Concave Side Apical Control in Early Onset Scoliosis Managed with Growing Rods

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Abstract:

Objective: To evaluate curve correctability, complications, and rate of growth following treatment.

Background: Distraction-founded techniques such as traditionally growing rods or magnetically controlled growing rods are the almost globally accepted management patterns for early onset scoliosis. However, periodic lengthening operations are still needed. Moreover, an MCGR is difficult to contour, and implant-associated problems are common. We developed concave side apical control of the growing rod in which an additional anchor site is inserted at the apex to enhance stability and assist in the adjustment of axial deformity.

Methods: Entirely skeletally immature early onset scoliosis (EOS) cases with a progressive curve of >40° and without bone or soft tissue weakness were appropriate for this study. Coronal Cobb angle, sagittal parameters, complications, spinal length, and reoperations were documented with at least a 3-year follow-up.

Results: In this study, 15 patients were involved. The mean age was 7 years. The mean preoperative Cobb angle was 48°, which postoperatively became 12° with the percentage of coronal correction reaching 75.73%. The mean Cobb angle degrees of correction were 39°. T1-S1 height increased by 10 mm/year. Postoperative complications occurred in two cases with single rod technique and rod breakage.

Conclusions: The concave side apical control of the growing rod seems to be a hopeful surgical procedure for the management of EOS. Curve correctability in patients was 60% and can be sustained for a minimum of 2 years. Reoperations and complications might not be constricted, but the complication frequency looks more reasonable than in the current systems.

Keywords:

Apical control, Distraction, Early onset scoliosis, Growing rod, Growth-friendly

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Introduction

For most spine surgeons, early onset scoliosis (EOS) poses a challenging condition to address. In addition to maintaining satisfactory body outgrowth, proper assertion must be assigned to ensure appropriate balance, alignment, and holding of the deformity from progression. Distraction-founded techniques like traditional growing rods (TGRs) or magnetically controlled growing rods (MCGRs) are the almost globally accepted management patterns[1,2]. These implants undertake the function of an inside brace to hold the deformity progression by ensuring balance and letting the growth of the body[1,2]. These implants require to be anchored to the cranial and caudal fixation sites commonly formed by two vertebrae proximally and two vertebrae distally, and intermittent distractions attain the required lengthening of the body[3-6].

TGRs were commonly applied in severe cases of EOS during the last decades but required periodic operative distraction under general anesthesia associated with comparatively elevated rates of infection[7,8]. MCGRs were presented approximately 10 years ago and were first published in 2012[9]. They are recommended for single or dual rod submission along with the requirements of each patient. MCGRs permit for non-invasive lengthening of the rod via electromagnetic stimulus without anesthesia[9].

Thus far, periodic lengthening operations are still needed. Furthermore, the MCGR is difficult to contour, and implant-

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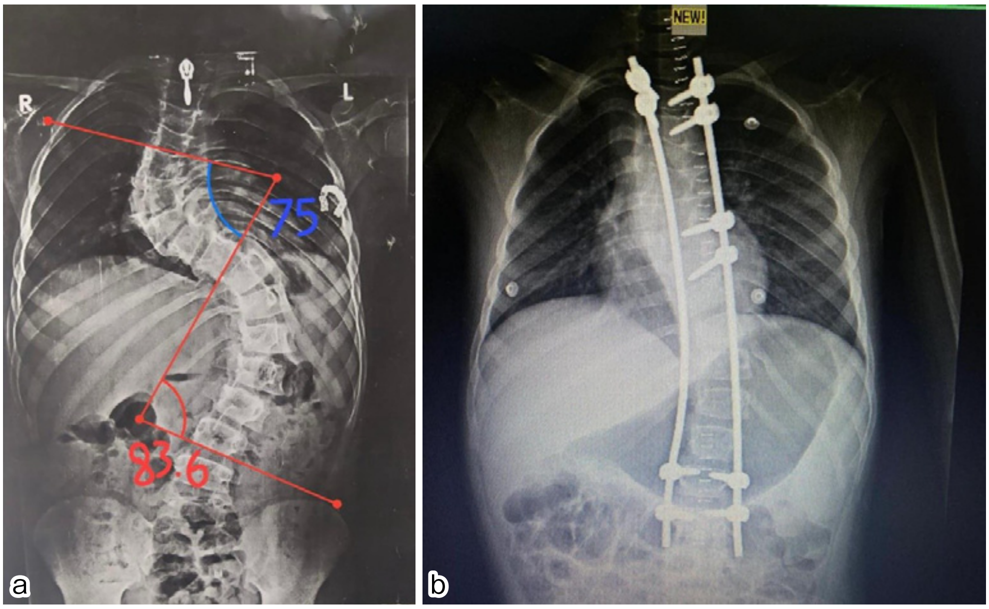

Figure 1. Figure 1 shows (a) preoperative and (b) postoperative X-rays using the double rod technique.

associated complications are common, with a prevalence of nearly 50% in the initial 4 years[10]. Most of these complications are mechanical, including rod fractures, anchor failures, and a failure to distract[11]. The last category has specific failure methods of the interior mechanism (e.g., screw fractures or drive pin) and is assumed to be produced by elevated-attritional forces inside the actuator[12,13]. Although recent varieties of MCGRs have evolved, mechanical complications persist[14].

Current reviews have reported that fewer than one in five retrieved MCGRs work yet as planned[15-17]. MCGRs are also an expensive system, impeding their usage in enormous portions globally. To handle these problems, we developed concave side apical control of the growing rod, in which an additional anchor site was inserted at the apex to enhance the stability and assist in axial deformity adjustment[18]. For better correction, spine development, and lesser implant-associated problems, double rods as an alternative to single rods have been recommended in TGR management[10,19].

The technique used in this study is carried out to allow apical control and decrease the apical rotation that occurred with the use of TGRs, therefore halting the deformity progression and facilitating the definitive correction of deformity when conducted.

We intended to evaluate the curve correctability, rate of growth, and complication rate following treatment during a minimum of 3-year follow-up.

Materials and Methods

The study has been approved by the IRB of the spine unit at Ain shams university hospitals (R315/2023). In this study, 15 patients were involved. Entirely skeletally immature (i.e., open triradiate cartilage on roentgenogram) EOS cases since 2017 with a progressive curve of >40° for an indication for growing rod operation were included. Patients with bone diseases such as osteogenesis imperfecta were excluded. For the present study, only cases with a minimum of 3-year follow-up were involved. Such research complied with STROBE recommendation for reportage observational reviews[20].

Preoperative clinical and radiological investigations were carried out. Clinically, the muscle power, abdominal reflexes, appearance of a hump, shoulder asymmetry, and pelvic obliquity were assessed. Additionally, echocardiography and pelviabdominal ultrasound for evaluation of the kidneys were conducted. Employing the Cobb angle, the degree of scoliosis and dorsal kyphosis were calculated on the posteroanterior and lateral spine radiographs. MRI whole spine was conducted on all patients to exclude spinal cord anomalies.

Surgical technique

All cases were operated on by the same team of surgeons. Surgery was conducted via a posterior midline skin incision, by separate small incisions after level identification by C-arm. Pediatric pedicle screws were placed via the freehand technique at the three pre-planned sites for pedicle screw placement, identified using an image intensifier. Single and double rod techniques can be carried out (Fig. 1, 2). In the single rod technique, the rod was placed on the concave side, whereas in the double rod technique, which was more rigid and more stable, the rods were placed on both convex and concave sides.

Pedicle screws are put at the planned proximal and distal anchorage sites on the convex and concave sides with additional screws added to the apex of the curve on the concave side to achieve apical control and fusion. The rods are

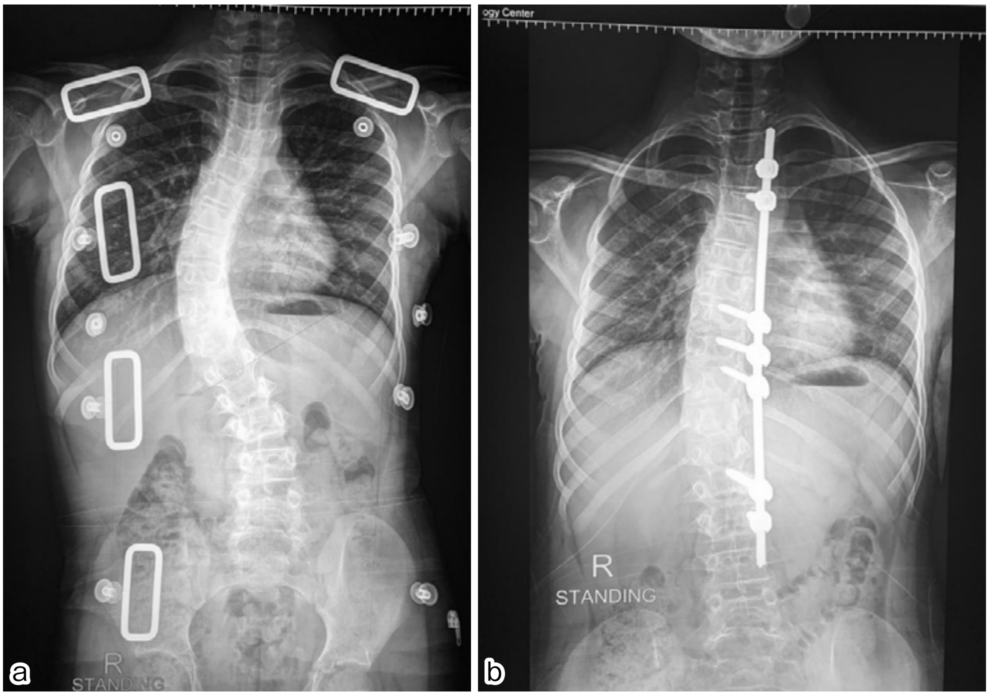

Figure 2. Figure 2 shows (a) preoperative and (b) postoperative X-rays using the single rod technique.

passed sub-muscularly and fixed with nuts to the screws. The rods are contoured with dorsal kyphosis and lumbar lordosis. The rod diameter was 5 mm and was made of titanium. In curves with a high Cobb angle, rod derotation on the concave side was carried out to correct the deformity and aid in rod placement within the anchor sites.

The concave side is the correction side so when a single rod is put, it will be on the concave, not the convex, side; moreover, when putting screws on the convex side, more than 3 years of growth remaining to auto-correct is needed, but with our technique, full correction is carried out at the operation via doing rod derotation on the concave side.

Multimodal neuromonitoring was applied intraoperatively. On listing compound muscle action potentials, a loss of 60% of wave amplitude was estimated as an alarm point for the surgeons to stop the surgery until wave retrieval[21]. Wake up Stagnara test[22] was also carried out for additional checking in all patients.

The patients wear a rigid thoracolumbar brace for 6 months. Shortly following the surgery, the coronal and sagittal curves were assessed. Lengthening was conducted usually in 6-month intervals. We left the rod long distally and opened the distal wound, loosened the nuts of the distal screws, and applied distraction distally. In the first lengthening operation, we loosened the distal nuts and applied distraction on the apical screws because fusion still had not happened and more control over the deformity could be obtained by distracting it. Then, we carried out lengthening on the lower instrumented vertebrae without approaching the apical ones. They performed it once per year and not every 6 months, as we were controlling the deformity with no risk of progression.

The technique is similar to that of TGR as regards the lengthening technique, but adding apical fixation was to add more control on deformity progression especially rotation, which facilitated the definitive surgeries. We conducted fusion in all the instrumented levels, so it is not an automatic fusion; we were aiming for fusion in the instrumented levels; otherwise, the screws or rod would break, but the segments in between were not fused, and definitive surgery was much easier as the deformity was corrected. Patients were followed up for at least 3 years. At the last visit, the coronal curve and thoracic kyphosis were assessed. Furthermore, the incidence of complications such as implant-associated complications (screw pull-out, screw or rod break, and screw migration) and surgical site complications were documented.

Statistical analysis

Sample size calculation was performed prior to the research. Data were analyzed using the Statistical Package for Social Sciences (version 27). Descriptive analyses were conducted to obtain the means, deviations for quantitative data, and numbers and frequencies for qualitative data. Different types of graphs were employed based on the type and distribution of data (pie and bar charts), and bivariate analyses were carried out using the Wilcoxon signed test, the Mann-Whitney test, and the chi-square test. P value of <0.05 was considered statistically significant.

Results

In this study, 15 patients were included, of whom eight were females and seven were males. Fourteen cases were idiopathic scoliosis, and one case was neurofibromatosis.

Fourteen cases were the main thoracic, and one case was a double major. UIV usually was D2 and D3. LIV usually was L1 and L2. The apical vertebra was usually D7 and D8.

The mean age group was 7 years old. The degree of deformity was assessed using Cobb angle measurement preoperatively and postoperatively. Neurological examination was conducted preoperatively and postoperatively.

Table 1. Demographics and Clinical Data among the Study Group (*N*=15).

Female *N* (%)	7 (53.3%)
Male *N* (%)	8 (46.7%)
Age	
Mean (*SD*)	7 (1)
Median (IQR)	(5–9)
Min–Max	5–9
Follow-up period (month)	
Mean (*SD*)	36 (18)
Median (IQR)	30 (25–45)
Min–Max	30–48
Pre coronal	
Mean (*SD*)	48 (11)
Median (IQR)	48 (40–52)
Min–Max	30–75
Post coronal	
Mean (*SD*)	12 (6)
Median (IQR)	10 (5–15)
Min–Max	5–25
% Coronal correction	
Mean (*SD*)	75.73 (9.01)
Median (IQR)	75 (68–85)
Min–Max	64–90
Degree of coronal correction	
Mean (*SD*)	39 (13)
Median (IQR)	35 (30–40)
Min–Max	25–80
Preneurological examination	
Frankel E	100%
Postoperative and last follow-up neurological No change	100%

As shown in Table 1, 2, the mean follow-up period was 36 months (30-48 months). The mean preoperative Cobb angle was 48° (30°-75°), which postoperatively became 12° (5°-25°) with the percentage of coronal correction reaching 75.73% (64%-90%). The mean Cobb angle degrees of correction were 39° (25°-80°) (Table 3, 4).

Spinal T1-S1 growth rate averaged 10 mm/year over 3 years. The first lengthening of the spine by correction is variable based on the magnitude and rigidity of the curve preoperative. It ranges from 40- to 80-mm lengthening. The T1-T12 height increased from 190 mm (130-250 mm) preoperatively to 220 mm (160-300 mm) at the final follow-up with a mean increase of 7 mm per year.

The single rod technique was applied to nine cases, and the double rod technique, to six cases. Postoperative complications occurred in two cases to which the single rod technique was applied, and rod breakage took place, which was managed with rod change as shown in Fig. 3. All patients were neurologically intact preoperatively and postoperatively.

Discussion

EOS is clarified as the start of scoliosis earlier than 10 years. Growth-friendly instrumentation is conducted with numerous procedures and hardware but frequently results in complications such as infection, implant failure, and accidental auto-fusion[21-24]. Worldwide, between these procedures and hardware, growing rods (single or double) are frequently employed, with favorable results[24,25]. The treatment is built on employing the growing forces of the immature spine. The rods put on internal forces and direct the spinal growth via consistent distractions. Growing rods avert long segment fusions and being nearer to the spine can transfer powerful manipulative and corrective forces[26]. Lately, management with a growing rod has been found to induce the vertebral bodies to grow inside the extent of instrumentation[27]. Moreover, Shah et al detected positive outcomes of growing rods on the sagittal balance and alignment. They verified that this management could correct the patient to a more neutral alignment[28].

Table 2. Comparison between the Two Techniques and Different Demographic and Clinical Data.

	Rod				
	Single rod		Double rod		
	Mean	*SD*	Mean	*SD*	*P* value
Age	7	1	7	1	0.061
Follow-up period (months)	36	11	36	14	0.776
Pre coronal	47	8	49	14	0.77
Post coronal	11	5	13	7	0.61
% Coronal correction	77.22%	9.15%	73.50%	9.14%	0.529
Degree of coronal correction	41	16	36	8	0.52
Op. time (min)	119	20	105	18	0.18
Blood loss	194	46	183	26	0.86

Table 3. Gender and Demographics and Clinical Data.

	Gender				
	Female		Male		
	Mean	*SD*	Mean	*SD*	*P* value
Age	7	1	8	1	0.02*
Follow-up period (months)	36	10	36	13	0.23
Pre coronal	52	10	44	10	0.12
Post coronal	14	6	9	4	0.20
% Coronal correction	72.25%	8.99%	79.71%	7.78%	0.09
Degree of coronal correction	43	16	34	7	0.33
Op. time (min)	115	19	111	21	0.61
Blood loss	200	46	179	27	0.43

*Sig *P* value, test of sig Mann-Whitney test.

Table 4. Coronal Angle Preoperative and Postoperative.

	Mean	*SD*	*P* value
Pre coronal	48.00	10.515	<0.001
Post coronal	11.87	5.743	

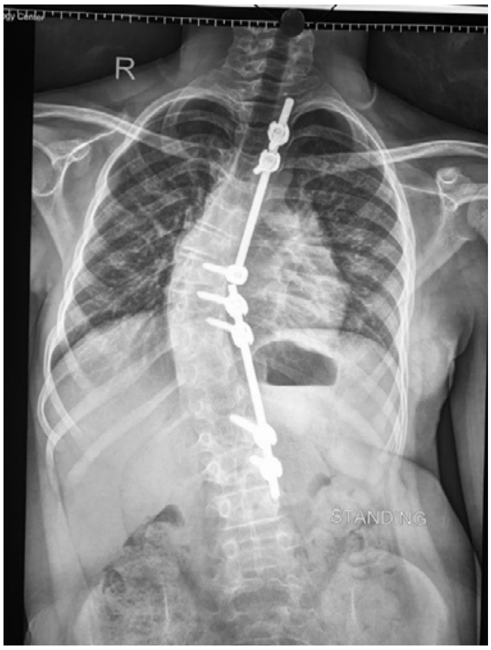

Figure 3. Figure 3 shows rod breakage.

This medium-term study recommends that a combination of TGR (single or dual) and a concave side apical control is possible and safe. This can correct and maintain alignment and growth that are equivalent to other TGR outcomes[25]. Our technique is to put screws in the concave side to control the deformity since when using TGRs, it is supposed to put screws in the upper and lower instrumented vertebrae leaving the apex vacant; however, rod breakage occurred and more deformity progression and rotation happened, so we added screws in the apex. Apical rotation following operation did not vary significantly over time. In this study, Cobb angle correction postoperatively was ≥60% for all patients, and this was preserved during ≥2-year follow-up. This is even better than the current procedures that count on repetitive lengthening[29].

As mentioned earlier, the concave side is the correction side, so when the single rod is applied, it will be on the concave side. Moreover, convex hemiepiphysiodesis requires more time to take effect, which is not less than 3 years of growth. With our technique, full correction for deformity can be achieved especially in >70° curves with full control over the deformity. The growth rate is maximal in the first 5 years of life, so the chance of convex side control would be missed as we usually operate on those patients after the age of 5 years. Moreover, most of the literature confirms that to perform convex hemiepiphysiodesis, the deformity needs to be <50°. Regarding growth rate, T1-S1 was 10 mm/year over 2 years, which appears to be higher than stated for other growth-preserving procedures[29] and consistent with physiological growth[29]. Sankar et al. studied the growth rate attained per each distraction of TGR[30]. They stated that the growth rate reduced with each further lengthening procedure over time. Lately, Cheung et al. reported a comparable reduced percentage of lengthening with MCGR[31]. We noticed greater lengthening rates in the first-year results (11 mm/year) than the lengthening rate from after the first year until the last follow-up (5 mm/year distraction).

Akbarnia et al. studied the balance of the TGR in a group of patients with EOS with a minimum 2-year follow-up[32]. The coronal balance altered from 2.80 to 1.80 cm and was 2 cm at the last follow-up. The sagittal balance altered from 3.70 to 2.30 cm after surgery to 3.90 cm at the last follow-up[32]. If we compare these results with ours, we notice that the sagittal balance got better (0.6 cm), and the coronal balance was comparable.

Growth-friendly operations have elevated averages of both planned and unexpected operations due to surgical lengthening and complications[17]. In this study, the complication rate requiring reoperation was relatively low (2/15,0.3 per patient) once compared with others (TGR: 1.48-2.30, MCGR: 0.43-0.90)[22,33,34], although the figure of reoperations was yet high, because of the numerous numbers of lengthening surgeries. Yet, unplanned procedures due to complications do occur. MCGR reviews with a minimum of 2-year follow-up state that cases necessitating unplanned operation fluctuated from 39% to 75%. Ninety-two cases collected from four reviews encountered 17 patients of MCGR not working or operating properly and 12 patients of rod fracture necessitating unplanned surgery (a total of 31%)[34-37]. The reoperations required to revise these complications are a significant load for the patient and raise management charges intensely, possibly making MCGR management less cost effective than formerly defined, as estimations were built just on a relatively short follow-up[38,39].

This study involving 15 patients encountered two cases of rod fracture requiring reoperation (a total of 20%). The complications related to implants fluctuated from 48% to 75% in reviews with a 3-year follow-up at minimum[34,36,37]. One review stated a complication percentage of 0.23 per patient per year[37]. Our results show a comparable or lower complication percentage of 0.2 per patient per year. Nevertheless, our patient group is small to attract deductions.

The outcomes of this study indicate fulfillment in names of efficiency and safety that are at least comparable to or better than dual TGRs. In TGRs, we noticed that the rib hump increases at the time of definitive fusion. With apex control, we conducted rod derotation and apical fusion, and we noticed that the rib hump did not increase with time and at the time of definitive surgery when compared with the traditional technique without apical control. Although the addition of the screws at the concave side of the apex is more challenging, the outcomes are acceptable. These outcomes are distant from perfect but are presently the most ideal of all known growth-preserving procedures. Whether the added apex control is an additional benefit for three-dimensional correction and biomechanical stability is yet to be studied. The simplices of the technique are also helpful; we detected good distraction. This contrasts with MCGRs, where failure of distraction is common due to driving mechanism component failure[8,11,13,14,34].

There was not any infection in any of the cases conducted. The average number of lengthening procedures was 4 per patient. We found that after three lengthening procedures, the rate of lengthening decreased and, in some cases, we were not able to do any further lengthening. Loss of coronal correction did not occur. Out of the 15 cases, seven did final correction and fusion and what was noticed was that the deformity was almost corrected, and there was no need to do rod derotation in any case, and rod application was much easier. The sagittal profile was maintained.

The degree of rotation improved when compared with the TGRs without apical control, and that facilitated the definitive correction in the cases that reached final fusion. Adding screws on the concave side of deformity allowed apical fusion to occur with much more deformity control and rotation control when compared with TGRs without apical control.

Limitations of this study involve the absence of a control group. An additional limitation is that most patients had just short- to medium-term follow-up. It is likely that as follow-up increases, other complications will occur.

Conclusion

The concave side apical control of the growing rod seems to be a hopeful surgical procedure for the management of EOS. Curve correction in patients was 60% and can be sustained for at least 2 years. The mean T1-S1 height gain during follow-up was 10 mm/year, which compares positively to current systems. Reoperations and complications might not be inhibited, yet the complication frequency looks reasonable when compared with current systems, and there are chances to lower this further.

The double rod technique is much stronger with lower complication rates compared with the single rod technique but is technically much more demanding and difficult. The concave side apical control allows for distraction on this side with much more deformity correction and control especially in large Cobb angle cases when compared with traditional ones.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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Author Contributions: All authors contributed to the study's conception and design, material preparation, data collection, and analysis, and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

1- Tameem Mohammed Elkhateeb, MD (Contribution: study design, manuscript preparation, surgical intervention, database creation, and research writing)

2- Mohamed Wafa, MD (Contribution: Research idea, study plan, collection of scientific material, surgical intervention, database creation, research writing, conducting of measurements, and manuscript preparation)

3- Mahmoud Ahmed Ashour, MD (Contribution: study design, manuscript preparation, surgical intervention, database creation, and research writing)

Ethical Approval: This prospective case study was approved by the institutional review board of the Faculty of Medicine at Ain Shams University Hospitals FAMSU R315/2023 according to the ethical standards of the institution and national research committee and with the 1964 Helsinki Declaration and its later recommendations or comparable ethical standards.

Informed Consent: All individual participants involved in the study provided informed consent.

Consent to Participate: All patients involved in this

study provided informed consent to participate in this study and publish this study. All steps and details of the procedures were explained to the participants. They have consented to the submission of the case report to the journal.

Consent to Publish: The authors affirm that human research participants provided informed consent for publication of the images in Fig. 1, 2, and 3.

Availability of Data and Materials: The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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