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GROWING ROD TECHNIQUE FOR THE TREATMENT OF PROGRESSIVE EARLY-ONSET SCOLIOSIS

PROGRESİF ERKEN BAŞLANGIÇLI SKOLYOZLARIN TEDAVİSİNDE BÜYÜYEN ROD TEKNİĞİ

Yunus ATICI[1],
A. Yener İNCE[2],
Mustafa CANİKLİOĞLU[3]

[1]Orthopedics and Traumatology, MD, S.B. Metin Sabancı Balta Limanı Bone Diseases Training and Research Hospital 2nd Orthopedics and Traumatology Clinics, Istanbul.
[2]Orthopedics and Traumatology, MD, Çamlıca German Hospital, Istanbul.
[3]Orthopedics and Traumatology, MD, Assoc. Prof., S.B. Istanbul Training and Research Hospital Orthopedics and Traumatology Clinics, Istanbul

SUMMARY:

Many different etiologies may cause progressive spinal deformities that are grouped together as early-onset scoliosis, including infantile and juvenile idiopathic scoliosis, congenital scoliosis, neuromuscular scoliosis, and various syndromes. After development of the spinal instrumentation system, the dual rod method was described by McCarthy and developed and popularized by Akbarnia and Marks. The goal of the growing rod technique is to achieve correction of the deformity, and to maintain it during the treatment period while allowing spinal growth. The growing rod system for the treatment of early-onset scoliosis is preferred for cases with a curve greater than 45° and patients younger than 10 years of age.

Key words: Early onset scoliosis, growing rod, indications

Level of evidence: Review article, Level 5

ÖZET:

Erken başlangıçlı skolyoz (EBS), birçok farklı etiyoloji (konjenital, nöromüsküler, infantil ve jüvenil idiopatik, çeşitli sendromik skolyozlar) sahip skolyoz tipini kapsar. Spinal enstrümantasyon sistemlerinin gelişmesi sonrası; çift rod tekniği Mc Carty tarafından tanımlanmış, Akbarnia ve Marks tarafından geliştirilerek popüler hale gelmiştir. Büyüyen rod tekniğinin amacı; spinal büyümeye izin vererek spinal deformitenin düzeltilmesini sağlamak ve korumaktır. Büyüyen rod sistemi, EBS'larda 45° den büyük eğriliklerde ve 10 yaşından küçük hastalarda tercih edilmektedir.

Anahtar Sözcükler: Erken başlangıçlı skolyoz, büyüyen rod, endikasyonlar

Kanıt Düzeyi: Derleme, Düzey V

Address: Op.Dr. Yunus Atıcı, Ali Fakih Mah., Eski Fıstıklı Sok., Seray Apt., No:9 / 11, Fatih / İstanbul.
E-mail: yunatici@hotmail.com
Tel.: 0505 4921945
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INTRODUCTION:

Early-onset scoliosis (EOS) occurs in young children and is a common name given to various diagnoses (congenital, neuromuscular, idiopathic, and various scoliosis syndromes). Whatever the etiology, the age of onset of the scoliosis plays an important role in the treatment[6]. The complete development of the alveoli occurs by age 8, particularly in the first three years. When scoliosis occurs before the age of 8, it damages the alveolar and pulmonary artery development in the lung, and thorax development[15]. Surgery without fusion is among the techniques that help control EOS while also allowing growth. Today, the most popular technique is the dual growing rod technique[50].

CLINICAL AND RADIOLOGICAL EVALUATION:

The progression of the curvature directs the treatment of EOS. Progression of curvatures with a Cobb angle under 25˚ is seen very rarely. These patients should be observed with X-rays taken at 4–6 month-intervals. If the progression of the curve is 10˚ or more, active treatment should be begun. The progression risk is high for curves with Cobb angles between 20˚ and 35˚. If progression of the curvature of these patients in follow-ups at 4–6 month intervals is detected, surgical treatment should be started. If the curve is more than 35˚, treatment should be immediately considered. If it is more than 45˚, surgical treatment should definitely be performed[4-5].

THE HISTORY OF THE GROWING ROD TECHNIQUE:

Surgical treatment of progressive scoliosis is a problem for small children. Previously, the traditional treatment options of early-onset scoliosis included brace, plaster, and/or spinal fusion treatment. If the curve is particularly severe, it is not effective to control the progression with a plaster or a brace. Also, the plaster and brace prevent pulmonary and thorax development. Circumferential arthrodesis is preferred to stop the progression of the curvature by spinal fusion and to prevent crankshaft phenomena. It was detected that the crankshaft phenomenon risk was higher for children who received isolated posterior spinal fusion[16,41]. Spinal fusion and segmental spinal instrumentation can treat scoliosis effectively and prevent crankshaft phenomenon, but a short body and a disproportionate body structure will occur in advanced stages. In addition, spinal fusion adversely affects lung development at young ages and can result in respiratory failure[20,51].

Hemi-epiphysiodesis can be performed to the convex side of the curve with or without instrumentation. This prevents the progression of curvature by preventing the growth of the convex side, which has high growth potential, while allowing the growth of the concave side, and aims to provide spontaneous correction. This technique is more effective for congenital curves and can be applied gradually. Because the normal growth potential is not achieved, it is not applied in cases of idiopathic infantile and juvenile scoliosis[32].

In 1962, Harrington defined the non-fusion instrumentation technique to eliminate these problems. Harrington tried to treat with distraction by placing laminar hooks to the concave side, distally and proximally to the scoliosis.

Harrington preferred the use of this system in children with progressive scoliosis under the age of 10 (without fusion). With Harrington rod use, large progressions and a number of complications (especially rod fracture and hook dislocation) have been observed[22].

The earliest studies involved the use of Harrington rods, applied by performing periodic extensions to the system. This technique has been subsequently been modified in modern scoliosis surgery courses[6].

Moe modified and improved the technique, by applying the Harrington rod with a subcutaneous distraction method. He applied limited fusion by performing subperiosteal dissection to the hook edges. He aimed to place the rod easily and to form less scar tissue by making the central part of the rod smooth. Also, he aimed to prevent the rod breaking by allowing for the sagittal contour and thickening the rod. He used a Milwaukee brace for postoperative immobilization. He applied extension at 6–12 month intervals or whenever a loss of correction of more than 10° occurred. He obtained 84% of expected growth and reported a 50% complication rate. These complications included fracture of the rod and lamina and hook dislocation. He reduced the rod fracture complication by thickening the rod[8-39].

Initially, Moe and Tello suggested adding a bone graft to the hook edges when placing the instrumentation.

They also suggested the avoidance of major distraction in order to prevent lamina fracture[39,49].

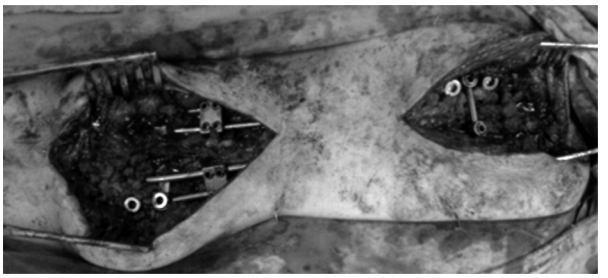

Figure-1. Patient B.E. An image of the growing dual rod domino system being placed during surgery[1]

In 1977, Marchetti and Faldini defined the end-fusion technique for the treatment of early-onset scoliosis. During the first stage, the end vertebral edges forming the Cobb angle were subperiosteally explored and grafted. In the second stage, the Harrington rod was placed six months after fusion was provided. In the third stage, they applied serial distractions 6–8 weeks after the placement of the hooks and rod until maturity. Fusion applied to the anchor edges significantly reduced hook complications[30].

Before 1980, Luque defined the spinal segmental instrumentation without external support or fusion technique (segmental vertebral fixation with sublaminar wires without fusion). He then modified the method to use an L rod instead of a Harrington rod. Luque found that his rods were broken in high rates around partial spinal growth, and this required repetitive extending. In many patients, spontaneous fusion also occurred in the instrumentation area[25-27]. Undesired fusion was detected in the long-term follow-up of patients for whom the Luque trolley system was used.

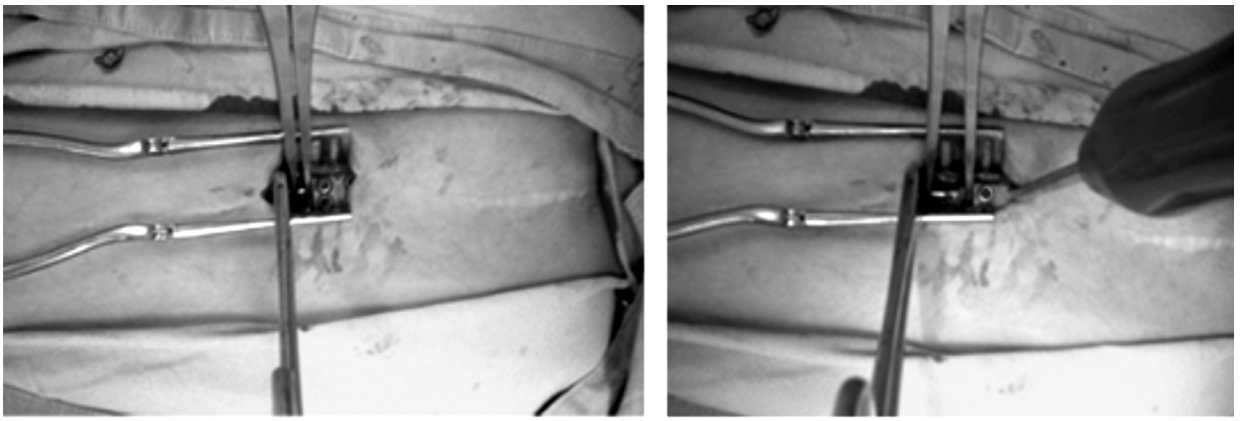

Figure-2. A. Loosening of the proximal rod screws connected to the transverse connector and placement of the distractor, **B.** Tightening the domino screws after the application of extension by distractor (distraction) over the proximal rod[1]

The reason for this autofusion was thought to be sublaminar wiring when performing subperiosteal exploration[17,31].

For the patients for whom the Luque trolley system was used, spontaneous spinal fusion resulted in a high complication rate and difficult revisions.

Some authors tried to treat patients by intervening ribs found at the convex side of the curve[11,47]. Barnes applied Milwaukee orthosis to 48 patients with infantile idiopathic scoliosis after rib resection and compared them to 19 patients who received only Milwaukee orthosis.

He did not find any difference between the two groups[11]. Taylor et al. applied rib resection and costodesis to 24 children with infantile idiopathic scoliosis. They stated that improvement continued for ten patients and deterioration slowed in 14 patients[47].

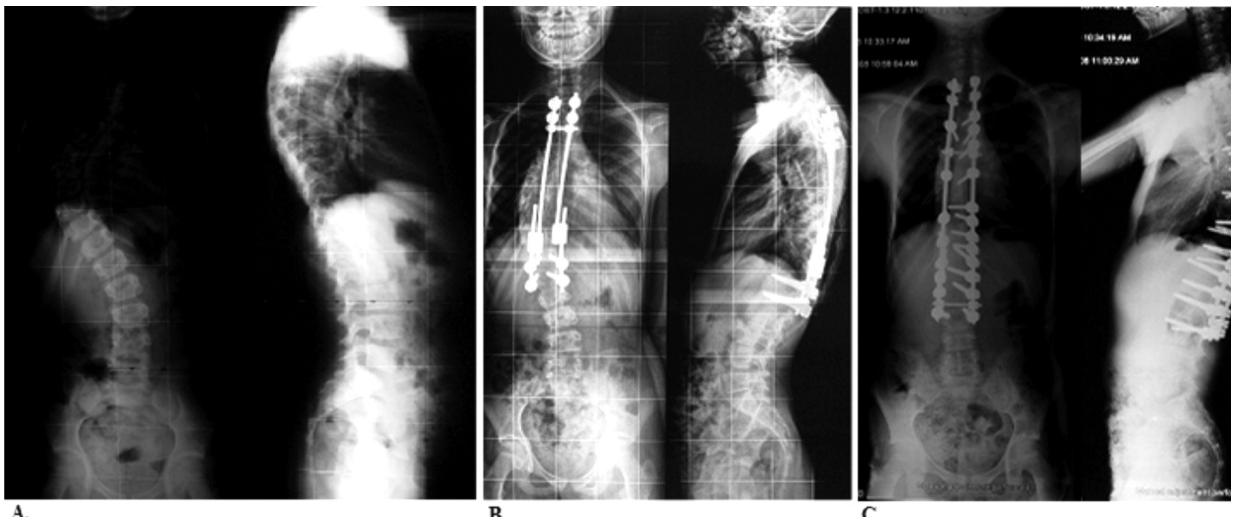

Figure-3. The patient T.Y. **A.** Preoperative anterior and lateral radiograph **B.** Anterior and lateral radiograph after one distraction **C.** Radiograph after fusion[11]

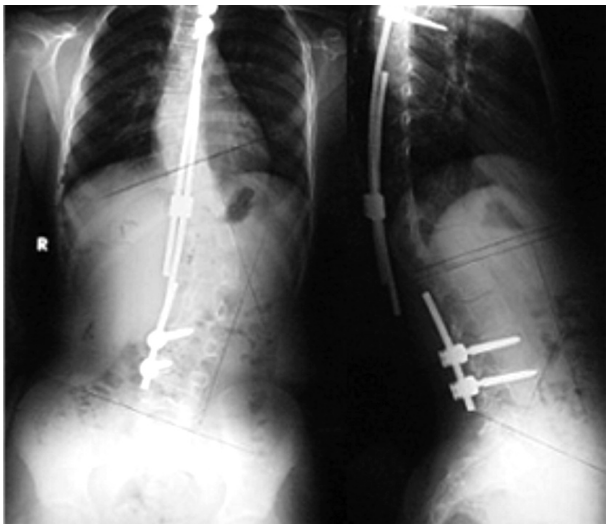

Figure-4. Rod fracture in patient B.T.

In the single growing rod technique, Morin defined the use of a claw for detection in the proximal and distal regions. A claw is composed of one or two distal vertebral segments included in a hook and a sublaminar hook placed in a supralaminar or transverse process[40].

Blakemore et al. defined the use of an apical isolated submuscular single rod with or without fusion. They did not report any spinal growth rates. Despite complications, the author believed that this technique was useful, due to the improvement of correction[13].

In studies performed with the single rod technique using the Blakemore and Harrington rod system by Mineiro[37] and Acaroğlu[1], similar results were obtained.

The difficulties in the correction of curvatures due to high complication rates and stiffness in the middle segment (the distracted part) triggered studies into the improvement of the technique. The aim was to reduce complication rates by improving the dual rod method.

Important modifications were made to the original rod designed by Harrington. Despite modifications in the use of the single rod, complications commonly developed. After the development of spinal instrumentation systems, Asher Isola defined the main principles of the use of instrumentation[9].

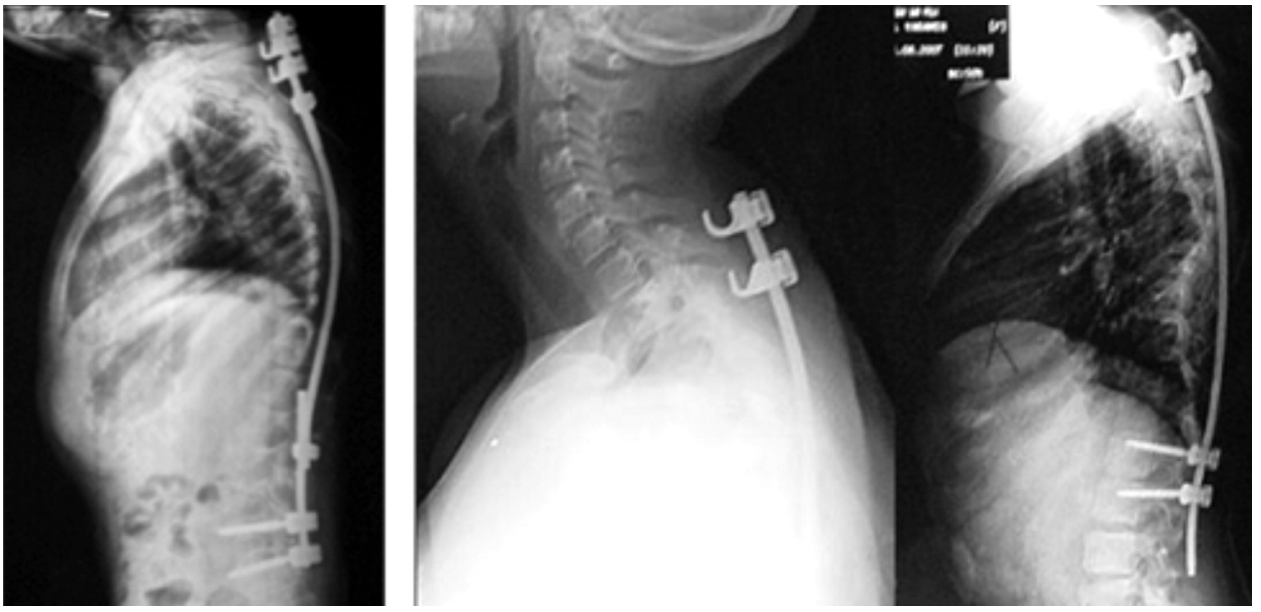

Figure-5. Dislocation of the upper hooks in patients M.K. and S.Y.

McCarthy defined the use of dual rods[35]. Akbarnia and Marks popularized the use of the dual extendable rod and played a role in its improvement[7,8].

McCarthy developed the shilla growing rod system and stated that application of this technique in humans was successful after conducting an animal experiment[36]. They placed pedicular screws at the convex of the curve. After correction, they applied limited fusion to this site. They placed shilla polyaxial screws specific to the cephalic and caudal parts. They aimed to provide dual stainless steel rods that allowed growth by automatically gliding through the screws in the caudal and cephalic parts[34].

The aim of the shilla growing rod technique is to prevent repetitive extensions.

The treatment of progressive curves in early-onset scoliosis has developed in recent years, and two surgical techniques (the dual growing rod technique and VEPTR) have come to the forefront.

FOR CURVES WITH WHICH ETIOLOGY DO WE CONSIDER THE GROWING ROD METHOD?

The aim of the growing rod technique is to provide and protect correction of the spinal deformity while allowing spinal growth. If the EOS includes surgical indication criteria, we can apply this technique to all curves with various etiologies. If there is no growth potential, this technique should not be used[6]. In a multi-center study, a consensus for some issues (curve amount, flexibility, etiology, age) has emerged for the use of the growing rod technique with spinal deformity. In multi-centered clinics, 265 patients received the growing rod technique. The average Cobb angles of the main curves were more than 50–60° (87%, curves more than 50°). It was observed that this system was preferred in children aged less than 8–10 (94% of them were under the age of 10)[54,55].

HOW DO WE ESTABLISH THE GROWING ROD SYSTEM?

According to the length of the vertebrae of the children, the preferred skin incision can be a single length midline or double midline. Two or three levels (at least two levels) should be preferred by preparing the upper and lower anchor sites subperiosteally. For fixation to distal or proximal vertebrae, hook, screw or claw options can be used. Rods whose contours are prepared can be submuscularly or subcutaneously placed to prevent any undesired fusion. The system is designed for maximum stability. The choice of position for the distal and proximal vertebrae is related to the diagnosis, type of curve, age of child and localization of curve. Generally, the T2–4 levels are preferred as an anchor site at the upper level. The position of the hook can be the transverse projections or supralaminar localization. At the lower level, the vertebra below the last vertebra under the scoliosis is chosen. The diameter of the pediatric rod is 3/16 inch (4.5 mm). The rods are cut into two segments and a sagittal contour is given to the rod. After placing the rods and connecting them with a tandem connection or domino, they are connected to anchors. The use of a transverse connection is usually used when the hook is used alone. Limited fusion is applied by introducing bone tissue to the edges of the fixation sites. Facet fusion is needed at this level for the stability of the fixation sites.

Rods prepared by tandem connection are connected to each other at the thoracolumbar junction, to give a minimal impact on the sagittal contour. The distraction process is applied from the tandem connection or domino. A brace is used until fusion occurs at the edges of the fixation sites, generally for six months. It has been shown that a corset minimizes spinal movement and protects the rod. The extension process is usually applied at six-month intervals[6,7].

To avoid sagittal complications due to a poor layout, the rod and proximal and distal fixation sites should be chosen to be suitable to the current skeletal structure. When junction kyphosis occurs or is initially present, the system should be established more proximally. A level choice at T1 should particularly be evaluated in terms of the junction kyphosis that can occur in this region.

In further extensions, the rod contour (suitable kyphosis and lordosis) should be checked. If the deformity is flexible and a sagittal layout is given to the rod, this can either form or correct kyphosis, due to the lever effect. If the deformity is initially present in the sagittal layout, placement of the instrumentation is more difficult. The risk of failure of the hooks or screws is greater in the presence of excessive sagittal deformity. Excessive sagittal correction should not be performed, in order to avoid implant dislocation[23].

DO WE PREFER SCREW OR HOOK AT THE PROXIMAL AND DISTAL BASIS POINTS OF GROWING ROD SYSTEM? SHOULD WE USE INTERCONNECTORS?

In a biomechanical animal study performed by Mahar et al., they placed screws and hooks in different combinations. They detected that maximum force was required to displace the system for a screw-screw interconnected group[29]. Generally, the use of four screws at two levels is preferred to secure the dual rod at the distal site[3-4]. In our cases, we observed less dislocation in the patients for whom screws were chosen for fixation, and more dislocation in the patients for whom the hook was preferred. The use of screws instead of a hook decreases the dislocation rate[10].

WHEN DO WE PERFORM SACROPELVIC FIXATION OF DISTAL ANCHORS IN THE USE OF THE GROWING ROD TECHNIQUE?

It has been shown that pelvic fixation is more effective in controlling the sagittal and coronal balance for patients with severe scoliosis (neuromuscular, syndromic) and/or kyphosis. In these patients, it seems that the use of pelvic fixation for the distal site is better tolerated, provides better body balance, and less rod fracture is observed.

Also, the lumbar lordosis is better protected. The use of a rod and screw instead of a hook is more effective for pelvic fixation[8,28,43,45].

SHOULD WE USE DUAL OR SINGLE RODS WHEN USING THE GROWING ROD SYSTEM? SHOULD THE SYSTEM BE PLACED SUBCUTOENOUSLY OR SUBMUSCULARLY?

In a multi-centered, retrospective study, it was shown that unplanned surgery and complication rates were less when using dual rods rather than a single rod. It was reported that wound problems, unplanned surgery and complication rates were less in the patients for whom the system was placed submuscularly[12].

In a study carried out by Thompson et al., they stated that the use of dual rods (compared to a single rod) provided better initial correction and maintenance of correction, allowed greater vertebral growth, and the complication rates were less[51,52].

According to our experience, in agreement with the literature, the complication rate seems to be less in the patients for whom a dual rod system was used, and more extension is obtained[10,53].

HOW IS THE DISTRACTION PROCEDURE APPLIED?

Tandem connectors or dominos are first palpated and then marked. Partial exploration is performed by entering through a small midline incision. The screws established at the end of each connector are loosened (especially proximal screws).

Generally, distraction is performed toward the proximal region. Then a distractor is placed between the rods in tandem connectors and the distraction process is applied. After distraction, the screws on the tandem connectors are tightened.

First, distraction is generally applied to the system on the concave side. Until the desired extension is reached, the distraction is gently applied.

If the rods are connected to each other by dominos for extension, the cutaneous tissue and fascia just over the domino is opened. A side of the domino is loosened and distraction is applied until further distraction of the rod becomes impossible. The loosened domino screws are tightened and the process is ended. The distraction time should be determined according to the progression of the curvature, the sitting height, the diagnosis, and the age.

However, the current approach is to apply distraction every six months.

When insufficient distraction is observed, the process is ended[5,30].

The surgeon should not apply too much force during distraction because implant failure or lamina fracture can occur. Especially during the first distraction, excessive distraction should be avoided.

Failure can occur if fusion has not yet occurred between the edges of the screw and the hook edges[5,7].

WHEN DO WE APPLY FUSION AFTER GROWING ROD USAGE? HOW DO WE DETERMINE FUSION LEVEL?

When making a decision regarding fusion in scoliosis, the curve progression, the growth potential of the vertebrae and the development of lung capacity should be considered. Factors such as chronological age, height, weight changes, skeletal and sexual development determine maturity.

Commonly used maturity determinants are the Risser sign, menarche age and chronologic age[42]. The lowest age limit for fusion is age 10 for girls and 12 for boys[50].

Maximum spinal growth is generally estimated from the iliac apophis cartilage complex and puberty development. When patients reach puberty, distraction should be ended and final correction and arthrodesis (posterior spinal

fusion) should be applied when there will be no benefit from further extension. Final arthrodesis generally includes the removal of current implants, new instrumentation of the vertebrae, and correction of the curvature, if possible[5].

The fusion level is chosen to be at the same levels that were initially established for distraction, if there is no progression in the curve. At the initial surgery, the maintenance of the sagittal and coronal balance is important. To avoid proximal junction kyphosis, it is necessary to place the top of kyphosis into the rod. Short instrumentation should not be used, especially for non-idiopathic cases[7].

DISCUSSION

Many authors have used the Harrington rod system and obtained good results. However, methods for improvement have been studied due to the high rate of complications (rod fracture, hook dislocation etc.). It is not clear to which ages and degrees of curvature the growing rod method should be applied. Similarly, it is not certain at what intervals the growing rod should be extended, and when fusion should be performed. Discussions are still ongoing.

In publications in which early-onset scoliosis was treated with the growing rod method, the average ages at the onset of treatment were as follows: 5.66 in the study by Mineiro[37], 6.7 in the study by Blakemore[13], 6.1 in Acaroğlu's[1] study, 5.3 in the study by Teli[48], 5.4 in the study by Akbarnia[7], and 6.1 in the study by Li[24]. In a study by Thompson, in which a single rod was used[51], the average age was 7 for the apical fusion group and 8.7 for the group without apical fusion, and it was 7 for the group for which the dual rod was used (Range: 5.3–8.7).

In a multi-center study, surgeons have indicated that surgery using the growing rod method was preferred for patients with a main curve with a Cobb angle of more than 50° [54].

The duration of the extension period is an important factor that affects the treatment period, growth, correction and number of complications. It has been suggested based on the literature that distraction should be routinely performed every six months, as better correction, more extension, fewer complications, less unplanned surgery and a shorter active treatment is provided for the groups where the duration of the extension period was less than six months[2,3].

In studies where early-onset scoliosis was treated with the growing rod method, the average fusion age was reported to be 12 in the study by Acaroğlu[1], 12.41 in the study by Mineiro[37], 11.2 in the study by Sponseller[44] (five patients) and 10.24 in the study by Akbarnia[7] (seven patients). Blakemore[13,54] stated that he performed spinal fusion when the age of the child was appropriate (generally 10 in girls and 12 in boys) and maturity occurred.

In a study by Thompson[51], the average fusion age in the single rod-apical fusion group was 10.9, while it was 11.7 in the group treated with only a single rod and 11 in the group treated with dual rods (Range: 10.24–12.42)

Thompson[51] analyzed patients treated with growing rods by dividing them into three groups, and showed that the best correction was seen in the dual rod group, followed by the group with no apical fusion and a single rod. The least correction was in the group with single rod treatment and apical fusion. They suggested

not applying apical fusion. In a follow-up of our patients, we observed that the use of dual rods provided better correction than the use of a single rod.

For patients with early-onset scoliosis that were treated with the single rod method, the average increase in T1–S1 in the literature was as follows: 2 cm in the study by Mineiro[37] (0.5–4.5 cm), 4 cm in the study by Acaroğlu[1] (1.8–7.7 cm), and 0.5 cm/year (an average of 1.9 cm) in the study by Teli[48] (11 patients received annulotomy from the anterior).

For patients with early-onset scoliosis who were treated with the dual rod method, the average increase in T1–S1 in the literature was as follows: in a study by Sponseller[46] it was 12.3 cm (1.84 cm/year) in a group receiving extension for less than six months and 8.78 cm (1.02 cm/year) in a group receiving extension for longer than six months, and 10.7 cm (1.46 cm/year) in all patients. It was 1.6 cm/year in the study by Li[24], and 2 cm/year in the study by Thompson[51]. In the study by Akbarnia[7], it was 11.78 cm (1.66 cm/year) in fusion patients, and 8.69 cm (1.01 cm/year) in patients receiving ongoing treatment (Range: 1.01–2 cm/year).

In the patient group that was treated with the single rod method in our study, we observed that the average length increase between T1–S1 was 1.54 cm/year, while it was 2.33 cm/year in the patients who received the dual rod technique[10].

In the studies in the literature where early-onset scoliosis was treated with the growing single rod method, the complication rates were as follows: 100% in the study by Mineiro[37] (70% due to implant, 59% rod fracture, 11% hook dislocation), 24% in the study by Blakemore [13] (55.5% hook dislocation, 33.3% rod fracture), 50% in the study by Acaroğlu[1] (46% due to implant, 30.8% hook dislocation, 7.7% rod fracture), 40% in the study by Teli[48] (30% due to implant, 15.4% rod fracture, 7.7% hook dislocation), and 19% in the single rod study by Thompson[51] (80% due to implant, 60% hook dislocation, 20% rod fracture) (Range: 19–100%).

In the studies in the literature where early-onset scoliosis was treated with the growing dual rod method, the complication rates were as follows: 45.5% in the study by Li[24] (100% due to implant, 20% rod fracture, 60% hook dislocation), 48% in the study by Akbarnia[7] (45.5% due to implant, 18% rod fracture, 18% hook dislocation), 29% of patients in the dual rod study by Thompson[51] (50% rod fracture), 22.7% in the study by Ahmadi[2] (100% due to implant, 40% rod fracture), and 46% in the study by Sponseller[46] (Range: 22.7–48%).

In our study, complications developed in 87.5% of the patients treated with the growing single rod method (75% due to implant, 33.3% rod fracture, 29.2% hook dislocation) and 57.1% of the patients treated with the growing dual rod method (57.1% due to implant, 14.2% hook dislocation).

The complication rate was also lower in our patients treated with the dual rod method, in agreement with the literature[10].

For patients with a follow-up of at least two years who received the dual rod method by Ahmadi[2] and where a screw was used as an anchor at the upper site, no anchor dislocation was reported in any patient. In a biomechanical study carried out by Mahar[29], it was found that the use of a

screw at the anchor sites was superior to the use of a hook.

In the literature, it has been shown that the use of dual rod and screws decreases complications due to the implant. Although fewer complications occur in the use of dual rods, high complication rates that are observed when using dual rods can be due to multiple factors. Immune deficits and weak bone quality may explain the high rate of complications, especially in syndromic and congenital scoliosis[24].

It has been stated that autofusion may occur in the use of growing rods. One debate surrounds the application of final fusion. Thickening in the periostea of the curve, a fibrotic bridge around the facet, and lack of sufficient mobilization despite removal of fibrotic tissues have been detected, and overcome with osteotomy to provide flexibility[1]. Distraction also increases the risk of spontaneous fusion (facet ankylosis due to excessive fibrosis[1,21]. Cahill[14] et al. treated nine patients with immature vertebrae with an extendible rod method and 89% autofusion occurred. In these patients, Smith-Petersen osteotomy was applied to seven patients during fusion, and correction was obtained.

The use of the growing dual rod technique has become quite popular in recent years. Successful results have been obtained with the use of the growing rod method for scoliosis with known etiology, but not for idiopathic scoliosis. The growing rod method has been used in the treatment of scoliosis with Marfan syndrome[44], cerebral palsy[56], myelomeningocele[33], neurofibromatosis[18] and congenital early-onset[19], and successful results have been reported.

It seems that the use of a growing rod (single or dual) is useful for the treatment of spinal deformity and allows spinal growth. Akbarnia and Thompson detected that the growing rod method protected correction safely and effectively, allowed spinal growth, provided sufficient stability and allowed the development and improvement of the thorax[3,7,46,50]. The application of dual rods is a technique that is more stable, stronger, and results in a greater increase at the T1–S1 space[5,7]. Akbarnia and Marks and some other authors obtained safe and effective results from periodical extensions with the growing rod method. In addition to providing better correction of the curve and allowing spinal growth, they reported fewer complications[2,7,51].

The growing rod method is problematic for the surgeon, the child, and the patient's family. With current techniques and without fusion, it is not possible to know how many surgeries will be required, which the families wish to know[6]. There is still no exact answer to the questions of when treatment should be started and when fusion should be performed[3]. The surgeon should be careful when choosing which patients will receive growing rod treatment. The surgeon should inform the family about potential complications, stages of surgical treatments, and the treatment period in detail[6].

Serial operations are needed in the use of growing rods to maintain correction. As a result, the risks of infection and implant failure increase. A remotely controllable magnetic growing rod system was developed for the solution of these problems, without the need for serial operations. However, results of this treatment are still unclear. Despite technical improvements, complications of the surgical

treatment of early-onset scoliosis still occur, and high complication rates (rod fracture, anchor luxation, wound problems, and layout disorders) are observed. Many operations are required for the growing rod technique. In addition, these children are at high risk due to comorbidity (especially pulmonary difficulties), and the treatment period is quite long. All extensions are performed under anesthesia[52]. For now, the growing dual rod method allows normal spinal growth with minimal limitations, and provides and maintains spinal and chest deformity corrections[6].

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