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Dual Interlocking Telescopic Rod Provides Effective Tibial Stabilization in Children With Osteogenesis Imperfecta

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Abstract

Background Interlocking telescopic rods for the management of osteogenesis imperfecta (OI)-related long bone fractures are a modification of the Sheffield rod. An interlocking pin anchors the obturator at the distal epiphysis, which spares the distal joint, while a T-piece anchors the sleeve at the proximal epiphysis. However, these devices are associated with some problems, including failure to elongate and difficulty with removal. A dual interlocking telescopic rod (D-ITR), in which the sleeve and the obturator are anchored with interlocking pins, was developed to address these problems.

Questions/purposes In this study, we compared the D-ITR with an older version of a single interlocking telescopic rod (S-ITR) based on (1) surgery-free survival and rod survival; (2) cessation of rod elongation and elongated length of the rod; and (3) risk of refracture and complications related to the interlocking telescopic system.

Methods This article compares the D-ITR with the S-ITR using a historically controlled, single-surgeon, retrospective design comparing two implants for the management of fractures in children with OI. Before August 2007, we exclusively used the S-ITR (n = 17 patients, 29 tibiae); from July 2008 until October 2014, we exclusively used the D-ITR (n = 17 patients, 26 tibiae). During the 1-year transition period, we performed five of these procedures (two S-ITR in two patients and three D-ITR in three patients), and implant use was based on availability with our preference being the D-ITR during that time when it was available. The general indications for use of both devices were the same: patients with OI and a tibial fracture who were older than 3 to 4 years of age and whose tibial canals were wide enough to accept an intramedullary rod. Younger patients were treated other ways (generally without surgery) and those with narrower canals with thinner, nonelongating rods or Kirschner wires, as indicated. All patients in both groups were available for followup at a minimum of 2 years (mean ± SD, 9.6 ± 3.0 years in the S-ITR group and 5.3 ± 2.1 years in the D-ITR group) except for one patient in the D-ITR group who died > 1 year after the procedure resulting from reasons unrelated to it. For the between-group comparison, we used only the followup data collected up to the ninth postoperative year in the S-ITR group. The truncated followup period of the S-ITR group was a mean of 5.0 ± 1.6 years.

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Each author certifies that he has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

This study was conducted at the Seoul National University Children's Hospital, Seoul, Korea.

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The mean age in the S-ITR group was 7 years (range, 3-12 years) and it was 8 years (range, 3-14 years) in the D-ITR group. There were nine boys and 10 girls in each group. Two orthopaedic surgeons other than the operating surgeon performed chart review to address our three research purposes. Survival analyses were performed using the Kaplan-Meier method. The overall pooled risk of refracture and major complications potentially associated with the interlocking telescopic rod system was compared between the groups.

Results With the numbers available, there were no differences between the D-ITR and the S-ITR in terms of mean surgery-free survival time (5.7 [95% confidence interval {CI}, 4.5-6.9] versus 5.1 [95% CI, 4.1-6.1]; years; $p = 0.653$) or mean rod survival time (7.4 [95% CI, 6.4-8.4] versus 6.0 [95% CI, 5.1-6.9] years; $p = 0.120$). With the numbers available, cessation of elongation (4% in the D-ITR group versus 19% in the S-ITR group; $p = 0.112$) and elongated length (45.3 $\pm$ 24.3 mm in the D-ITR group versus 44.2 $\pm$ 22.3 mm in the S-ITR group; $p = 0.855$) also did not differ between the groups. The pooled proportions of refracture or complications after the index surgery were higher in the S-ITR group (25 tibias [81%]) than in the D-ITR group (15 tibias [54%]; $p = 0.049$). Eight tibias in the S-ITR group had proximal migration of the sleeve compared with no patients in the D-ITR group ($p = 0.005$).

Conclusions In patients with OI, the modified D-ITR provides effective tibial stabilization with similar or better results than the S-ITR design. Anchoring the sleeve at the proximal epiphysis with an interlocking pin provides better anchorage and allows easier removal.

Level of Evidence Level III, therapeutic study.

Introduction

The concept of multiple osteotomies and intramedullary rodding, as introduced by Sofield and Millar in 1959 [14], remains valid and in widespread use for long bone stabilization in patients with osteogenesis imperfecta (OI). However, a nonelongating rod in a growing child may result in frequent revision because the long bones outgrow the rod [1, 4, 11]. This led to the development of the Bailey-Dubow rod, which consists of a hollow outer sleeve and an inner obturator rod and telescopes along with longitudinal growth of long bones as T-pieces at the ends of the sleeve and the obturator are anchored at both epiphyses [3]. The issue of T-piece disengagement seen with the original Bailey-Dubow rod [11, 13, 15] gave rise to the Sheffield rod [15], which contains a fixed T-piece at the ends of the sleeve and obturator. However, distal joint arthrotomy and penetration of the T-piece through the articular surface are required to install the obturator and necessitate medial malleolar osteotomy or deltoid ligament transection at the distal tibia [10, 13]. Although the previous study reported that symptoms and degenerative radiographic changes at the ankle were rare at a mean age of 25 years [12], the procedure is quite traumatic and caused concern about the longer term outcome. Accordingly, subsequent models of telescopic rods such as the interlocking telescopic rod, the Fassier-Duval rod (Pega Medical, Laval, Quebec, Canada), and the Peditst telescopic rod (Peditst, Istanbul, Turkey) were developed to allow antegrade insertion of the obturators, thereby avoiding distal arthrotomy and sparing the articular cartilage [2, 6, 8].

These telescopic rod models use a somewhat bulky proximal anchoring system such as a T-piece or screw-in fixation. In addition, if the sleeve migrates distally into the medullary cavity, it can be removed only through a cortical window or an additional osteotomy because of this anchoring system. To address these issues, we designed a new dual interlocking telescopic rod (D-ITR) by modifying the conventional single interlocking telescopic rod (S-ITR) [6].

In this study, we compared the D-ITR with an older version of a S-ITR based on (1) surgery-free survival and rod survival as a primary outcome; (2) cessation of rod elongation and the elongated length of the rod; and (3) risk of refracture and complications related to the interlocking telescopic system.

Patients and Methods

The study was approved by the institutional review board. This article compares the D-ITR with the S-ITR using a historically controlled, single-surgeon (T-JC), retrospective design comparing two implants for the management of fractures in children with OI. From April 2000 to August 2007, we exclusively used the S-ITR (n = 17 patients, 29 tibias); from July 2008 until October 2014, we exclusively used the D-ITR (n = 17 patients, 26 tibias). During the 1-year transition period, we performed five of these procedures (two S-ITR in two patients and three D-ITR in three patients), and implant use was based on availability with our preference being the D-ITR when it was available. The procedures covered all operations using ITR during these periods. All patients in both groups were available for followup at a minimum of 2 years (mean $\pm$ SD, 9.6 $\pm$ 3.0 years in the S-ITR group and 5.3 $\pm$ 2.1 years in the D-ITR group) except for one patient in the D-ITR group who died > 1 year after the procedure for reasons unrelated to it. Hence, 19 patients (28 tibias) comprised the D-ITR group and 19 patients (31 tibias) the S-ITR group. For the between-group comparison, we used only the followup data collected up to the ninth postoperative year in the S-ITR group, which was the longest followup period in the D-ITR group. The truncated followup period of the S-ITR group was a mean of 5.0 $\pm$ 1.6 years (range, 2.0-8.7 years). The mean age was 7 years (range, 3-12 years) in the S-ITR group and 8 years (range, 3-14 years) in the D-ITR group. There were nine boys and 10 girls in each group. The demographic data for the D-ITR and S-ITR groups were comparable (Table 1). All patients received cyclic intravenous pamidronate or zoledronate at 3- to 4-month intervals or at a 6-month interval (respectively) from the time of diagnosis to skeletal maturity.

The D-ITR (C&S Medical, Gyeonggi, Korea) has an outer hollow sleeve and an inner obturator rod. The obturator is identical to that of the S-ITR. Instead of a T-piece, the sleeve has a hole for an interlocking pin and a slot at the proximal end for rotational control during insertion (Fig. 1). The sleeve is anchored with an interlocking pin at the proximal epiphysis of the tibia much like the obturator, and the pin is threaded to prevent backing out (Fig. 2).

One surgeon (T-JC) performed all operations. The surgical technique of the S-ITR has been described previously [6] and is nearly identical to that of the D-ITR. The only difference between the two techniques was that the S-ITR uses a T-piece, whereas the D-ITR uses an interlocking pin as an anchoring mechanism at the proximal tibial epiphysis. Inserting the interlocking pin through the sleeve hole or obturator is technically demanding, especially at the proximal tibial epiphysis because the pin must travel farther through the epiphysis to the sleeve compared with the distal epiphysis insertion. The first step for successful interlocking pin placement is to implant the sleeve and obturator in the appropriate rotational alignment. The second step is to obtain a true lateral projection with the image intensifier showing the hole in the rods, which occasionally proves difficult in patients with severe lower limb deformity. However, because of osteopenia of the typical OI epiphysis, the interlocking pin can be manipulated easily during insertion, and the procedure is less challenging than it may appear. All tibias were immobilized with a long leg splint for 4 to 6 weeks postoperatively.

The general indications for use of both devices were the same: patients with OI and a tibial fracture who are older than 3 to 4 years of age and whose tibial canals are wide enough to accept an intramedullary rod. Younger patients were treated other ways (generally without surgery) and those with narrower canals with thinner, nonelongating rods or Kirschner wires, as indicated. The specific indication for the index operations and the number of osteotomies performed at the index operations are shown (Table 2). We applied adjunctive unicortical locking plate fixation during the index operation or during the followup period in eight tibias (eight of 28 [29%]) of the D-ITR group and in two tibias (two of 31 [6%]) of the S-ITR group (p = 0.036). We performed adjunctive cross-pin fixation during the index operation in six tibias (six of 28 [21%]) of the D-ITR group and nine tibias (nine of 31 [29%]) of the S-ITR group (p = 0.561). Application of adjunctive unicortical locking plate fixation or cross-pin fixation during the index operation was determined by rotational stability at the fracture or osteotomy site [7].

In the analysis of surgery-free survival, any additional surgery except scheduled plate or cross-pin removal was defined as an endpoint. In the rod survival analysis, the endpoint was defined as replacement or removal of the sleeve and/or obturator. Repositioning any part of the rod, removal of an interlocking pin, or rod bending was not considered an endpoint if the sleeve and obturator remained in the tibia. We measured the length of rod elongation immediately postoperatively and at the latest followup on lower leg AP radiographs. Distal migration of the sleeve or proximal migration of the obturator into the medullary cavity was considered as cessation of rod elongation. We excluded from the analyses the tibias in which the ITR was not successfully interlocked at either proximal or distal epiphysis on the cessation of rod elongation or elongated length of rod because these rods played the role of a nonelongating rod instead of an elongating rod. In addition, we compared the overall pooled risk of refracture and major complications related to the interlocking telescopic system of the D-ITR and S-ITR groups. Minor complications such as superficial wound infection and mild

Table 1. Demographics of the dual and single interlocking telescopic rod groups

Demographics	D-ITR (n = 28)	S-ITR (n = 31)	p value
Age at rod insertion* (year)	8.1 ± 2.6	7.0 ± 2.9	0.114§
Age at the latest followup* (year)	13.4 ± 3.6	12.0 ± 3.3	0.122§
Followup period* (year)	5.3 ± 2.1	5.0 ± 1.6‡	0.563§
Male† (female/male)	16/12	17/14	1.000‖
Laterality† (left/right)	14/14	15/16	1.000‖
Sillence type† (I/III/IV/V)	5/11/9/3	7/7/15/2	0.438‖

*The values are expressed as mean ± SD.
†the values are expressed as the number of tibias.
‡only the followup data collected up to the ninth postoperative year were used for comparison between the groups.
§Student's t-test.
||Fisher's exact test; D-ITR = dual interlocking telescopic rod; S-ITR = single interlocking telescopic rod.

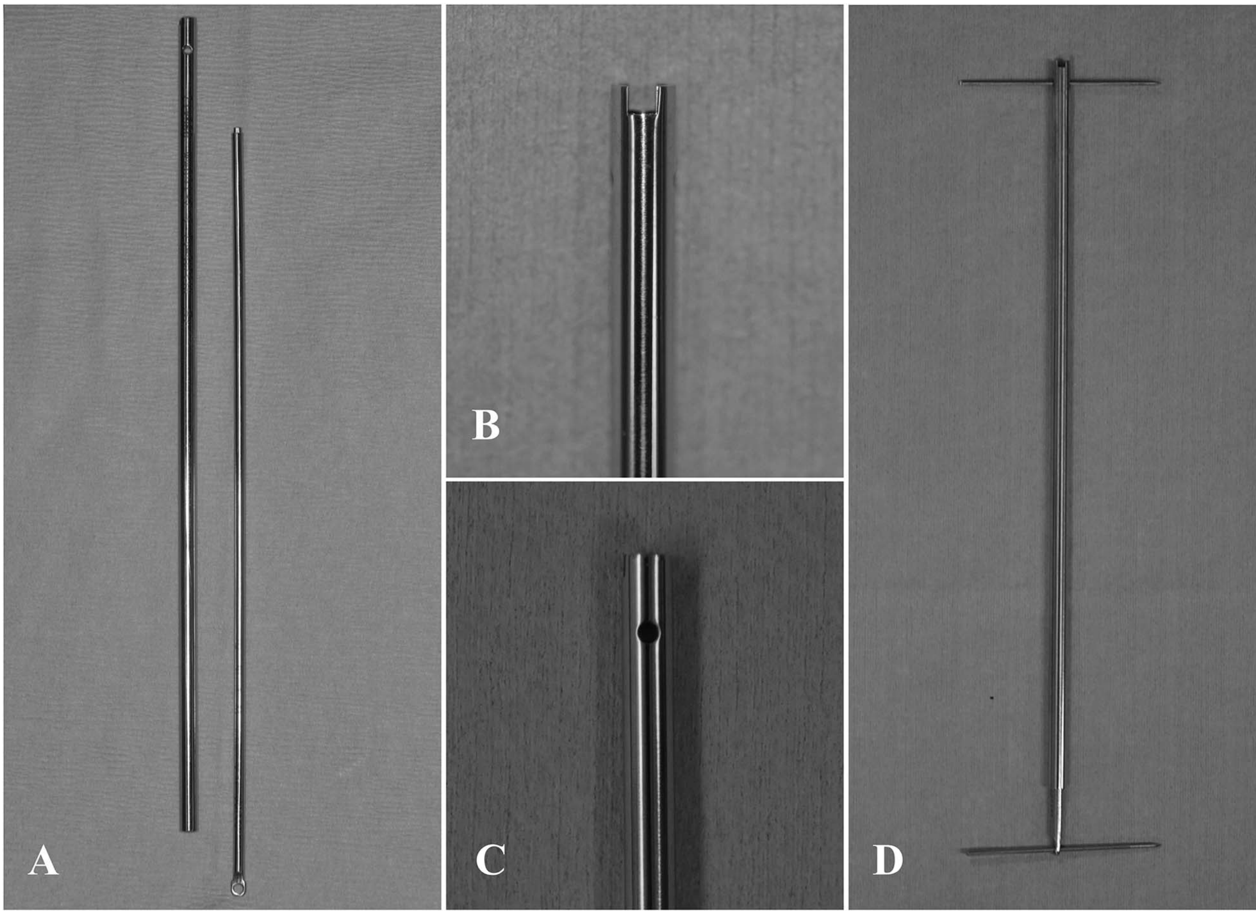

Fig. 1 A-D (**A**) Sleeve (left) and obturator (right) of the D-ITR system are shown. The obturator is identical to that of the S-ITR system. (**B**) The sleeve has a hole to hold the interlocking pin and (**C**) a slot for rotational control at its proximal end. (**D**) The D-ITR was assembled.

anteromedial bowing of the tibia without anterior cutting through of the rod were excluded from the analysis. Two orthopaedic surgeons (CHS, DJL) other than the operating surgeon performed chart review to address our three research purposes.

Statistical Analysis

We analyzed continuous data with the independent Student's t-test or the Mann-Whitney test based on the result of a Kolmogorov-Smirnov test of normality, and we analyzed categorical data with the Fisher's exact test. Survival analyses were made using the Kaplan-Meier method. Survival free of additional surgery and rod survival between the groups was compared using the log-rank test. Probability values < 0.05 were considered statistically significant. A post hoc power analysis was performed. When effect size of hazard ratio is 0.5, an experiment based on two groups with sample sizes of 28 and 31 archives at least 70% power to reject the null hypothesis of zero effect size using a two-sided log-rank test and a significance level (α) of 0.05 (performed with STATA 15.1 software; Stata Corp, College Station, TX, USA).

Results

There was no difference in mean surgery-free survival or mean rod survival between the groups. The mean surgery-free survival times were 5.7 years (95% confidence interval [CI], 4.5-6.9) in the D-ITR group and 5.1 years (95% CI, 4.1-6.1) in the S-ITR group (p = 0.653). After the index operation, 13 of 28 D-ITR tibias (46%) and 19 of 31 S-ITR tibias (61%; p = 0.302) underwent additional surgery. The mean rod survival times were 7.4 years (95% CI, 6.4-8.4) in the D-ITR group and 6.0 years (95% CI, 5.1–6.9) in the S-ITR group (p = 0.120). Rods were replaced or removed in seven tibias (seven of 28 [25%]) in the D-ITR group and in 14 tibias (14 of 31 [45%]) in the S-ITR group (p = 0.173).

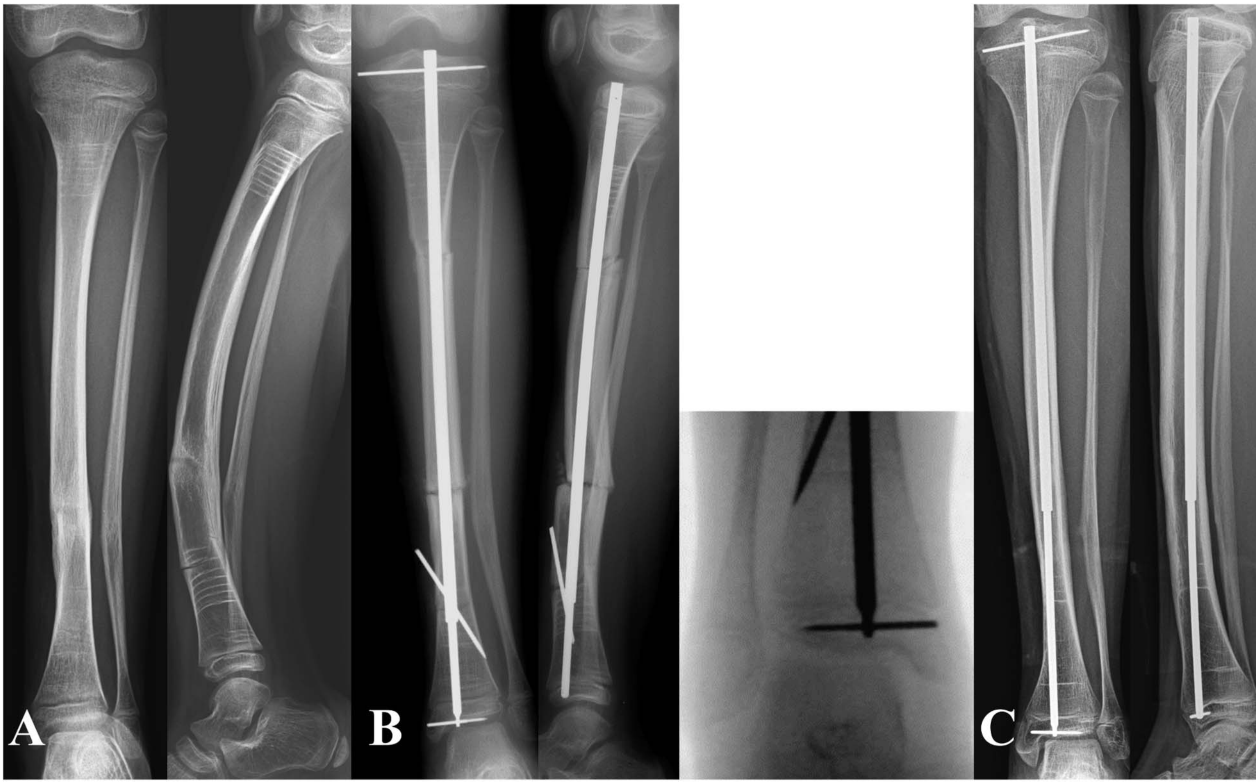

Fig. 2 A-C (**A**) AP and lateral tibia radiographs of an 8-year-old girl with OI type IA are shown. The tibia had marked anterior bowing with persistent anterior cortical gap at its apex. (**B**) The tibia was straightened by multiple osteotomies and fixed with the dual interlocking telescopic rod. Intraoperative AP view confirmed that the interlocking pin was within the distal epiphysis. (**C**) The rod telescoped successfully for 6.5 years.

With the numbers available, we found that cessation of elongation and elongated length did not differ between the groups. All but one D-ITR (25 of 26 [96%]), which were interlocked at both epiphyses at the index operation, successfully elongated as the tibial grew longitudinally over a mean followup of 5.2 years. Six S-ITR tibias (six of 31 [19%]) ceased to elongate at a mean 5.0 years of followup (odds ratio [OR], 6.00 [95% CI, 0.67-53.52]; p = 0.112), which resulted in migration of either the sleeve (three tibias) or obturator (three tibias) into the medullary cavity. The mean elongated length of the rod was 45 ± 24 mm (range, 7-93 mm) in the D-ITR group and 44 ± 22 mm (range, 0-84 mm) in the S-ITR group (p = 0.855) during the followup period. The mean difference in elongated length between the D-ITR and S-ITR groups was 1 mm (95% CI, -11 to 13 mm). D-ITR expanded by a mean of 20% ± 10% (range, 2%-38%) of its original length in the assembled sleeve-obturator, and S-ITR expanded by a mean of 22% ± 14% (range, 0%-46%; p = 0.528). The mean difference of the groups was 2% (95% CI, -8% to 4%).

The S-ITR group had a higher proportion of refracture or complications after the index operation compared with the D-ITR group (25 of 31 tibias [81%] versus 15 of 28 tibias [54%]; OR, 3.61 [95% CI, 1.13-11.52]; p = 0.049; Table 3). Eleven tibias (11 of 31 [35%]) in the S-ITR group had proximal or distal sleeve migration compared with none in the D-ITR group (p < 0.001). Eight proximal sleeve migrations underwent sleeve replacement or advancement because of pain or extension block of the knee. To remove three distally migrated sleeves during revision, the surgeon made a cortical window or an additional osteotomy (Fig. 3). In contrast, rod removal was easy in all seven D-ITR revision cases; the surgeon extracted the interlocking pins and removed them through the fracture or osteotomy site (Fig. 4). The proportion of other complications was comparable between the two groups. Three tibias (three of 28 [11%]) in the D-ITR group and two tibias (two of 31 [6%]) in the S-ITR group showed a persistent cortical gap at the fracture site (OR, 1.74 [95% CI, 0.27-11.26]; p = 0.661); this resolved in all patients once an adjuvant locking plate was placed with unicortical screw fixation. Two tibias in each group had tibial angulation and anterior cut through of the rods (two of 28 D-ITR tibias [7%] versus two of 31 S-ITR tibias [6%]; OR, 1.12 [95% CI, 0.15-8.49]; p = 1.000); all four underwent revision surgery.

Table 2. The indication for the index operations and the number of osteotomies performed at the index operation of the dual and single interlocking telescopic rod groups

Indication/number of osteotomies	D-ITR (n = 28)	S-ITR (n = 31)	p value*
Indication			
Repeated fractures and/or consequent deformity†	19	21	0.280
Progressive deformity without definite recent fracture†	6	10	
Impending disengagement between sleeve and obturator due to longitudinal tibia growth†	2	0	
Proximal migration of the sleeve of S-ITR†	1	0	
Number of osteotomies			
Single-level†	12	20	0.085
Multiple-level†	13	11	
None†,‡	3	0	

*Fisher's exact test.
†the values are expressed as the number of tibiae.
‡operations were performed as a result of impending disengagement between the sleeve and the obturator or proximal migration of the sleeve; D-ITR = dual interlocking telescopic rod; S-ITR = single interlocking telescopic rod.

The sleeve of the D-ITR was not interlocked at the proximal epiphysis in one tibia and the obturator of the D-ITR at the distal epiphysis in another because the interlocking pin was not properly inserted through the sleeve hole or obturator during the procedure (two of 28 [7%]). However, all obturators of the S-ITR were anchored with an interlocking pin at the epiphysis ($p = 0.221$). In another D-ITR tibia, we noticed intraoperatively that the sleeve was not anchored; however, we locked it with an additional pin.

Discussion

This study introduced a modified interlocking telescopic rod for the treatment of OI-related tibial fractures in which both the sleeve and the obturator are anchored by interlocking pins (D-ITR). The modification addressed concerns regarding difficult introduction and removal with older, somewhat bulky anchoring systems. Although we found no difference in surgery-free survival, rod survival, or elongation characteristics, we noted fewer complications involving sleeve migration in the D-ITR group.

This study has several limitations. First, the difference in outcome between D-ITR and S-ITR might have been affected by chronologic bias because this study spanned a long period. Some of the reduction in complications we observed here may not be related to a better implant but rather a better surgical technique, patient selection, or postoperative care. However, the D-ITR procedure was also technically more demanding than the S-ITR procedure, which might negatively impact the D-ITR outcomes. Similarly, the demographics of study participants

Table 3. Refracture and complications of the dual and single interlocking telescopic rod groups

Refracture/complications	D-ITR (n = 28)*	S-ITR (n = 31)*	p value†
Refracture‡	10	12	1.000
Proximal migration of the sleeve‡	0	8	0.005
Distal migration of the sleeve‡	0	3	0.239
Proximal migration of the obturator‡	1	3	0.614
Persistent cortical gap‡	3	2	0.661
Angulation of the tibia and anterior cutting through of the rods‡	2	2	1.000
Growth arrest of the proximal or distal physis‡	0	0	1.000
Backing-out, distal interlocking pin‡	1	2	1.000
Breakage of distal interlocking pin‡	1	0	0.475
Intraarticular placement of interlocking pin‡	0	0	1.000
Backing-out, proximal interlocking pin‡	1	Not applicable	

*Four tibias in the D-ITR group and seven tibias in the S-ITR group had two of these complications.
†Fisher's exact test.
‡the values are expressed as the number of tibias; D-ITR = dual interlocking telescopic rod; S-ITR = single interlocking telescopic rod.

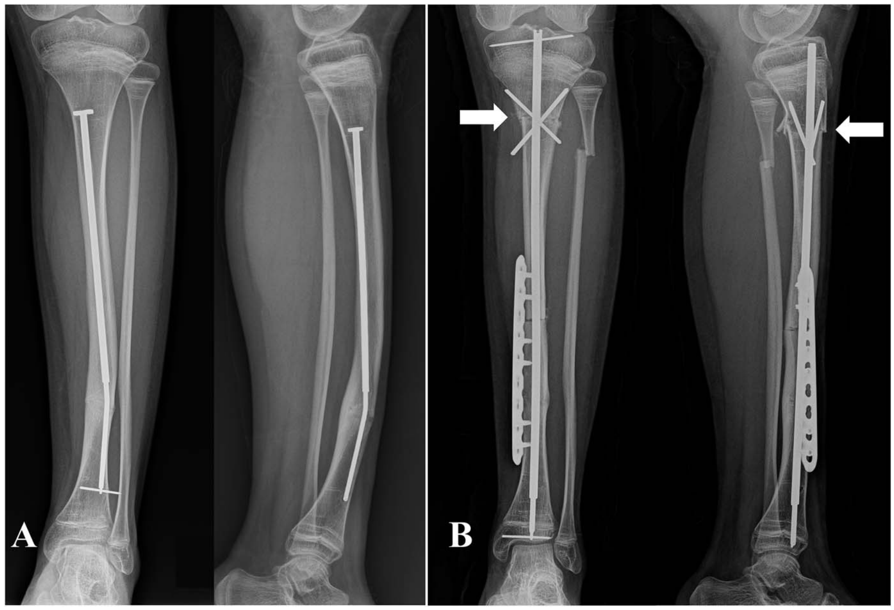

Fig. 3 A-B (**A**) Tibia radiographs of a 14-year-old boy with OI type IVA obtained 7.5 years after S-ITR installation are shown. Failure to telescope resulted in the distal migration of the sleeve and proximal migration of the obturator. The obturator was easily removed after the interlocking pin was extracted. (**B**) However, sleeve removal resulted in an additional osteotomy at the proximal tibia (arrow).

did not differ significantly between the groups, and operative indications and postoperative care protocols have not changed over time. Second, as a retrospective study, there was no standardized indication for revision or additional surgery as an endpoint in survival analyses before the study began. However, our indications for revisions for either S-ITR or D-ITR did not change over the study period. Third, we evaluated only mid-term radiologic outcomes. We did not assess long-term clinical outcomes such as activity level. Although mid-term radiologic outcome may be one of the most important prognostic factors for long-term clinical outcome, other factors such as Sillence type could affect the long-term prognosis more than radiologic outcomes. Fourth, > 25% of the D-ITR group had adjuvant unicortical locking plate fixation compared with only 6% of the S-ITR group, because this technique was devised in the later period of S-ITR use [7]. The plate fixation should have provided a more favorable environment to achieve bony union. However, it should not affect the main advantage of D-ITR over S-ITR: more stable proximal anchorage and easier removal during revision surgery. Therefore, the tibias with unicortical locking plate application were not necessarily advantageous in terms of complications. Fifth, the sample size was relatively small, which may be partly attributed to the rarity of the disease. We could not analyze the outcome by sex as a result. Therefore, we could not assume that the devices perform identically in both sexes, although OI is not a gender-specific disease and there was no sex-related difference in operative indication. Lastly, bilateral tibias from a single patient were considered independently in the statistical analysis. Statistical independence may be compromised in the presence of bilateral cases within one patient, which can be correlated with each other. To address this issue, representative data from a single patient can be analyzed by randomly selecting a single side. However, such a method is not applicable to our approach. Because OI is a rare disease and the individual morphology of the tibia differed markedly and bilaterally, side- and/or site-specific assessment may be a meaningful strategy.

There was no difference in median surgery-free survival or mean rod survival between the groups. Comparing the survivorship among telescopic rodding procedures in patients with OI is a challenge because severity of the disease in the study participants, age at the time of rod insertion, age at the latest followup, and definition of an endpoint in survival analyses are all diverse. D-ITR in our study showed a similar or higher survival rate and longer survival time compared with other telescopic rod systems, including S-ITR [2, 9, 10, 12]. A study involving the Fassier-Duval rod for the femur or tibia reported 46% revision at a median 5 years of followup, and revision for the tibia was performed at a mean of 40 months after the index operation [2]. Those results were inferior to the D-ITR results noted in this study, which showed 25% rod removal

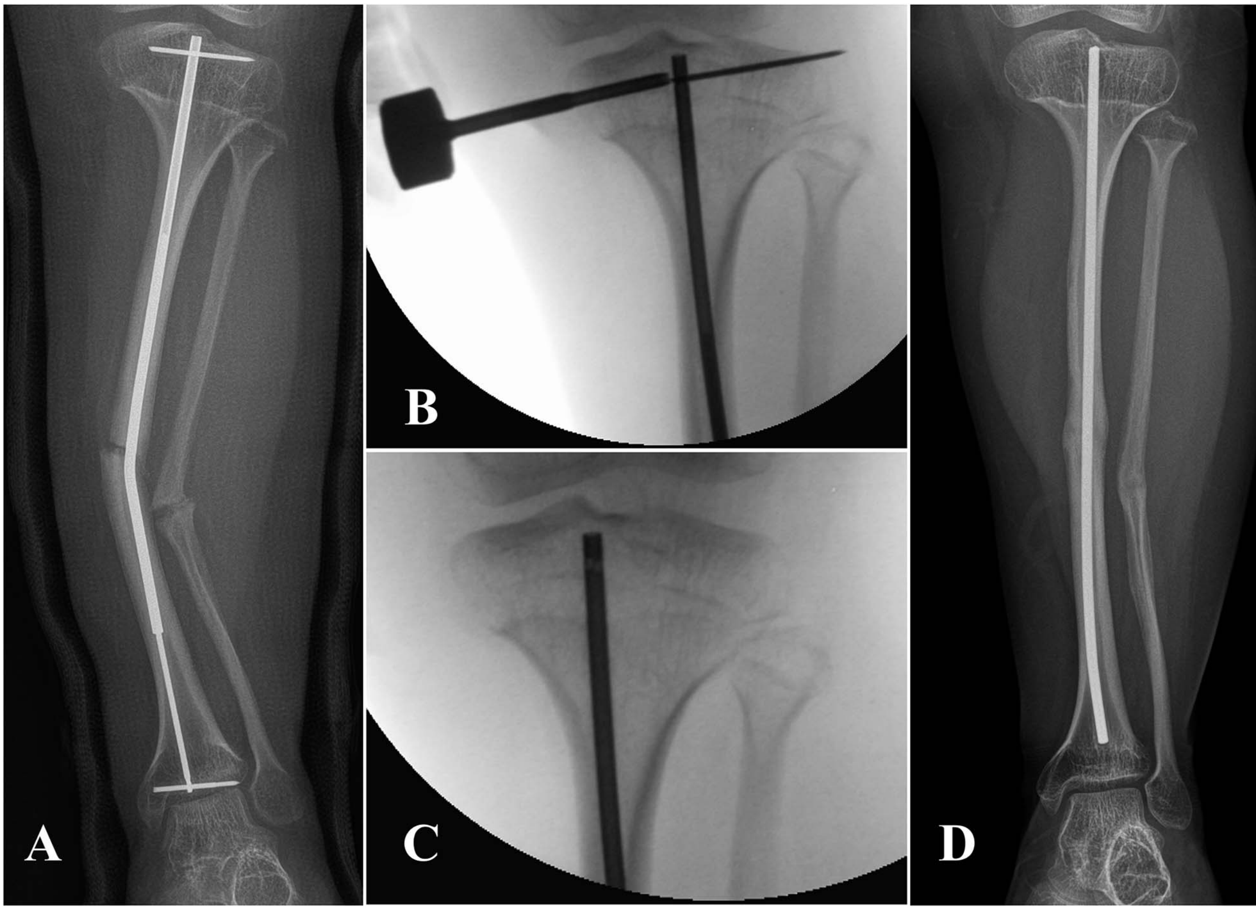

Fig. 4 A-D (**A**) A 16-year-old girl with OI type III sustained tibial and fibular shaft fractures 5.8 years after stabilization with a D-ITR. (**B**) During revision surgery, the interlocking pin was pushed out of the epiphysis with a pin impactor, (**C**) which converted the sleeve into a simple, smooth rod. The sleeve was removed easily through the fracture site. The obturator was removed similarly. (**D**) Because the patient was skeletally mature, a nontelescopic flexible rod was used for internal fixation.

or replacement at a mean followup of 5.3 years and 89 months of mean survival time; however, the study participants may not be comparable. The D-ITR in our study also appears to have longer mean survival time compared with a single rush rod (43 months) and Sheffield rod (43 months) [9]. Sheffield rodding in the femur or tibia in another study showed only a 35% rate of rod exchange at an average followup of 19 years [12].

With the numbers available, we did not see a difference between the D-ITR group and the S-ITR group in cessation of elongation and overall elongated length. In the previous study in which age at the index operation and followup period were similar to ours, Bailey-Dubow rodding in the femur or tibia showed a 50% rate of cessation of elongation [17], which was higher than those of D-ITR and S-ITR in our study. Wilkinson et al. [16] reported that 37 Sheffield rods for the femur or tibia had expanded by a median of 21% of their original length during a followup period similar to the current study, a result that mirrors our own.

We had fewer complications, particularly with sleeve migration, in the D-ITR group than the S-ITR group. This study showed that the T-piece of the S-ITR sleeve provided less effective anchorage than the interlocking pin of the D-ITR. No D-ITR sleeves migrated either proximally or distally during the followup period. In one tibia of D-ITR with failed telescoping, the obturator migrated proximally while the sleeve remained in situ. Apparently, a longer interlocking pin at the proximal epiphysis provided better anchorage than at the distal epiphysis. The screw-in mechanism of the sleeve in the Fassier-Duval rod may appear to provide firm anchorage; however, its relative bulk may spread across the physis in a small child with a thin epiphysis and migrate distally into the medullary cavity by physeal growth. Birke et al. [5] reported migration of the sleeve of the Fassier-Duval rod in one of eight tibias with a mean followup of 1.6 years. In another study with nearly 5-year median followup of tibial and femoral Fassier-Duval rodding in 58 patients, proximal migration of the sleeve occurred in two patients [2]. A study involving Bailey-Dubow rodding in the femur or tibia at a similar age as our study population showed 40% internal migration of the rod without fracture [17], which was more frequent than our results with either D-ITR or S-ITR. Nicolaou et al. [12] reported migration of a Sheffield rod in three of 23 (13%) tibias at a mean followup of 19 years, although they did not present which component of the rod had migrated or the direction of migration.

With other models of telescoping rods, removal during revision surgery is a challenge because the anchoring system is bigger than the middle rod. Whether they are in situ or have migrated into the medullary cavity, removal of the rod with anchoring systems such as a T-piece, screw-in, threaded tip, or corkscrew may seriously damage the articular cartilage or the physis. To prevent such damage, a cortical window or additional osteotomy may be needed. In contrast, the D-ITR is converted into a simple, smooth rod as soon as the interlocking pin is removed (Fig. 4), which can then be removed easily through the fracture/osteotomy site or even through the articular surface with minimal damage. This may be a distinct advantage over other telescoping rod systems.

In this study, three tibias (11%) in the D-ITR group and two tibias (6%) in the S-ITR group had persistent cortical gaps at the fracture site, which were treated with adjuvant locking plates and unicortical screw fixation, and eventually resulted in bony union. The nonunions may be attributed to fracture configuration and intramedullary rodding, which did not provide rotational stability independent of the telescopic rod's anchoring system [7]. The Fassier-Duval rod was also associated with a 14.5% incidence of cases with nonunion or incomplete union [2].

In conclusion, the D-ITR provides effective tibia stabilization in patients with OI. Compared with the S-ITR and other currently available telescopic rod systems [2, 9, 10, 12], the D-ITR has similar or better survivorship and seemingly less frequent complications related to sleeve migration [2, 5, 12, 17]. Although technically demanding, proximal interlocking provides better anchorage and allows easier removal. Prospective long-term clinical studies that include functional outcomes will help determine the role of the D-ITR in the treatment of patients with OI.

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