for final published version:

Teoh, Kar. H., Von Ruhland, Christopher, Evans, Samuel Lewin ORCID: <https://orcid.org/0000-0003-3664-2569>, James, S. H., Jones, A., Howes, J., Davies, P. R. and Ahuja, S. 2016. Metallosis following implantation of magnetically controlled growing rods in the treatment of scoliosis: a case series. *The Bone & Joint Journal* 98-B (12) , pp. 1662-1667. 10.1302/0301-620X.98B12.38061 file

Publishers page: <http://dx.doi.org/10.1302/0301-620X.98B12.38061>
<<http://dx.doi.org/10.1302/0301-620X.98B12.38061>>

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Metallosis following magnetically controlled growing rods in scoliosis: a case series

Abstract

Aims

We present a ~~consecutive~~ case series of five patients who had revision surgery following magnetic controlled growing rods (MCGR) for early onset scoliosis. Metallosis were found during revision in four out of five patients (80%) and we postulated a mechanism for rod failure based on retrieval analysis.

Patients and Methods

Retrieval analysis was performed on the seven explanted rods. The average duration of MCGR from implantation to explantation was 35 months (range: 17 – 46 months).

Results

Six out of seven rods had tissue metallosis and pseudo-capsule surrounding the actuator. Four out of seven rods were pistoning. Two rods were broken. All rods had circumferential markings. A significant amount of metal debris was found when the actuators were carefully cut open. Analytical electron microscopy demonstrated metal fragments of predominantly titanium with a mean particle size of 3.36 microns.

Conclusion

This study highlights concerns with tissue metallosis in MCGR. We also suggest a possible failure mechanism in MCGR based on the results of our retrieval analysis.

Clinical relevance of the paper

Early reports of this device have shown promising results, and there has been no previous documentation of metallosis following MCGR implantation. The clinical long term implications of this metallosis is currently unknown and close follow up in this group of children is indicated.

Introduction

Early onset scoliosis (EOS) is an abnormal complex, three-dimensional deformity of the spine that is diagnosed before age 10. The best treatment for EOS remains unknown with the options ranging from using a brace to surgery as these curves are usually progressive. If these children fail non-operative treatment i.e. casting or bracing, then surgery is an option. The main aim of surgery is to correct the severe curve while maintaining growth of the spinal column until the child is close to skeletal maturity (growth sparing spinal surgery), when they can have a final operation to correct and stabilize the curve.

Growth sparing spinal surgery in EOS can usually be achieved by growing rods (a device which can be distracted to allow spinal growth). Conventional growing rods usually require repeated surgeries under general anaesthesia every six months throughout childhood to lengthen the rods and are associated with high complication rates¹⁻². This has fuelled the popularity of magnetic controlled growing rod (MCGR) in EOS. The main benefit of MCGR is the avoidance of repeated surgical lengthening procedures, leading to a reduction in surgical complications such as wound infections, anaesthetic risk, and delayed recovery for the child. Other claimed benefits include an improved quality of life, reduction in psychological trauma to the child and family and potential loss of earnings for parents because of reduced time away from school for the child, and work for the parent³. Benefits for the healthcare service include cost savings from theatre time, theatre consumables, in-hospital stay and treatment of complications, as repeated surgeries are no longer required.

An MCGR has a magnetic actuator (motor) that can ~~unwind~~ rotate the growing rod when used with a hand-held external remote controller device (ERC), thus allowing non-invasive spinal lengthening in the outpatient clinic. In the United Kingdom, the National Institute for Health and Care Excellence (NICE) approved its use on grounds of both efficacy and cost-effectiveness in June 2014⁴. In the United States, it received marketing clearance by the Food and Drug Administration (FDA) in February 2014. In 2012, Cheung et al reported the first case series of MCGR in the Lancet⁵. Since then, there have been other publications reporting promising early results⁶⁻⁸. Recently, however, our centre had to revise patients with MCGR and we found metallosis in them. There have been no previous reports in the literature of metallosis following MCGR

implantation. Here we report this finding, which occurred in four out of five patients during revision of MCGR, and describe possible mechanisms of rod failure based on retrieval analysis.

Methods

Study design and patients

This study was a patient series of young children with severe EOS undergoing treatment with MCGR who required revision surgery at our centre. The MCGR used was the MAGEC system (Ellipse Technologies, Inc.). In our centre, we have implanted 14 MCGR in patients with early onset scoliosis. We have revised five patients so far in our centre and four out of five patients had metallosis. This data was prospectively gathered after we encountered the severe metallosis as shown in Figure 2 (index case). This study is a retrospective analysis of prospectively gathered data in four patients with metallosis during revision surgery.

The main focus of this work is to report the peri-operative findings at revision surgery in this cohort of patients. Informed consent was taken from both the child and their parents for peri-operative photographs to be taken.

Retrieval analysis was performed on the explanted rods in conjunction with the company (Ellipse Technologies) and our local engineering and electron microscopy departments. Histo-pathological examination was also performed on the intra-operative tissue samples. Two rods were cut in our laboratory and five rods were cut by the company (Ellipse Technologies).

Based on the retrieval studies, we hypothesize the likely mechanism of rod failure.

Surgical procedure and our follow-up protocol

The MAGEC system comprises 1 or 2 sterile titanium implantable growth rods with a magnet in the actuator that drives the lengthening process magnetically. The diameter of the rods used depended on the child's body weight and the choice of a single or a dual rod construct was down to surgeon's preference. The diameter of the MAGEC rods used in our series was all 5.5 millimetres.

After surgery, patients were followed up in clinic at 6 weeks initially. Non invasive distraction of the MAGEC rods were started between at 3-6 months from initial implantation. Outpatient extensions of the MCGR were performed every 8 weeks in our centre using a hand-held magnetic external remote controller by placing it over the

internal magnet in the MCGR. Pre-extension and post-extension ultrasound imaging was performed in all patients.

Results

Five patients with EOS were revised for various reasons (as outlined below with each case) following treatment with magnetically controlled growing rods. The demographics of these patients are summarized in table 1. The average age at implantation of MCGR was 9 years. The average duration of MCGR from implantation to explantation was 35 months (range: 17 – 46). The weight, age and indication for MCGR were all in compliance with the recommendations of the MCGR manufacturer. Seven rods were explanted for analysis from the four patients (one single rod construct, three double rod constructs) who were found to have metallosis around their MCGRs during revision surgery. Six out of these seven rods had evidence of metallosis around the actuator.

Peri-operative findings

Patient 1, who had a single rod MCGR construct, was lost to follow up for 6 months and did not have any distractions during this period. When they returned for outpatient lengthening, it was found on ultrasound that the internal magnetic mechanism had collapsed. This was also confirmed on radiographs (Figure 1). During surgery, extensive metallosis debris was found while dissecting down to the rod (Figure 2). Pus was also found incidentally around the lower two-thirds of the MCGR. All the pedicle screws were also loose. This patient was clinically well prior to the revision operation and did not exhibit any signs of infection.

Patient 2, who had a double rod MCGR construct, developed proximal junctional kyphosis (i.e. loss of spinal alignment above the construct) and had to undergo revision surgery. During revision surgery, one rod had tissue metallosis around it while the other rod broke on retrieval.

Patient 3, who had a double rod MCGR construct, was revised as one of the rods had fractured. Following discussion with his family, the decision was taken to proceed to definitive correction and fusion as he was already age 15. During revision surgery, both rods had severe metallosis with pseudo-capsule formation around the actuator (Figure 3a & b).

Patient 4, who had a double rod MCGR construct, was revised as the MCGRs were failing to distract and, as a consequence, he was developing significant deformity

distally i.e. at the lumbo-sacral junction. Again both rods had severe metallosis around them, along with pseudo-capsule formation.

Patient 5, who had a single rod construct, underwent revision for a non-functioning magnetic rod that had stopped distracting with the ERC and a scoliosis curve that was worsening, leading to progression of rib deformity. We made a single attempt under light general anesthesia in theatre to distract the magnetic rod with the ERC, but this also did not work. This patient was a well-known multiple-revisions case who had conventional growth rods since the age of 4 complicated by previous infections. Hence, for that very reason, the conventional growth rods were converted to single-rod MCGR construct at age 10. He was initially listed for a revision from single-rod MCGR construct to double rod MCGR construct but due to the metallosis seen in the earlier cases, he was revised to a conventional dual growing rod system instead. Interestingly, he was the only case which we revised where there were no metallosis seen.

Retrieval results of rods

The retrieval results are summarized in Table 2. **Six out of seven rods** had tissue metallosis and pseudo-capsule surrounding the actuator. **Four rods** were pistoning (Figure 4a & b). All rods had circumferential markings (Figure 5). Significant amounts of metal debris were found when the actuators were carefully cut open in the laboratory (Figure 6a, b & c). On assessing the distraction mechanism, it was found that the locking pin had fractured leading to free pistoning of the two cylinders which make up the device.

Histology

Histology was performed on tissue samples taken from around the growing rods. Microscopic findings consistently showed accumulation of black and grey granular particles, hyalinised fibrous tissue, and chronic inflammation reaction with lymphoid and plasma cell infiltrates (Figure 7).

Electron microscopy

Analytical electron microscopy of the material seeping out of the actuator due to pistoning demonstrated metal fragments, composed predominantly of titanium, with a mean particle size of 3.36 microns (Figure 8).

Microbiology

Intra-operative tissues samples grew coagulase negative staphylococcus in one patient.

The other three had no growth.

Discussion

We report the first case series of four patients who were found to have metallosis at revision surgery of MCGRs. To our knowledge, there have been no previous reports in the literature of metallosis of MCGRs. We do not know its precise incidence or its clinical implications at this point in time. We believe this is a unique complication attributed to MCGRs since this has not been reported previously in conventional growing rods.

The problem that concerned our centre was the severe metallosis seen peri-operatively in these ~~consecutive~~ four patients. With the recent metal-on-metal total hip replacement (MoM-THR) problems (i.e. metallosis and pseudotumour) still fresh in the minds of the orthopaedic community⁹⁻¹⁰, it was worrying, upon revision, to see such levels of tissue metallosis around the actuator of these MGCRs in children. MCGRs have only recently been introduced in the market and formally approved for use by NICE and the FDA last year. We were one of a few centres to adopt their early use in 2011, and, in agreement with other centres, reported promising early results⁶⁻⁸. Our earlier implementation of this technology may explain why we are now seeing this metallosis phenomenon, unlike other centres where it was introduced later.

The spine is deep, just like in hip joints of MoM-THR. There may be little exteriorly to suggest problems occurring inside. It is hard to appreciate and visualise the amount of metallosis and tissue destruction except at revision. In conventional growing rods, the rods are extended through an open approach every six months, while in MCGRs, they are extended externally by a machine. This may be another reason why this phenomenon has not been reported so far, ~~although we are aware of anecdotal reports of MCGRs with metallosis.~~

Our histological studies showed chronic inflammatory response in reaction to the metal debris, suggesting metallosis. Metallosis is defined as aseptic fibrosis, local necrosis, or loosening of a device secondary to metal corrosion and release of wear debris¹¹. This is an uncommon condition which comprises local damage and changes in tissue characteristics provoked by a metallic foreign body in the host¹². Our patients did not exhibit features to suggest pseudotumour formation, which has been associated with metal on metal hip replacements, and which is defined as a granulomatous lesion or a destructive cystic lesion, neither infective nor neoplastic,

that is at least 5 cm in size, has developed in the vicinity of the total joint replacement (with or without communication with the joint), and resembles a tumour¹⁰.

The locking pin in the magnetic actuator was found to be ~~consistently~~ broken (Figure 9a & b) in the explanted rods we analysed. The locking pin measures 6mm x 2mm and connects the magnet to the lead screw. As the magnet is rotated by the external remote controller, the lead screw moves the rod in the actuator and thus lengthens the MCGR. With a broken locking pin, this mechanism fails and leads to rod pistoning or telescoping. This leads to the formation of metal debris inside and around the actuator, accounting for the metal debris when the actuator was cut open (Figure 6a, b & c). Soft tissue metallosis occurs as a result of this metal debris, leading to the formation of a pseudo-capsule by the immune system. Based on our retrieval analysis, we believe that this is a possible ~~likely~~ mechanism of metallosis and rod failure (Figure 10). However, not all the rods were pistoning, therefore it is likely that this proposed mechanism of failure does not explain the whole picture of metallosis.

Our retrieval analysis also showed that all the rods had circumferential wear markings on them suggesting that these markings were likely to have been caused at earlier stages before the failure of the locking pin, rather than by a telescoping/pistoning process after failure. These circumferential wear markings on the rods are caused by the stresses during the process of MCGR lengthening. These rings could be a source of corrosion and metal reaction in the surrounding tissue. The retrieval analysis conducted by the engineers in Ellipse Technology suggests that circumferential wear markings (Figure 5) could possibly cause the metallosis instead.

The retrieval analysis was done in collaboration with the manufacturers and our engineering and electron microscopy departments. We have returned all 7 rods to the manufacturer ~~for further analysis~~ with a view to improving future versions of the MCGRs. We have been informed that alterations will be made to the locking pin to prevent further breakages. We are also aware that previous clinical studies have led to design refinement of the rod, with the addition of a keeper plate intended to maintain rod length, preventing slippage and loss of distraction when the rod is placed under high stress⁶.

MCGR is an evolving technology which needs further refinement. We plan to follow up these children closely as we do not know what long-term clinical implications this could have for them. Our series highlights the need for regular clinical follow-up for new devices and the importance of registries. We are aware that the National Health Service in the United Kingdom has commissioned the use of the MAGEC system with the proviso that payment to hospitals will occur with the entry of the patients' details, progress and record of complications into the British Spine Registry.

In summary, this study highlights concerns with metallosis as a consequence of MCGR. We also describe likely failure mechanisms in MCGR based on the results of our retrieval analysis. The incidence and long term implications of this metallosis is currently unknown and close follow up in this group of children is required.

Legend

Figure 1a and b. Radiograph showing loss of correction following collapse of internal magnetic mechanism

Figure 2. Image showing black soft tissue while dissecting down to the rod

Figure 3 a) Image showing soft tissue metallosis around the actuator and pseudocapsule formation and b) following pseudo-capsule excision

Figure 4 a & b) Images illustrating pistoning/telescoping of MCGR

Figure 5 Image illustrating circumferential markings on the MCGR

Figure 6 a, b & c. Images illustrating significant metal debris in the actuator after cutting it open carefully. Note the metal debris around this area.

Figure 7 Low magnification images of a region of high particulate density of the pseudo-capsule

Figure 8 Electron micrograph showing typical metal particles found in the rod

Figure 9a & b. Images showing a broken locking pin (magnified view) and relationship between the size of a locking pin and a typical ballpoint pen tip.

Figure 10. Our proposed cascade of metallosis/rod failure

Table 1. Demographics of the four patients with MCGRs requiring revision

Table 2. Retrieval analysis of the explanted MCGRs

Role of funding source

There was no funding for the study. However the retrieval analysis of the explanted MCGR was performed in cooperation of Ellipse Technologies. They had no role in any of data collection, analysis or interpretation of the results, writing or editing of the report, or the decision to submit the study for publication.

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Patient	Sex	Age at implantation of MCGR	Weight at implantation of MCGR (kilograms)	Aetiology of EOS	Primary/Revision Procedure	Rod Construct	Reason for revision	Duration (months)
1	F	8y 5m	17.5	Congenital	Primary	Single	Lost to follow up for 6 months - broken pin in magnetic rod and deep infection	37
2	M	4y 6m	19.2	Syndromic	Primary	Double	Development of proximal junction kyphosis	34
3	M	11y 2m	39.1	Idiopathic	Revision	Double	Rod breakage at distal end	39
4	M	10y	28.5	Congenital	Revision	Double	Failure of rod to distract +Distal decompensation	17
5	M	11y 2m	32.4	Idiopathic	Revision	Single	Failure of rod to distract	46

Table 1. Demographics of the five patients with MCGRs requiring revision

Patient	Tissue Metallosis	Rod	Markings on the Rod
1	+++	Pistoning	+++
2	Right + Left - none	Intact Right - broken at retrieval	+++
3	Bilateral +++	Both Pistoning Left – broken prior to revision	+++
4	Bilateral +++	Right - Intact	+++

		Left - Pistoning	
5	Patient 5 had no metallosis therefore explanted rod was not analysed		

Table 2. Retrieval analysis of the seven explanted MCGRs