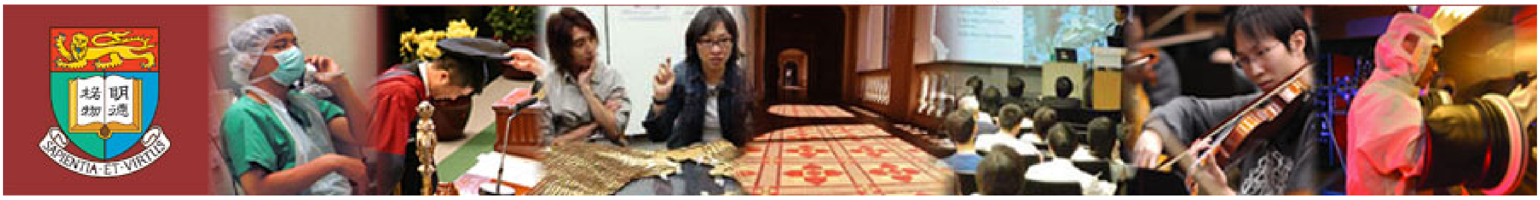

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Clinical Study

Clinical utility of ultrasound to prospectively monitor distraction of magnetically controlled growing rods

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Abstract

BACKGROUND CONTEXT: Growing rods are commonly used for surgical treatment of skeletally immature patients with scoliosis, but require repeated surgeries for distractions and are fraught with complications. As an alternative, the use of magnetically controlled growing rods (MCGR) allows for more frequent non-invasive distractions to mimic normal growth. However, more plain radiographs are needed to monitor increased distraction frequency, thereby increasing ionizing radiation exposure to the developing child. The use of ultrasound, which emits no radiation, has been found in a cross-sectional study to be reliable in measuring MCGR distractions.
PURPOSE: The study aims to address the prospective clinical utility of ultrasound compared with plain radiographs for assessing MCGR distractions.
STUDY DESIGN: This is a prospective study.
PATIENT SAMPLE: The study includes patients with early-onset scoliosis undergoing distractions after MCGR implant.
OUTCOME MEASURES: The distraction length on plain radiographs and ultrasound was measured.
METHODS: This is a prospective study of patients treated with MCGR. Patients with both single- and dual-rod systems were included. Outpatient distractions were performed at monthly intervals, targeting 2 mm of distraction on each occasion. Assessment of distraction length was monitored by ultrasound at each visit; plain radiographs were taken every 6 months and were compared with ultrasound measurements.
RESULTS: Nine patients (5 female, 4 male), with a mean of 29 distractions (standard deviation [SD] ±14.3), were recruited. The mean distracted length per 6 months was 5.7 mm (SD ±3.6 mm) on plain radiographs and 5.2 mm (SD ±3.9 mm) on ultrasound for the concave rod, and 6.1 mm (SD ±3.6 mm) on plain radiographs and 5.9 mm (SD ±3.8 mm) on ultrasound for the convex rod. Excellent inter- and intra-rater reliabilities were observed for radiographic and ultrasound measurements. An excellent correlation was noted between the two imaging modalities ($r=0.93$; $p<.0001$).

FDA device/drug status: Approved (Magnetically controlled Growing Rod).

Author disclosures: ***JPYC:*** Employment: University of Hong Kong (Paid to the author), outside the submitted work. ***CB:*** Employment: University of Hong Kong (Paid to the author), outside the submitted work. ***DS:*** Board membership: *The Spine Journal*, *Journal of Spinal Disorders and Techniques*, *Journal of Orthopaedic Surgery*, *Spine* (Editorial board member), outside the submitted work; Employment: University of Hong Kong (Paid to the author), outside the submitted work; Grants/Grants Pending: RGC, AOSpine (I, Currently as PI and Co-I); Travel/Accommodations/Meeting Expenses Unrelated to Activities Listed: AOSpine (B, Travel as council board member of AOSpine East Asia), outside the submitted work. ***AKBGA:*** Nothing to disclose. ***KMCC:*** Board Membership: Scoliosis Research Society, outside submitted work; Consultancy: Ellipse Technologies (B, Paid to the institution), outside submitted work; Employment: University of Hong Kong (Paid the author), outside the submitted work; Grants/Grants Pending: RGC (F, Paid to the institution), outside the submitted work; Travel/Accommodations/Meeting Expenses Unrelated to Activities Listed: AOSpine, SRS (B, Paid to the author), outside the submitted work; Other: Endowed Professorship (H, Paid to the institution), outside the submitted work.

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CONCLUSIONS: This is the first prospective study to validate that ultrasound assessment of MCGR distraction lengths was highly comparable with that of plain radiographs. The present study has verified that ultrasound can be used to document length changes by distraction over time and that it had high clinical utility. Ultrasound can be a reliable alternative to plain radiographs, thereby avoiding radiation exposure and its potential detrimental sequelae in the developing child.

Keywords: Controlled; Correlation; Distraction; Growing; Magnetically; Rod; Ultrasound

Introduction

Scoliosis deformity in young children is particularly difficult to manage. If left untreated, these deformities are at risk of rapid progression, cosmetic disfigurement, and pulmonary insufficiency [1–8]. By addressing the need to control these deformities while allowing for physiological spine growth, distractible spinal implants or growing rods were developed [9–11]. Patients are recommended to receive open distraction surgeries using these traditional growing rods (TGRs) every 6 months to effectively control progression of spinal deformity, gradually straighten the spine, and mimic spinal growth [9,10,12–16]. However, this method of treatment has significant limitations, including the need for repeated surgeries, and increased risk for anesthetic and wound complications [1,2]. Repeated admissions for surgery also add further psychological distress to both the child and the family. Furthermore, TGR surgery has increased cost implications [17], and hence creates a substantial burden on health care.

In response to the limitations of TGR, a remotely distractible, magnetically controlled growing rod (MCGR) system has been developed to allow for gradual lengthening on an outpatient basis [18,19]. This allows for safe spinal lengthening with continuous neurologic monitoring and real-time feedback by the patient. Moreover, the rods can be retracted if any pain is experienced during the distraction. Preliminary studies have shown its clinical [18,20–22] and cost [17] effectiveness, as well as its safety in the gradual correction of severe deformities [23]. The MCGR may also potentially mimic normal physiological growth more closely as smaller and more frequent distractions can be performed without invasive surgery [18,21].

However, with increased distraction intervals, the requirement for plain radiographs to confirm and monitor distractions is increased. Unfortunately, the health risks of ionizing radiation exposure increase with each x-ray exposure in the developing child. This is a valid concern as ionizing radiation exposure to children has been linked to breast cancer and subsequent mortality [24–26]. Other effects of ionizing radiation exposure also include the development of sarcomas and heart disease, among other conditions [27–30]. "Ultrasonography" is a non-invasive, non-ionizing imaging modality that has been shown to be feasible in the assessment of distractions [31]. In the authors' practice, ultrasound has been incorporated into a routine measurement tool for distraction lengths since 2013. As such, the present study aimed to address the prospective clinical utility of ultrasound compared with plain radiographs for assessing MCGR distractions.

Materials and methods

This was a prospective study of patients treated with MCGR for early-onset scoliosis at a single institute. All patients had preoperative Cobb angle of >30° and were skeletally immature (premenarche status for female patients, open phalangeal physis, Risser 0). Ethics approval was obtained from the local institutional review board. The Scoliosis Research Society definition of early-onset scoliosis (spine deformity diagnosed before the ages of 8–10) was adopted. Patients with early-onset scoliosis were included only if they were skeletally immature (ie, premenarche status for female patients, open phalangeal physis, Risser 0) at the time of surgery. All patients were consecutively recruited from April 2013 to March 2015.

All patients had MCGR inserted as previously described [18]. Either hooks or screws were used as fixation anchors at the upper and lower instrumented vertebra. Only one set of cross-links was used for dual-rod systems, which was placed near the lower instrumented vertebra. Outpatient distractions were performed at monthly intervals with expected 2-mm distraction on each occasion. Ultrasound assessment (Fig. 1) was performed at each follow-up pre- and post-distraction to confirm the distraction length according to previously described methods [31]. Distraction length was measured at the extended portion of the rod between the end of the housing unit and the reference point at the neck of the rod. Anteroposterior standing plain radiographs were obtained at each six monthly follow-up to measure the radiographic parameters. Distraction length was directly measured on plain radiographs (Fig. 2) from the housing unit. Measurements were made on the digital image using the Centricity Enterprise Web V3.0 (GE Medical Systems, St. Louis, MO, USA, 2006). All radiographic measurements were calibrated and corrected for magnification using the diameter of the housing unit (9.02 mm) Both measurements on ultrasound and plain radiograph were measured to the nearest 0.01 mm. Independent observers measured the ultrasound (CB) and the plain radiographs (JPYC). Both observers were blinded to the other observer's measurements, and statistical analysis was performed blindly to

EVIDENCE & METHODS

Context
The authors present results of a small prospective series, regarding the utility of ultrasound (US) as compared with plain films for the evaluation of distraction in magnetically-controlled growing rods (MCGR). This study included only nine patients.

Contribution
The authors maintain that their study is the first prospective effort to demonstrate the clinical utility of US in the evaluation of MCGR. The authors report excellent inter- and intra-rater reliability for the US measurements and high correlation between findings on US and plain film radiographs.

Implications
Given the design of this study and its limited patient sample, the findings can be seen as proof of concept only. Familiarity with the US technique may also mean that the authors' experience may not be the same in the hands of other clinicians or at other medical centers less familiar with this radiographic imaging technique. The results of this work should be seen as Level IV evidence, despite the prospective study design, in light of the small sample, limited amount of follow-up and the potential for expertise bias to confound the results.

—*The Editors*

the patient's identity. Both observers performed inter- and intra-rater reliabilities for radiograph and ultrasound measurements independently, and these were not assessed on the same day. Neither observer was trained as an ultrasonographer, and only one to two sessions of technical guidance were provided before the present study was initiated. As the plain radiographs were performed at 6-month intervals, the corresponding ultrasound measurements taken at the same follow-up visit were used for comparison. Both imaging modalities were compared to assess the correlation between the measured distractions. We have previously established the protocol and reliability of ultrasound assessment [31] and are not the focus of the present study.

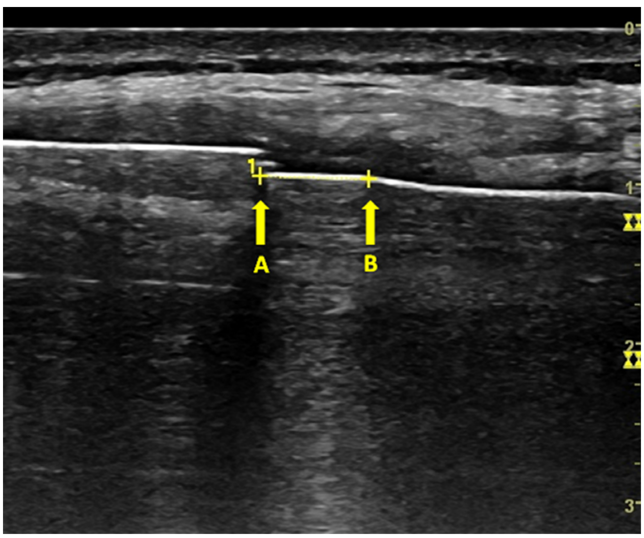

Fig. 1. Ultrasound measurement of the magnetically controlled growing rod between (A) the end of the housing unit and (B) the neck of the extended part.

Statistical analysis

All ultrasound and radiographic data were coded and entered on separate spreadsheets (Microsoft Excel, Redmond, Washington, USA, 2013) until the analysis was performed. SPSS version 20 (IBM, Chicago, IL, USA) was used to perform statistical analysis. Descriptive and frequency

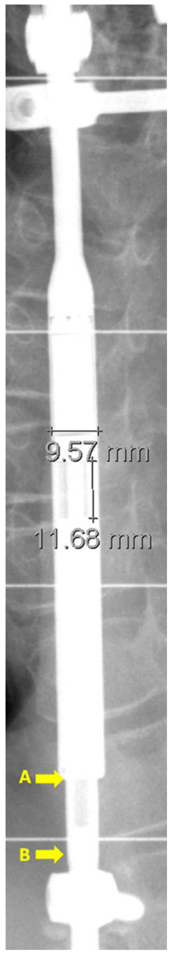

Fig. 2. Radiographic measurement of rod distraction length in the housing unit of the magnetically controlled growing rod. The distracted length here was measured at 11.7 mm, and the diameter of the housing unit was measured at 9.6 mm. The diameter of the housing unit must be measured on x-rays to calibrate the measurements for magnification error. Because the actual housing unit diameter was 9.02 mm, the actual distracted length here was calculated to be 11.0 mm. In this figure, Points A and B indicate the corresponding reference points used for ultrasound measurements in Fig. 1.

Table 1
Patient characteristics

Diagnosis	Sex	Age at implant (years)	Rod contructs	Number of distractions	Incidents that may have affected the distraction lengths
CHARGE syndrome	M	12.2	Dual	32	Conversion from TGR to MCGR stopped distractions on the concave rod at ~2 years after implant for gradual curve correction.
Congenital scoliosis	F	10.5	Dual	49	Nil
Ehlers-Danlos syndrome	F	5.6	Single converted to dual	45	Conversion from single rod to dual rod 3 years after initial implant
Juvenile idiopathic scoliosis	F	4.3	Dual	15	Nil
Juvenile idiopathic scoliosis	F	9.9	Single	35	Concave rod slippage 2.5 years after implant
Neurofibromatosis	M	14.8	Dual	22	Nil
Neurofibromatosis	M	4.8	Single converted to dual	15	Conversion from single rod to dual rod 1 year after initial implant
Noonan syndrome	F	14.6	Single	41	Single-rod insertion with slippage of rod at the end of each distraction starting 3 months after implant
Sotos syndrome	M	7.4	Dual	10	Nil

M, male; F, female; TGR, traditional growing rod; MCGR, magnetically controlled growing rod.

statistics were performed of the data. Mean and standard deviations (SDs) were obtained where appropriate. Reliability assessment was based on intraclass correlation, which had been shown to be an appropriate statistical tool for this analysis [32]. The intraclass correlation could be interpreted based on the following alpha values: 0 to 0.29 indicated poor agreement, 0.30 to 0.49 indicated fair agreement, 0.50 to 0.69 indicated moderate agreement, 0.70 to 0.80 indicated good agreement, and >0.80 indicated excellent agreement [33,34]. Pearson correlation analyses were used to determine the correlation between ultrasound and radiographic measurements. A p-value of <.05 was considered statistically significant, and a correlation coefficient (r) greater than 0.9 was considered an excellent correlation.

Results

A total of nine patients (6 female, 3 male) with a mean age of 9.2 years (SD ±4.0) at rod implant were assessed. Diagnoses of patients included CHARGE syndrome (n=1), congenital scoliosis (n=1), Ehlers-Danlos syndrome (n=1), juvenile idiopathic scoliosis (n=2), neurofibromatosis (n=2), Noonan syndrome (n=1), and Sotos syndrome (n=1). Table 1 listed the details of each patient. There was a mean follow-up of 42.6 months (SD ±18.0), with a mean of 29 distractions (SD ±14.3). The patients with Ehlers-Danlos syndrome and Noonan syndrome, one with juvenile idiopathic scoliosis, and one with neurofibromatosis had single rods inserted due to their small size. The patients with Ehlers-Danlos syndrome and neurofibromatosis nevertheless had conversion to dual rods 3 years and 1 year after implant, respectively. The patient with CHARGE syndrome was also a conversion case (ie, TGR to MCGR).

A total of 34 sets of plain radiographs were taken. From these, 38 sets of data points were used for correlation analysis. The mean distracted length per 6 months was 5.7 mm (SD ±3.6 mm) on plain radiographs and 5.2 mm (SD ±3.9 mm) on ultrasound for the concave rod, and 6.1 mm (SD ±3.6 mm) on plain radiographs and 5.9 mm (SD ±3.8 mm) on ultrasound for the convex rod. Excellent correlation (Fig. 3) was noted between the two imaging modalities (r=0.93; p<.0001). The mean measurement difference between the two imaging modalities was 0.3 mm (SD ±1.4 mm, 95% confidence interval: 0.19–0.75, p=.20). Excellent reliability was obtained for radiograph and ultrasound measurements (Table 2).

Discussion

Our study is the first prospective study to illustrate that the ultrasound can reliably document rod distractions with radiographic measurements. One element to note in our analysis is that the ultrasound measurement is not identical to the radiographic measurements as the two imaging modalities used different reference points for measurements. Ultrasound mea-

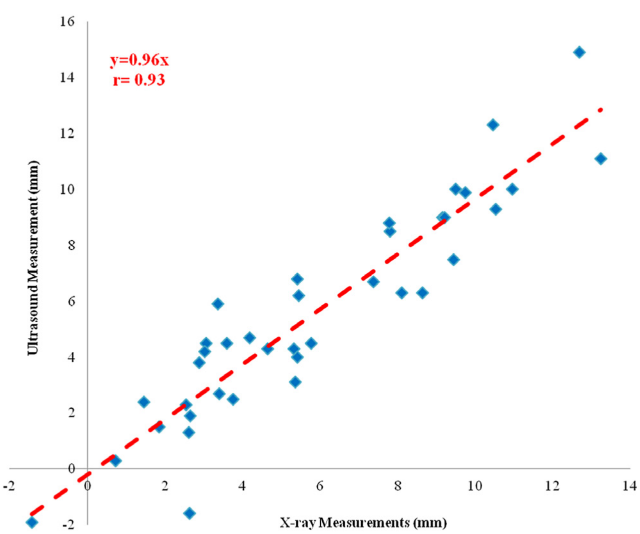

Fig. 3. Correlation chart for the radiographic and ultrasound measurements in magnetically controlled growing rod distractions.

Table 2
Reliability analysis for radiograph and ultrasound measurements

	Radiograph (ICC)	95% CI	p-value	Ultrasound (ICC)	95% CI	p-value
Intraobserver (JPYC)	1.00	(1.00–1.00)	<.0001	0.99	(0.94–1.00)	<.0001
Intraobserver (CB)	1.00	(1.00–1.00)	<.0001	0.99	(0.96–1.00)	<.001
Interobserver	1.00	(1.00–1.00)	<.0001	0.86	(0.52–0.98)	.001

ICC, intraclass correlation; CI, confidence interval.

sures the distance of the extended portion of the rod between the end of the housing unit and the neck of the rod, whereas plain radiograph measures the expanded housing unit. Nevertheless, the measured changes in rod length between the two imaging modalities are highly correlated. Thus, this correlation study confirms our hypothesis that ultrasonography is at least as accurate as radiographs in measuring changes in rod length.

By demonstrating good correlation, a significant reduction in the number of radiographs can be adopted in these distraction clinics. Because distractions can be closely monitored by a non-invasive imaging modality without radiation, radiographs are only required every 6 months or even annually for assessment of balance and curve control, which has significant implications on our patients. Assuming a protocol that demands monthly distractions, and pre- and post-distraction plain radiographs were taken to confirm distraction on site, a patient with MCGR inserted at the age of 8 with skeletal maturity at the age of 13 may require up to 120 whole spine radiographs for monitoring. Using our adopted protocol, the number of radiographs can be dropped to 10 (six monthly radiographs) or 5 (annual radiographs).

Besides the issue with radiation, there are some other perceived advantages of ultrasound for follow-up assessments with MCGR. For radiographs, the image of the housing unit may be skewed if the patient is lurched forward or backward for an anteroposterior view, and tilted to the side for a lateral view. Without standing upright, the housing unit may appear to be shortened, leading to a misinterpretation of loss of distraction. As the ultrasound examines the patient in a prone position, measuring directly over the extended portion of the rod, the issue with patient positioning can be avoided. This discrepancy can also explain the differences noted in one of the two negative data points in the correlation analyses. This suggests that ultrasound is slightly more accurate in this regard.

Ultrasound is a real-time assessment and can potentially monitor any structural problems with the rod during or immediately after any patient discomfort, failure of distraction, or rod slippage. As with MCGR, the application of the ultrasound is still relatively new and further analysis is warranted. Future studies should include real-time visualization of the rod slippage phenomenon at the housing unit, whether loss or failure of distraction occurs, as well as observation of the effects of increasing distraction forces on the anchor points at the upper and lower instrumented vertebra. Studies on the learning curve required to master this technique should also be performed.

The present study has inherent limitations, including the relatively small sample size and the short follow-up. However, the aim of the present study is to assess the correlation of measurements made on the ultrasound and on the plain radiographs. Thus, there are sufficient data points from the nine patients to support the conclusion that the ultrasound measurements are at least equal to the radiographic measurements. Despite being able to reduce the number of radiographs required during interval follow-up, radiographs are still needed every 6 or 12 months. These routine radiographs are important to assess the patient's overall balance, curve magnitude, and any complications that may arise from distractions, such as proximal junctional kyphosis or failure, and rod fracture.

Conclusions

This is the first prospective study between ultrasound and radiograph measurements of MCGR distraction. The results show that ultrasound assessment of MCGR distraction lengths has excellent correlation with plain radiographs. The present study has verified that ultrasound can be used to document length changed by distraction over time. Although ultrasound can never fully replace radiographs, it is a valuable adjunct in routine assessment. With the ultrasound, the detrimental sequelae associated with ionizing radiation exposure in these young patients undergoing surgical management with MCGR can be avoided.

References

[1] Akbarnia BA, Emans JB. Complications of growth-sparing surgery in early onset scoliosis. Spine (Phila Pa 1976) 2010;35:2193–204.

[2] Bess S, Akbarnia BA, Thompson GH, Sponseller PD, Shah SA, El Sebaie H, et al. Complications of growing-rod treatment for early-onset scoliosis: analysis of one hundred and forty patients. J Bone Joint Surg Am 2010;92:2533–43.

[3] Campbell RM Jr, Smith MD, Mayes TC, Mangos JA, Willey-Courand DB, Kose N, et al. The characteristics of thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis. J Bone Joint Surg Am 2003;85-A:399–408.

[4] Cheung JP, Samartzis D, Cheung KM. Management of early-onset scoliosis 2013. Available at: http://www.boneandjoint.org.uk/content/focus/management-early-onset-scoliosis. Accessed March 23, 2015.

[5] Goldberg CJ, Gillic I, Connaughton O, Moore DP, Fogarty EE, Canny GJ, et al. Respiratory function and cosmesis at maturity in infantile-onset scoliosis. Spine (Phila Pa 1976) 2003;28:2397–406.
[6] James JI. Idiopathic scoliosis; the prognosis, diagnosis, and operative indications related to curve patterns and the age at onset. J Bone Joint Surg Br 1954;36-B:36–49.
[7] James JI, Lloyd-Roberts GC, Pilcher MF. Infantile structural scoliosis. J Bone Joint Surg Br 1959;41-B:719–35.
[8] Redding GJ, Mayer OH. Structure-respiration function relationships before and after surgical treatment of early-onset scoliosis. Clin Orthop Relat Res 2011;469:1330–4.
[9] Akbarnia BA, Breakwell LM, Marks DS, McCarthy RE, Thompson AG, Canale SK, et al. Dual growing rod technique followed for three to eleven years until final fusion: the effect of frequency of lengthening. Spine (Phila Pa 1976) 2008;33:984–90.
[10] Akbarnia BA, Marks DS, Boachie-Adjei O, Thompson AG, Asher MA. Dual growing rod technique for the treatment of progressive early-onset scoliosis: a multicenter study. Spine (Phila Pa 1976) 2005;30:S46–57.
[11] Winter RB, Moe JH, Lonstein JE. Posterior spinal arthrodesis for congenital scoliosis. An analysis of the cases of two hundred and ninety patients, five to nineteen years old. J Bone Joint Surg Am 1984;66:1188–97.
[12] Elsebai HB, Yazici M, Thompson GH, Emans JB, Skaggs DL, Crawford AH, et al. Safety and efficacy of growing rod technique for pediatric congenital spinal deformities. J Pediatr Orthop 2011;31:1–5.
[13] Sponseller PD, Thompson GH, Akbarnia BA, Glait SA, Asher MA, Emans JB, et al. Growing rods for infantile scoliosis in Marfan syndrome. Spine (Phila Pa 1976) 2009;34:1711–15.
[14] Sponseller PD, Yazici M, Demetracopoulos C, Emans JB. Evidence basis for management of spine and chest wall deformities in children. Spine (Phila Pa 1976) 2007;32:S81–90.
[15] Thompson GH, Akbarnia BA, Campbell RM Jr. Growing rod techniques in early-onset scoliosis. J Pediatr Orthop 2007;27:354–61.
[16] Thompson GH, Akbarnia BA, Kostial P, Poe-Kochert C, Armstrong DG, Roh J, et al. Comparison of single and dual growing rod techniques followed through definitive surgery: a preliminary study. Spine (Phila Pa 1976) 2005;30:2039–44.
[17] Rolton D, Richards J, Nnadi C. Magnetic controlled growth rods versus conventional growing rod systems in the treatment of early onset scoliosis: a cost comparison. Eur Spine J 2014;24:1457–61.
[18] Cheung KM, Cheung JP, Samartzis D, Mak KC, Wong YW, Cheung WY, et al. Magnetically controlled growing rods for severe spinal curvature in young children: a prospective case series. Lancet 2012;379:1967–74.
[19] Wick JM, Konze J. A magnetic approach to treating progressive early-onset scoliosis. AORN J 2012;96:163–73.
[20] Akbarnia BA, Mundis G, Salari P, Yaszay B. Innovation in growing rod technique; study of safety and efficacy of remotely expandable rod in animal model. J Child Orthop 2009;3:513–14.
[21] Akbarnia BA, Cheung K, Noordeen H, Elsebaie H, Yazici M, Dannawi Z, et al. Next generation of growth-sparing techniques: preliminary clinical results of a magnetically controlled growing rod in 14 patients with early-onset scoliosis. Spine (Phila Pa 1976) 2013;38:665–70.
[22] Dannawi Z, Altaf F, Harshavardhana NS, El Sebaie H, Noordeen H. Early results of a remotely-operated magnetic growth rod in early-onset scoliosis. Bone Joint J 2013;95-B:75–80.
[23] Cheung JP, Samartzis D, Cheung KM. A novel approach to gradual correction of severe spinal deformity in a pediatric patient using the magnetically-controlled growing rod. Spine J 2014;14:e7–13.
[24] Doody MM, Lonstein JE, Stovall M, Luckyanov N, Land CE. Breast cancer mortality after diagnostic radiography: findings from the U.S. Scoliosis Cohort Study. Spine (Phila Pa 1976) 2000;25:2052–63.
[25] Ronckers CM, Doody MM, Lonstein JE, Stovall M, Land CE. Multiple diagnostic X-rays for spine deformities and risk of breast cancer. Cancer Epidemiol Biomarkers Prev 2008;17:605–13.
[26] Ronckers CM, Land CE, Miller JS, Stovall M, Lonstein JE, Doody MM. Cancer mortality among women frequently exposed to radiographic examinations for spinal disorders. Radiat Res 2010;174:83–90.
[27] Grant EJ, Ozasa K, Ban N, de González AB, Cologne J, Cullings HM, et al. A report from the 2013 international symposium: the evaluation of the effects of low-dose radiation exposure in the life span study of atomic bomb survivors and other similar studies. Health Phys 2015;108:551–6.
[28] Samartzis D, Cheung KM. Ionizing radiation exposure and the development of intervertebral disc degeneration in humans: myth or reality. Spine J 2011;11:979–82.
[29] Samartzis D, Nishi N, Cologne J, Funamoto S, Hayashi M, Kodama K, et al. Ionizing radiation exposure and the development of soft-tissue sarcomas in atomic-bomb survivors. J Bone Joint Surg Am 2013;95:222–9.
[30] Samartzis D, Nishi N, Hayashi M, Cologne J, Cullings HM, Kodama K, et al. Exposure to ionizing radiation and development of bone sarcoma: new insights based on atomic-bomb survivors of Hiroshima and Nagasaki. J Bone Joint Surg Am 2011;93:1008–15.
[31] Stokes OM, O'Donovan EJ, Samartzis D, Bow CH, Luk KD, Cheung KM. Reducing radiation exposure in early-onset scoliosis surgery patients: novel use of ultrasonography to measure lengthening in magnetically-controlled growing rods. Spine J 2014;14:2397–404.
[32] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307–10.
[33] Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159–74.
[34] Vangeneugden T, Laenen A, Geys H, Renard D, Molenberghs G. Applying concepts of generalizability theory on clinical trial data to investigate sources of variation and their impact on reliability. Biometrics 2005;61:295–304.