Serial Casting as a Delay Tactic in the Treatment of Moderate-to-Severe Early-onset Scoliosis

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Background: Serial casting can cure mild infantile idiopathic scoliosis. Its use in delaying surgery in older children and those with larger curves or syndromes is poorly defined.

Methods: A review of a single center's experience with casting was performed. Patients were included if they had a syndromic, neuromuscular, or congenital scoliosis or were older than 2.5 years with an idiopathic scoliosis measuring > 50 degrees.

Results: A retrospective review was performed on 29 patients meeting all inclusion criteria. Of these, 12 were idiopathic and 17 were nonidiopathic curves. Average age at first cast was 4.4 ± 2.1 years, and 3.0 ± 1.8 cast changes were performed over 1.4 ± 1.1 years. Patients were transitioned to a brace and followed up for 5.5 years (range, 2.2 to 11.4 y). The main thoracic Cobb angle before casting was 68.8 ± 12.3 degrees, which corrected to 39.1 ± 16.4 degrees in a cast. Cobb angle after cast removal was 60.9 ± 18.4 degrees, which increased to 76.3 ± 24.0 degrees at final follow-up. T1-T12 height increased to 1.1 ± 2.6 cm during the treatment period ($P = 0.05$). There were 5 minor complications. Fifteen patients (51.7%) required surgical treatment for their scoliosis at most recent follow-up and an additional 7 patients (24.1%) were delayed until a definitive anterior/posterior spinal fusion could be performed. Surgery was delayed 39 ± 25 months from the first cast. Growing rods were required in 8 patients (27.6%). The patients who ultimately underwent surgical intervention (SG) were more likely to have a larger postcasting residual main thoracic Cobb angle than those who did not require surgery [NS; 69.5 ± 14.6 degrees (SG) vs. 51.6 ± 17.9 degrees (NS), $P = 0.007$] and had a greater progression of their curves after cast removal [20.9 ± 13.5 degrees (SG) vs. 9.4 ± 11.0 degrees (NS), $P = 0.02$].

Conclusions: Serial casting is a viable alternative to surgical growth sparing techniques in moderate-to-severe early-onset scoliosis and may help delay eventual surgical intervention. Although a cure cannot be expected, an average of 39 months of delay was achieved in this patient cohort and 72.4% have avoided growing spine surgery.

Level of Evidence: Level IV, case series.

Key Words: early-onset scoliosis, scoliosis, casting, Mehta, growing rods, VEPTR

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Scoliosis affecting children less than 5 years of age, also known as early-onset scoliosis (EOS), continues to represent a significant challenge for the orthopaedic surgeon. Although nonoperative techniques such as serial casting or bracing have shown success in younger patients and those with smaller curves,[1–4] a transition toward the use of operative growing spine and chest wall-based techniques in moderate-to-severe scoliosis has occurred over the past decade.[5] Although still used in some centers for infants with idiopathic scoliosis (IS), serial casting is often no longer the choice in older children or those with progressive curves.[6] Growing rods (GR)[7–10] and the vertical expandable prosthetic titanium rib (VEPTR)[9,11–15] have filled a void in the management of more severe spinal deformity in the young patient as they allow pulmonary and spinal growth to occur while the scoliotic deformity is managed. The appeal of these techniques is unfortunately offset by the need for multiple surgical exposures and an increased risk of associated complications including wound healing problems, infection, premature fusion, implant failure, decreased chest wall compliance, and injury to local structures from hardware migration.[16–19] Although the lack of cure offered by serial casting in older children with larger curves limits its applicability as a definitive treatment,[2,20] the ability to delay surgical intervention becomes appealing in light of the complications associated with growing spine techniques. As no prior studies have assessed the benefits of serial casting in patients with moderate-to-severe EOS, we wished to analyze the results of serial casting for these more difficult deformities at a single center with delay in surgical intervention as the primary outcome measure.

METHODS

A retrospective review of all patients undergoing casting for scoliosis between 1998 and 2010 at a single institution was performed after an Institutional Review Board approval was obtained. Patients with IS were included if casting was begun after the age of 2 years 6 months or had a primary scoliosis of >50 degrees. Because Mehta[2] was

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unable to cure patients who began casting after 2 years 6 months and those with curves >50 degrees, we chose to specifically focus on this patient population to evaluate whether there was any benefit of casting in moderate and severe EOS. Patients were also included if they had any form of non-IS (syndromic, neuromuscular, or congenital etiologies), who traditionally fare poorly with nonoperative treatment. Patients were excluded if they were still undergoing casting at the time of review. All patients were followed up to a minimum of 2 years from the beginning of treatment.

Baseline demographics including age at presentation, age at first cast, underlying etiology (idiopathic, neuromuscular, syndromic, or congenital), preoperative magnetic resonance imaging (MRI) findings, duration of cast treatment, number of casts placed, age at cast removal, use of precasting halo traction, duration of postcasting brace wear, and eventual surgical intervention in appropriate patients were collected. Radiographic measurements included major curve magnitude (Cobb angle), thoracic and pelvic inlet dimensions as described by Emans et al,[21] maintenance or loss of correction after cast removal, and major curve magnitude after surgical intervention if appropriate. All measurements were made by a single author with both interobserver and intraobserver reliability measurements performed with a second observer.

Casting Technique

Patients were casted using either translational (Risser)[1] underarm casting or derotational (Mehta/Cotrel) casting.[4,22,23] Casting was performed under anesthesia on a standard Risser table using longitudinal traction across the chin cranially and the pelvis caudally. A silver-impregnated casting shirt (Knit-Rite, Kansas City, KS) was used to minimize skin irritation and act as an antimicrobial layer. A layer of cotton webril was used for padding. A plaster cast was then applied and appropriate molding performed. A final layer of fiberglass was rolled over the plaster to provide support and increase the cast durability. It should also be noted that placing a plaster cast first minimizes the potential for increased peak pulmonary pressures seen with an application of a fiberglass cast alone as the fiberglass tends to contract as it hardens. The cast was applied either underarm or over the shoulder according to surgeon preference. Risser casting was performed using a 3-point translational force focused on the apex of the curve (Figs. 1, 3). The cast was then trimmed to minimize irritation of the axilla and iliac crests. A large abdominal window as well as a relief window over the concavity were removed. A change in casting technique came as a result of Dr Mehta visiting our institution in 2007 and has been adopted by all physicians since.

The Mehta derotational casting varied somewhat as the correction is performed using a combination of derotational and translational forces on the posterolateral aspect of the rib cage at the level of the deformity (Figs. 2, 3). An over-the-shoulder jacket is created and relief windows are cut. X-rays were obtained on the day of surgery after the cast was placed and the child awakened. Interval x-rays were occasionally obtained in older children where the cast was left for a longer time period. Casts were routinely changed between 3 and 4 months depending on the age of the child. Cast removal was left to the surgeon's discretion. A custom-molded thoracolumbarsacral orthosis brace was prescribed when curve correction was maximized and believed to be stable enough to transition into a brace. Lack of efficacy was demonstrated by curve progression, when the family requested discontinuation of the cast due to patient tolerance, or a complication occurred in the cast requiring removal. No data were collected to monitor brace compliance.

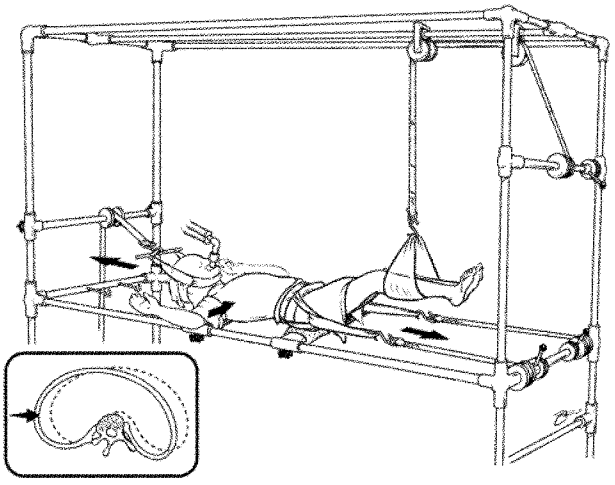

FIGURE 1. Risser/translational casting. Note that curve correction is accomplished through lateral translation. See text for details.

Statistical Analysis

Differences between 2 rates were compared using the Fisher exact test. Differences between the means of 2 independent groups were compared using the Student *t* test, assuming unequal group variances. Changes measured on a per-patient basis were assessed using the paired *t* test. Correlations between continuous variables were

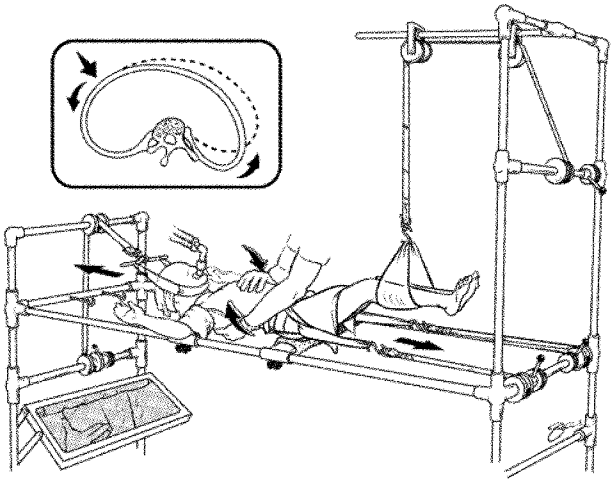

FIGURE 2. Mehta/Cotrel derotational casting. Note that curve correction is accomplished through spinal derotation.

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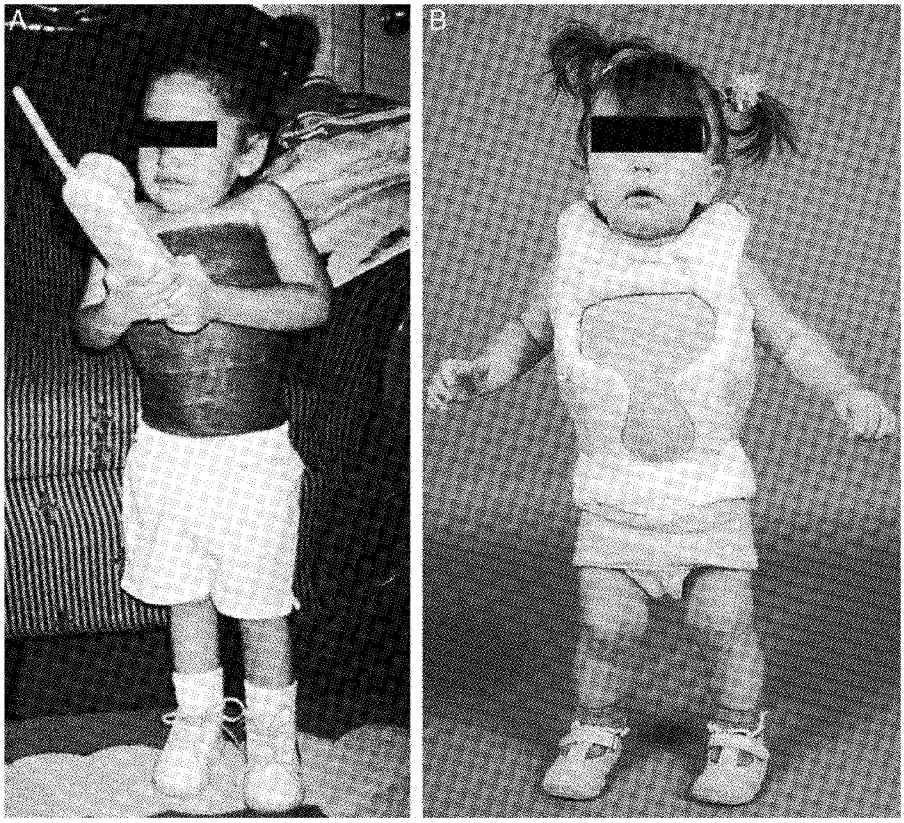

FIGURE 3. A, Child in Risser underarm translational cast; (B) child in a Mehta/Cotrel derotational cast with over-the-shoulder molding.

assessed using the Spearman correlation coefficient, so that the effect of outliers or extreme values could be minimized.

RESULTS

Twenty-nine patients treated with serial casting for progressive scoliosis at a single institution between 1998 and 2010 met all inclusion criteria. One patient had an associated congenital spinal anomaly, 14 had an underlying syndrome, 2 had a neuromuscular condition, and the remaining 12 patients had no discernable underlying condition despite a thorough workup with a developmental pediatrician. This latter group was deemed to be idiopathic. MRI of the spine was used routinely before initial casting with 28 of the 29 patients having a precast MRI available for review. Eight patients (28.6%) had neural axis abnormalities on MRI before initial casting, with 6 of these 8 patients (75%) requiring neurosurgical intervention.

Baseline Characteristics

The average age at first casting was 4.4 ± 2.1 years and patients were followed up for 5.5 years (range, 2.2 to 11.4 y). The patients underwent 3.0 ± 1.8 cast changes over 1.4 ± 1.1 years. Nine of the 29 patients (31.3%) underwent derotational Cotrel/Mehta casting, whereas 20 (68.7%) underwent translational Risser casting. Major curve magnitude before casting was 68.8 ± 12.3 degrees, which was corrected to 39.1 ± 16.4 degrees (45.4 ± 16.8%) in a cast. There was no difference in initial correction obtained between those children treated with a Risser cast and those with a derotational cast. Curve magnitude after cast removal was 60.9 ± 18.4 degrees, which subsequently increased to 76.3 ± 24.0 degrees at the final follow-up (Figs. 4, 5). T1-T12 thoracic height was measurable in all 29 patients and increased by 1.1 ± 2.6 cm ($P = 0.05$; Fig. 6), whereas pelvic width increased by 0.5 ± 0.7 cm ($P = 0.009$) from initial cast to either final follow-up (in those patients still undergoing nonoperative treatment) or the preoperative x-ray (in those who underwent surgery). Body mass index decreased by a clinically insignificant mean amount of 0.1 kg/m^2 during this same time period ($P = 0.67$).

Intraobserver and interobserver reliability studies were performed on major Cobb angle, T1-T12 height, and pelvic width using 2 independent observers. Intraclass correlation coefficient was very good for all the 3 (0.94, 0.98, and 0.98, respectively). Interclass correlation coefficient was also very good for all values (0.96, 0.97, and 0.98, respectively).

There were 5 known complications related to casting, which were noted in the clinical chart. Three patients had skin irritation, which resolved with cast removal, local skin care, and a short delay before the next cast. One patient required cast removal on the first postoperative

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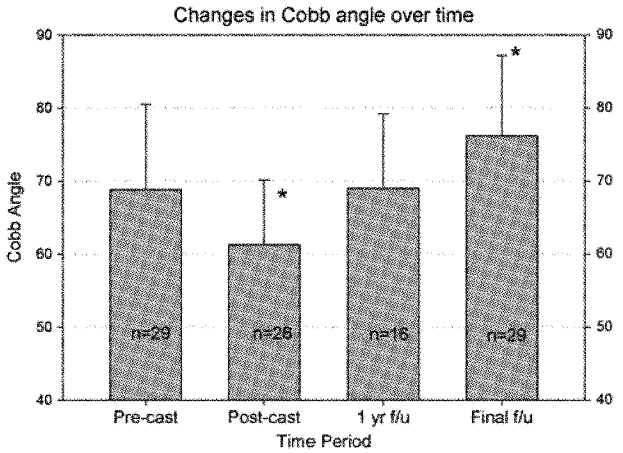

FIGURE 4. Change in Cobb angle from precasting to final follow-up at different time intervals. * represents statistically significant differences ($P<0.0001$) between postcast and preoperative Cobb/final Cobb angle (out of brace) for all patients.

day for vomiting, which was attributed to overzealous molding of the cast. One patient with a seizure disorder had an increase in the frequency of her seizures while in the cast requiring early removal. Although the retrospective nature of this study limits the ability to survey parents, there was no documentation in the clinical notes concerning cast intolerance.

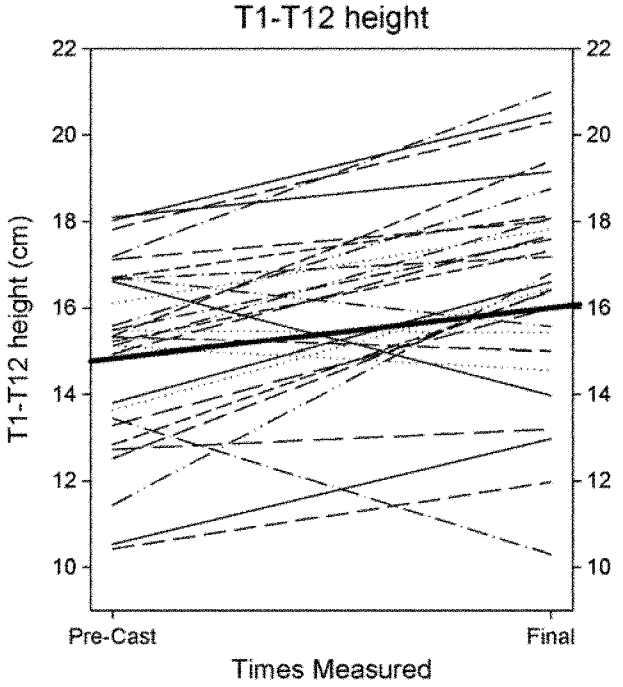

FIGURE 5. Change in thoracic height over time for all patients. Thoracic height was measured from T1-T12 and increased to 1.1 ± 2.6 cm ($P=0.05$) over the treatment period.

Associated Conditions

The patients were grouped according to etiology, with 17 patients having an associated or underlying condition referred to as non-IS (NIS; Table 1) with 12 having IS. The rib vertebral angle difference as described by Mehta averaged 42.2 ± 12.2 degrees in patients with IS and all patients had a phase II rib at initial presentation. As rib vertebral angle difference has not been formally described for neuromuscular or congenital curves, it was not measured in these cases. There was no difference between groups with regards to age at first cast [4.7 y (NIS) vs. 3.9 (IS), $P = 0.37$]. There was a larger precast magnitude in the NIS patients (72.2 vs. 63.4 degrees, $P = 0.05$) but no difference in percent correction with casting [44.5% (NIS) vs. 46.5% (IS), $P = 0.76$]. There was a greater initial loss of correction after cast removal (postcast magnitude 67.5 (NIS) vs. 51.5 degrees (IS), $P = 0.01$]. Curve magnitude either preoperatively or at the most recent follow-up was greater in the NIS patients; however, this did not reach statistical significance (80.6 vs. 69.8 degrees, $P = 0.21$). Six of the 12 patients in the IS group and 9 of the 17 patients in the NIS group have undergone surgical intervention at this time.

Age at Casting

Patients were grouped based on age at initial casting of ≥ 5 years. Fourteen of the 29 (48%) patients comprises the younger group (≤ 5 y), whereas 15 (52%) patients were in the older group. There was no difference in initial curve magnitude between groups. There was a trend toward older children undergoing fewer casts (2.5 vs. 3.6, $P = 0.09$) and less time in a cast (1.0 vs. 1.7 y, $P = 0.1$) when compared with younger patients. A similar amount of correction for both groups was obtained in the first cast (48.0% vs. 43.2%, $P = 0.46$) and there was no difference in final Cobb angle [79.4 (older) vs. 72.8 degrees (younger), $P = 0.45$]. There was no difference in the need for surgical intervention at follow-up between groups [8/14 (younger) vs. 7/15 (older), $P = 0.7$].

Surgical Intervention

Of the 29 patients evaluated, 15 (51.7%) had undergone surgery at final follow-up. Surgery was delayed an average of 39 ± 25 months in these patients from the first cast. Patients requiring eventual surgery (SG) had a larger, but statistically insignificant, precast thoracic Cobb angle than those who did not require surgery [(NS); 71.8 ± 12.5 degrees (SG) vs. 65.6 ± 11.8 degrees (NS), $P = 0.18$; Table 2]. As 7 staff surgeons participated in the care of these patients, varying indications for surgical intervention existed. All patients who had undergone surgery were believed to have significantly progressive curves resistant to cast treatment. The patients who ultimately underwent surgical intervention were more likely to have a larger postcasting residual main thoracic Cobb angle (69.5 ± 14.6 vs. 51.6 ± 17.9 degrees, $P = 0.007$) and a greater progression of their curves after cast removal [20.9 ± 13.5 degrees (SG) vs. 9.4 ± 11.0 degrees (NS), $P = 0.02$]. Patients who have thus far been managed

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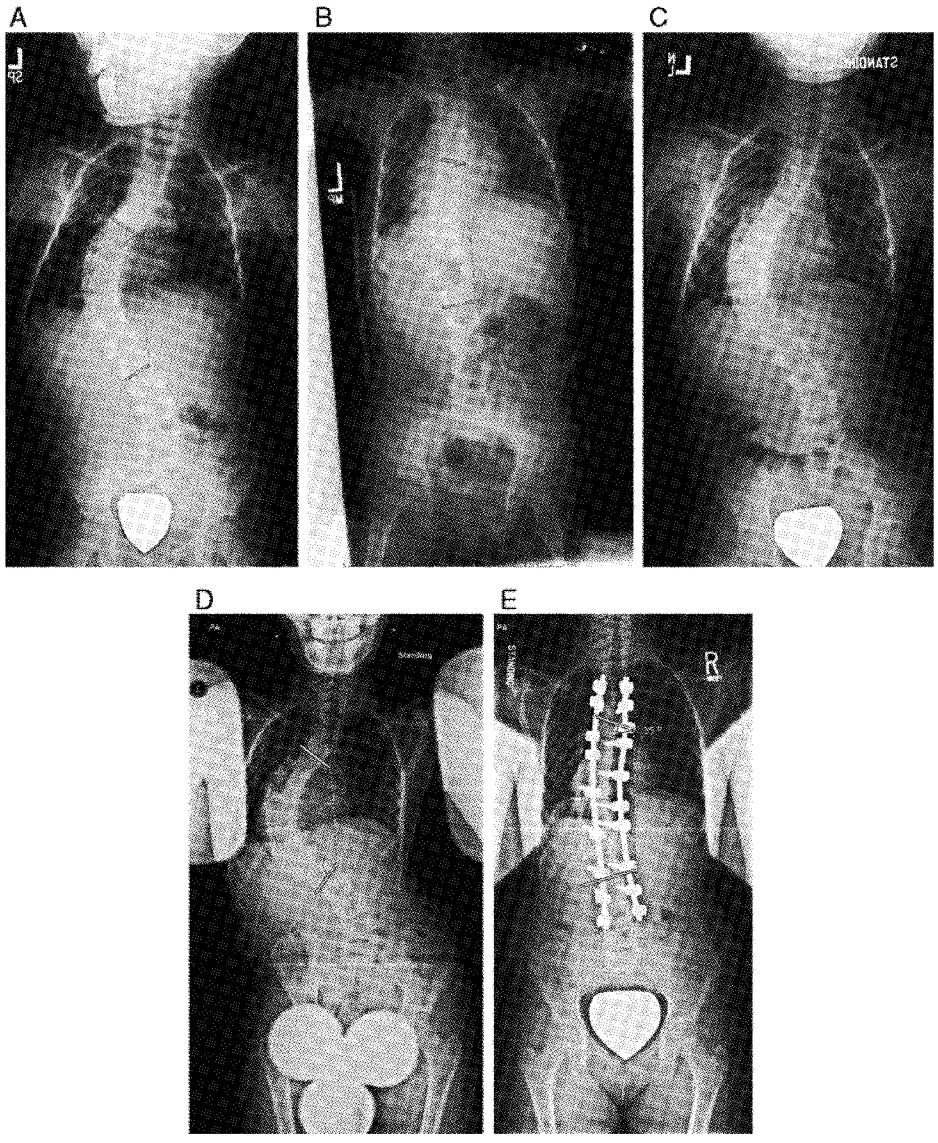

FIGURE 6. Child initially casted at age 3 years 3 months for progressive idiopathic scoliosis despite brace treatment. A and B, Precast and postcast x-rays at age 3 show good correction in a cast. C, The patient was transitioned to a brace for a short break in casting before being transitioned back into a cast at age 5. D and E, Curve progression occurred and the child underwent anterior thoracoscopic release and posterior spinal fusion at age 10 years 6 months. The total delay between initial casting and surgery was 87 months.

nonoperatively have maintained their curve magnitudes when compared with those requiring surgery (preoperative Cobb 90.5 ± 9.2 degrees in SG vs. most recent out of brace Cobb in NS group 60.9 ± 24.1 degrees, $P = 0.0005$) Children with IS were no more likely to require surgery than those with syndromic, neuromuscular, or congenital scoliosis (40% vs. 53%, $P = 0.71$). Neither age at presentation nor time from initial visit to the first cast correlated with eventual surgery. The presence of intrathecal abnormalities on MRI was not associated with an increased need for surgical intervention ($P = 0.42$).

Seven of the 29 patients (24.1%) had a definitive combined anterior/posterior spinal fusion (ASF/PSF; Fig. 6), whereas 8 (27.6%) patients had GR placed. Decision for surgical intervention was made at the surgeon's discretion. Definitive fusion was used in children who are believed to have achieved adequate thoracic height and pulmonary development, whereas GR have been used more for children with significant thoracic growth remaining, although this was based on the surgeon's evaluation. The retrospective nature of this study limited our ability to define true surgical indications; however, circumferential fusion was used rather than PSF alone in children less than 10 years of age in an attempt to avoid the crankshaft phenomenon. Patients requiring eventual circumferential fusion were older at presentation (6.0 vs. 3.3 y, $P = 0.004$) and older at the time of surgery (9.3 vs. 6.1 y, $P = 0.004$). There was a trend toward a longer delay to surgery in those undergoing ASF/PSF (2.2 vs.

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TABLE 1. Patients With Idiopathic Scoliosis Versus Those With Nonidiopathic Scoliosis

	Idiopathic (n = 12)	Nonidiopathic (n = 17)	*P*
Age at initial cast (y)	3.9 ± 2.2	4.7 ± 2.1	0.37
Time in cast (y)	1.26	0.95	0.42
Precast Cobb	63.4°	72.2°	0.05
Correction in cast	46.5%	44%	0.76
Postcast Cobb	67.5°	51.5°	0.01
Preoperative or most recent Cobb	80.6°	69.8°	0.21

See text for details.

1.0 y, $P = 0.09$). Preoperative primary curve Cobb angle was 90.5 ± 9.2 degrees, which corrected to 38.9 ± 17.3 degrees for those with circumferential fusion and 51.1 ± 11.5 degrees for those with GR ($P = 0.15$; Figures 6A–G). There was no difference in preoperative Cobb angles between groups [91.6 ± 6.8 degrees (GR) vs. 89.5 ± 11.2 degrees (ASF/PSF].

Patients treated with a Risser cast were more likely to require surgical correction than those treated with a Mehta cast (Risser 72% vs. Mehta 20%, $P = 0.0142$), although it must be noted that the follow-up in the Mehta casting group was significantly shorter (2.6 ± 1.4 vs. 4.7 ± 2.9 y, $P = 0.009$). There was no difference in the number of casts required between patients treated with Mehta versus Risser casting ($P = 1.0$)

DISCUSSION

IS is traditionally classified according to age of onset by the Scoliosis Research Society as infantile (less than 4 y old) or juvenile (between age 4 and 10), whereas Dickson[24] has less specifically identified EOS as deformity of any etiology occurring at less than 5 years of age Unlike adolescent IS, moderate and severe curves in this younger population can have profound physiologic effects, primarily respiratory, on the child. Pehrsson et al[25] found a significantly higher long-term mortality rate among patients with untreated infantile, juvenile, and "scoliosis of unknown cause." Patients with "severe" scoliosis (Cobb angles >70°) also had a higher mortality rate. The predominance of deaths was related to pulmonary failure. Spinal growth peaks during the first 5 years of life, whereas pulmonary development occurs until age 8. Severe scoliotic curves in the young child have a detrimental effect on pulmonary function.[26,27]

Before the advent of growth-sparing techniques, spinal fusion was the only reliable treatment for scoliosis that could not be controlled by nonoperative measures. Although progressive scoliosis could theoretically be better prevented using combined ASF/PSF, Goldberg et al[28] failed to show efficacy of circumferential fusion at controlling deformity. Continued deformity in the setting of ASF/PSF was found to impact both pulmonary growth and overall spinal cosmesis. Karol et al[29] reported that children who had undergone ASF/PSF at an average age of 3.3 years had a forced vital capacity of 57.8% of age-matched normal values on pulmonary function testing when measured at skeletal maturity. Furthermore, the extent and location of spinal fusion impacted forced vital capacity. As a result of these 2 studies documenting less than ideal outcomes from early definitive fusion, alternatives to fusion and delaying tactics have been more actively used in early-onset deformity.

Fusionless spine techniques with single or dual GR have been used for nearly 2 decades. Akbarnia and colleagues reported excellent curve correction in 23 patients with idiopathic, congenital, and syndromic scoliosis. Curves were reduced from 82 degrees preoperatively to 36 degrees at the final follow-up, whereas almost 9 cm of spinal growth as measured from T1-S1 was obtained. These children underwent 6.3 lengthenings after the index procedure and complications occurred in 48% of patients.[30] Similar results have been confirmed in other studies.[8] Bess et al[31] recently reported on 140 patients treated for EOS with GR and found a 58% complications rate with a 24% increase in complications for each additional procedure performed. The use of dual-growing rod systems may decrease the incidence of complications, however, implant migration, hardware failure, and wound healing issues still remain. Sankar et al[18] have also recently described a progressive decrease in spinal length gained at each lengthening surgery, presumably related to autofusion of the spine. This was especially notable after the seventh lengthening procedure.[18] Noordeen et al[32] similarly found the force required to expand the spine

TABLE 2. Patients Requiring Surgical Intervention Compared With Those Who Have Had Not Required Surgery at Most Recent Follow-up

	Surgical Group	No Surgery	*P*
Precast Cobb	71.8 ± 12.5 degrees	65.6 ± 11.8 degrees	0.18
Idiopathic	40%	60%	0.71
Risser cast	78%	22%	0.05
Time in cast	1.07 y	1.62 y	0.16
Loss of correction out of cast	20.9 ± 13.5 degrees	9.4 ± 11.0 degrees	0.02
First out of cast Cobb	69.5 ± 14.6 degrees	51.6 ± 17.9 degrees	0.007
Preoperative or final out of brace Cobb angle	90.5 ± 9.2 degrees	60.9 ± 24.1 degrees	0.0005

See text for details.

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during growing rod lengthening to roughly double at by the fifth procedure. Length obtained after the fifth lengthening averaged only 8 mm at each surgery. These studies suggest that a 4-year-old child treated with GR might reach a level of "diminishing returns" in spinal lengthenings before full lung development. Casting may represent a viable alternative to fusionless surgery in this situation, as patients in our series benefited from a 39-month surgery delay, or the equivalent of nearly 7 growing rod lengthenings.

Expansion thoracoplasty using the VEPTR (Synthes, Paoli, PA), first described by Campbell in 2003, is indicated in the management of thoracic insufficiency syndrome related to idiopathic,[33] congenital,[15] and neuromuscular[13,34] scoliosis and has provided an opportunity to treat previously fatal conditions caused by thoracic dysplasia. Although the pulmonary and physiologic benefits of VEPTR in children with thoracic insufficiency syndrome are becoming increasingly clear, the high incidence of complications continue to dampen enthusiasm for use in idiopathic and neuromuscular scoliosis.[35–37] Sankar et al[17] found a complication rate of 2.3 per patient treated with GR and 2.7 per patient treated with VEPTR. Seventy-two percent of patients required an unplanned surgical procedure for rod breakage, hardware migration, or infection. In contrast, a total of 5 complications were noted in this series of cast applications, representing 17.2% of patients, and 3 of these were minor skin irritations.

When diagnosed early, mild infantile scoliosis has been successfully treated and cured with serial casting. Mehta et al[2] reported long-term follow-up on 94 patients with scoliosis treated first at 19 months of age with an average Cobb angle of 32 degrees. No child had significant scoliosis at age 3 years 6 months nor had any child undergone surgery at 10-year follow-up. A second group of patients were noted to achieve incomplete correction. These patients were older at their initial casting (age 2 y 6 mo) and had larger curves averaging 52 degrees. Although the scoliosis in these patients was reduced, no child had resolution of their scoliosis at follow-up at age 10 years 4 months. Thirty-five percent required combined ASF/PSF by 12 years and 3 months of age. Although viewed as treatment failures in light of the comparison group who had been successfully cured of scoliosis, these children achieved both spinal and pulmonary growth in the period before their definitive surgery, thus lending justification to the technique by virtue of the growth achieved by delaying surgery with casting. Sanders et al[23] have recently led a North American resurgence of casting and reported treating 55 patients age 2.2 years with curves of 52 degrees including a subset of 14 patients casted at age 3.1 years for curves averaging 71 degrees. Nine total patients underwent surgery at final follow-up, however, the delay offered by casting is not specified.

Patients in our series were casted at an average age of 4.4 years, which represents a much older population than previously reported. This group included 17 patients with congenital scoliosis or an associated neuromuscular condition, a subgroup, which previously has not benefitted from casting. The average Cobb angle before casting was 68.8 degrees. Surgery was successfully delayed 39 months in approximately half of the patients, whereas the remainder have not required surgery and are still being managed in a brace. As 7 children (24.1%) were casted until definitive fusion at 9.3 years of age, these patients may be viewed as casting successes, whereas the 7 patients (27.6%) who eventually were converted to GR at age 6.1 years should represent more of a failure of casting to control the curve. In all, 72.4% of all patients have "avoided" growing spine surgery at an average of 5.5 years' follow-up. Not surprisingly, children who began casting at an earlier age were more likely to require growing spine surgery than those who started later. In the surgical patients, the Cobb angle was not significantly larger before casting than in those who have not required surgery (71.8 vs. 65.6 degrees, $P = 0.18$); however, most of the correction was lost at the final follow-up (20.9 vs. 9.3 degrees, $P = 0.02$). The presence of an associated neuromuscular or syndromic condition did not correlate with surgical intervention, although this may be limited by the small sample size, suggesting that casting may benefit this nonidiopathic population. Despite the significant preoperative curve size, patients could expect a roughly 50% correction in Cobb angle after surgery, perhaps due to the technically more robust corrective maneuvers possible with the older and presumably larger spinal elements. Thoracic growth as measured by T1-T12 height increased by a small but statistically significant 1.1 cm during treatment, suggesting that pulmonary development may not be overly delayed by casting.

Cast technique plays an important role in deformity management. Patients treated with a Risser cast were more likely to progress to surgery than those treated with a Mehta cast, however, Risser cast patients have been followed up almost twice as long and thus this observation must be interpreted carefully. Thoracic growth, measured by T1-T12 height, increased by a small but statistically significant 1.1 cm treatment, hopefully providing a positive effect on pulmonary development. In contrast, thoracic width was not measurable on many x-rays due to breast shielding. Any detrimental effects to rib and chest wall morphology produced by casting could therefore not be evaluated by radiographic analysis. In addition, the possible effects of casting on pulmonary function were not measured but present an area for future study. We currently use derotational casting, either over or under the shoulder, in most patients. It should be noted that these techniques require special equipment and training.

This study is limited by the traditional shortcomings inherent to retrospective studies as well as the relatively short-term follow-up of 5.5 years. Because of the limitations related to the retrospective nature of this study, we are unable to determine the specific indications for casting other than a progressive curve, which was resistant to other nonoperative modalities. The lack of a control group is also a significant limitation. In an attempt to limit radiation to this young patient population, thoracic width was not measurable on many x-rays due to breast shielding. Although thoracic height did increase during the overall treatment course, it

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remains difficult to interpret this longitudinal data as the initial descriptive study by Emans et al[21] used only cross-sectional data. Finally, the effects of casting on pulmonary function were not measured but certainly present an area for future study.

In conclusion, serial casting is a viable alternative to fusionless surgical techniques in delaying eventual surgery in many patients with EOS. We are unable to compare casting techniques based on the current data. The overall complication profile of serial casting is appealing and the morbidity remains low if careful attention is paid to proper technique. Nearly 75% of patients in this cohort have avoided growth-sparing surgery and its associated complications 5.5 years after initial casting. Further follow-up of patients currently being braced after casting will ascertain the value of and indications for continued delaying tactics before surgical treatment in EOS.

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