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ORIGINAL PAPER

Functional recovery of daily living and sports activities after cosmetic bilateral tibia lengthening

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Abstract

Purpose The aims of this study were to evaluate the recovery of physical function and to investigate whether there are factors that adversely affect functional recovery after cosmetic bilateral lengthening of the tibia.

Methods One hundred twenty-five healthy individuals who had undergone bilateral cosmetic tibia lengthening by the lengthening and then nail (LATN) method, lengthening over intramedullary nail (LON) method or intramedullary skeletal kinetic distractor (ISKD) were included in the study. Functional outcomes were evaluated using the Sports Activity Rating Scale (SARS), International Knee Documentation Committee (IKDC) Subjective Knee Form and patient self-reported ability scores.

Results SARS and IKDC scores decreased at post-operative one year and improved significantly at post-operative two years. SARS and IKDC scores recovered similarly to pre-operative levels. Average patient self-reported ability scores at post-operative two years were 94.6 and 89.9 for daily living and light sports, respectively. However, the average score for moderate-to-strenuous sports was 68.1 and 39 patients (31.2%) recorded below average score for the moderate-to-strenuous sports.

Conclusions Patients who had undergone bilateral cosmetic tibial lengthening may expect almost full recovery of daily and light sports activities at post-operativetwo years. However, several patients may feel some limitation in moderate-to-strenuous sports activities.

Keywords Bone lengthening · Tibia · Recovery of function · Activities of daily living · Sports

Introduction

Bone lengthening is the only available option for skeletally mature persons to increase their height. Numerous studies have reported favourable outcomes after cosmetic limb lengthening in terms of height gain, maintenance of joint mobility, satisfaction with the operation and improvement of self-esteem [1–5]. Furthermore, following developments in surgical methods, such as the lengthening and then nail (LATN) technique, the lengthening over intramedullary nail (LON) technique or the intramedullary lengthening device that have decreased the external fixation period, surgeons may expect better outcome and less complication [2, 5–13].

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With the improvements in surgical outcomes, studies of limb lengthening for stature have begun to focus on the changes of neuromuscular function [14–16]. Any factors that could reduce physical function would be considered major complications for healthy individuals who wish to increase their height for cosmetic reasons [2, 17]. Several studies have reported adverse effects of limb-lengthening surgery on the muscle strength, power or nerve conduction [16, 18–22]. However, small changes in neuromuscular function, in terms of performing daily or sports activities, may be not a clinically significant changes [16, 23].

To evaluate the changes in the physical function, the comparison of pre-operative and follow-up physical function is mandatory, and the physical function should be differentiated from the daily life activity to the sports activity considering the performance and frequency. Only few researches studied about the changes in physical activities with limited information, but the recovery of daily and sports activities has not been differentiated [2, 3]. Furthermore, the functional changes after operations using intramedullary lengthening devices or LATN technique have not been evaluated [2, 3].

Individuals who undergo cosmetic stature lengthening surgery are usually physically healthy; therefore, recovery of daily living and sports activities is likely to be an important factor in their decision-making process. The purposes of this study were to evaluate the recovery in the levels of daily living and sports activities after bilateral cosmetic tibial lengthening using advanced techniques and to investigate any factors related to the adverse effects on physical function using functional outcome questionnaires.

Materials and methods

This study was approved by the institutional review board at our institution (4-2015-0722) and we retrospectively reviewed prospectively collected data. Among the patients who underwent bilateral cosmetic stature lengthening from September 2010 to March 2013, 174 patients who had consented to participate in the study were recruited. The inclusion criteria were as follows: (1) operation at skeletal maturity, (2) bilateral tibial lengthening, (3) follow-up > two years. The exclusion criteria were as follows: (1) simultaneous correction for lower limb malalignment or malrotation, (2) skeletal dysplasia, (3) any syndrome or hormone disease related to the bone, (4) diagnosis of psychological problems or dysmorphic syndrome [24]. Finally, 125 healthy individuals were included in the study. Index surgery was performed using the lengthening and then nail (LATN) technique (63 patients) or the lengthening over intramedullary nail (LON) technique (50 patients) (Fig. 1) or the intramedullary skeletal kinetic distractor (ISKD) (12 patients) (Fig. 2). Average patient age was 24 years five months (range, 16–55 years): 23 years seven months (range, 16–35 years) for men and 27 years ten months (range, 18–55 years) for women. Average pre-operative height was 162.1 ± 7.5 cm (range, 144–175 cm): 164.9 ± 5.1 cm (range, 155–175 cm) for men and 150.5 ± 3.4 cm (range, 145–157) for women.

All surgeries were performed by the corresponding author. The surgical procedures performed in this study have been described in previous publications [2, 7, 8]. The ISKD (Orthofix Inc., Lewisville, TX, USA) was used for bilateral tibial lengthening without external fixator; however, the number of patients undergoing this procedure was very small, because it was not covered by national health insurance. A conventional tibial interlocking nail (EXPERT™ Tibial Nail, Synthes, CO, USA), Ilizarov ring fixators and Ortho SUV frames (S.H. Pitkar Orthotools Pvt., Pune, India) were used for all bilateral tibial lengthening procedures using the LATN and LON techniques. The latent period was seven to ten days for all segments. The distraction rate was set at 0.85–1 mm per day; however, it was adjusted depending on the amount of regenerated bone observed on radiographs, which were obtained every one to two weeks. Post-operatively, all patients were encouraged to perform daily exercises to improve the range of motion of adjacent joints and strengthen the involved muscles, under the guidance of a single registered physical therapist. During the distraction phase, full weight bearing was allowed in the LON and LATN techniques but was restricted during bilateral ISKD lengthening. Patients were followed up weekly or bi-weekly during the distraction phase, monthly during the consolidation phase, at six months and post-operative one year, and annually thereafter.

Levels of daily living and sports activities were assessed using the following three approaches: the Sports Activity Rating Scale (SARS) [25], the International Knee Documentation Committee Subjective Knee Form (IKDC) [26] and patient self-reported ability scores. The SARS (Supplement 1) was selected to enable estimates of how frequently individuals could undertake sports activities. The IKDC (Supplement 2) was used to estimate changes in function or pain during recovery from the operation. Patient self-reported ability scores were developed by the corresponding author and were used to assess subjective outcomes. Patient self-reported ability scores (Supplement 3) were consisted of activities of daily living (walking, sit-to-stand, stair climbing), light sports activities (golf, bowling, hiking) and moderate-to-strenuous sports activities (tennis, soccer, basketball). Each score was described by the patients as a percentage, compared to the pre-operative state, with '0' the worst score and '100' the best (corresponding to the pre-operative state).

The SARS and IKDC scores were recorded pre-operatively, post-operative one year and post-operative two years. Patient self-reported ability scores were evaluated at post-operative two years. Patient self-reported ability scores were analysed to identify any significant correlations with patient-

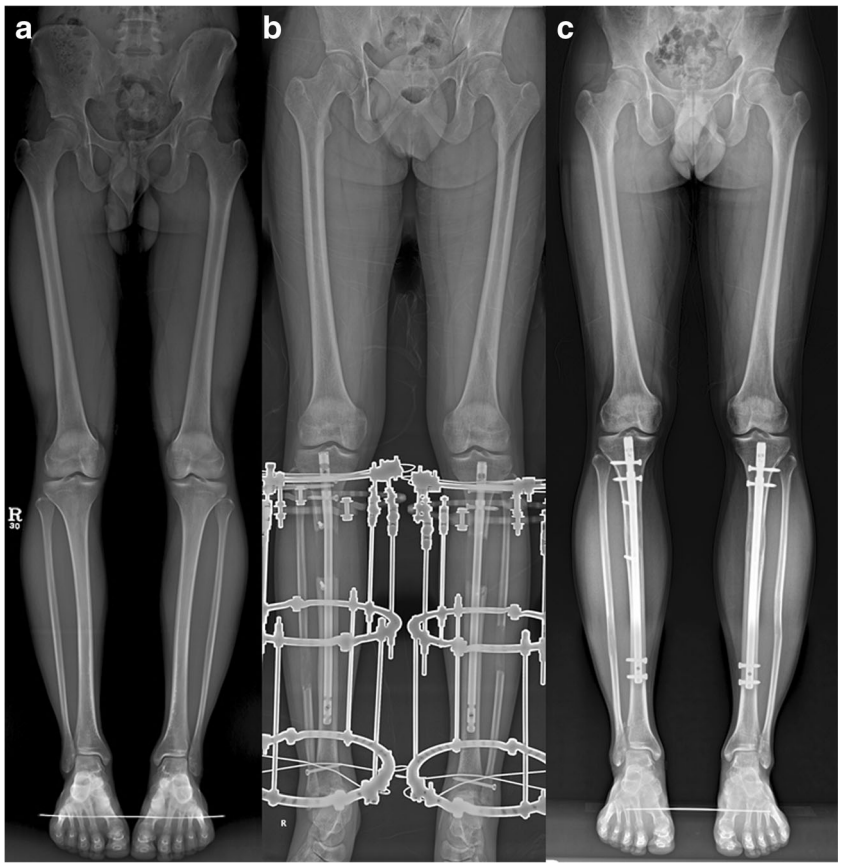

Fig. 1 A 24-year-old male with 164 cm height visited the clinic for the cosmetic limb lengthening (**a**). After lengthening over nail (LON) with Ilizarov (**b**), 5.5 cm lengthening of both tibia was done (**c**)

related (age, sex and preoperative body mass index (BMI)) or distraction-related factors (total length distracted, lengthened percentage of the segment, external fixator index, healing index and complications).

Statistical analysis

SAS version 9.4 (SAS Institute, Cary, NC, USA) was used for all statistical analyses. All continuous variables were tested for normality using the Shapiro–Wilk test, which allowed normal distribution assumption. Paired *t* tests were used to compare IKDC and SARS scores between pre-operative score, score at post-operative one year and scores at post-operative two years, respectively. Multiple regression analysis was conducted to identify any patient-related or distraction-related factors related to the functional scores. After univariate analysis, factors with $p < 0.2$ were selected for multivariate analysis. The level of significance was set at $p < 0.05$.

Results

The mean distraction length was 6.3 ± 0.9 cm (range, 2.8–8.3 cm), and the mean percentage lengthened at the index bone segment was 19.3 ± 3.5% (range, 9.0–25.8%). Ninety-four legs with equinus contracture recovered after physiotherapy, and four legs with mild equinus contracture completely recovered after Strayer gastrocnemius lengthening. Ten legs with knee contracture recovered a full range of motion after physiotherapy (Table 1) [27].

Mean SARS scores were 71.5 ± 18.9 pre-operatively, and 65.2 ± 24.1 at post-operative one year and 74.7 ± 19.8 at post-operative two years. Mean IKDC scores were 84.1 ± 18.3 pre-operatively, and 66.8 ± 16.8 at post-operative one year and 83.9 ± 15.3 at post-operative two years. Both SARS and IKDC scores were significantly decreased at post-operative one year; however, both SARS and IKDC scores were improved from post-operative one year to post-operative two years. There was no significant difference between pre-operative scores and scores at post-operative two years in SARS ($p = 0.111$) and IKDC ($p = 0.847$) (Table 2). However, patient self-reported ability scores at post-operative two years were 94.6 ± 7.5 and 89.9 ± 10.4 for daily living and light sports, respectively, and 68.1 ± 19.4 for moderate-to-strenuous sports. There was a significant correlation between IKDC and moderate-to-strenuous sports ($r = 0.338$, $p = 0.001$), but no significant correlation between SARS and moderate-to-strenuous sports ($r = 0.191$, $p = 0.077$).

Thirty-nine patients (31.2%) recorded below average score for the moderate-to-strenuous sports. In univariate analysis to find any factors related to the low moderate-to-strenuous

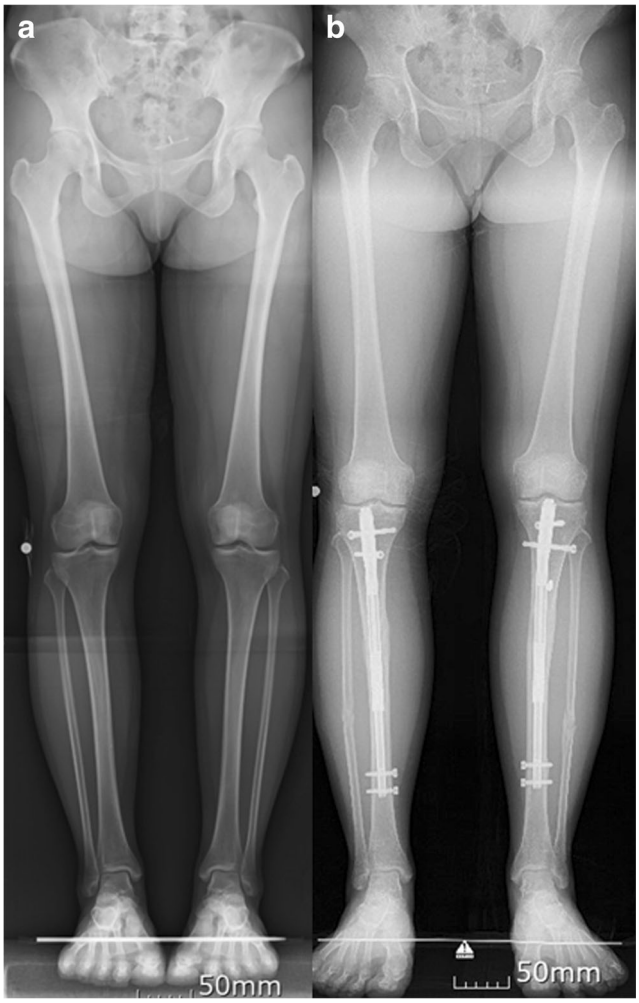

Fig. 2 A 31-year-old female with 150 cm height wanted the cosmetic limb lengthening with internal lengthening device (**a**). After lengthening by ISKD, 5.1 cm lengthening of both tibia was done without any complication (**b**)

sports, male patient and LATN procedure were associated with better moderate-to-strenuous sports scores in patient self-reports; however, no significant correlations were observed in multiple regression analysis including sex, height, operation method, complications and patient self-reported ability score for moderate-to-strenuous sports activities (Table 3).

Discussion

Cosmetic limb-lengthening surgery has evolved from the Ilizarov method to intramedullary lengthening and provides reliable outcomes, in terms of increased height [1–3, 7, 8]. With success in lengthening lower limbs and a reduction in complications, improvements in self-esteem and patient satisfaction have been reported [2, 6]. However, the recovery or changes in physical function after cosmetic lengthening have not been reported. We used the LATN technique, the LON technique and the ISKD, for cosmetic tibial lengthening and evaluated the recovery in the physical function in terms of daily and sports activity.

Table 1 Frequencies of complications

Complication	Number of segments
Problems	
Pin-site infection	28
Equinus contracture	94
Temporary hypoesthesia	26
Knee contracture	10
Delayed consolidation	6
Obstacle	
Pin breakage	6
Equinus contracture	4
Axial deviation	2
Impending compartment syndrome	1
Non-union	0
Deep infection	0
Sequelae	
Axial deviation	0
Major nerve palsy	0
Proximal migration of distal fibula	0
Joint contracture	0
Osteomyelitis	0

Table 2 Physical activity scores after bilateral cosmetic stature lengthening

Physical activity score		*p* value		
		Pre-operation vs post-operative 1 year	Post-operative 1 year vs post-operative 2 years	Pre-operation vs post-operative 2 years
Sports Activity Rating Scale (SARS)				
Pre-operation	71.5 ± 18.9			
Post-operative 1 year	65.2 ± 24.1	< 0.001	< 0.001	0.111
Post-operative 2 years	74.7 ± 19.8			
International Knee Documentation Committee (IKDC)				
Pre-operation	84.1 ± 18.3			
Post-operative 1 year	66.8 ± 16.8	0.032	< 0.001	0.847
Post-operative 2 years	83.9 ± 15.3			

Table 3 Multiple regression analysis of the relationship between patient-oriented or lengthening-related factors and moderate-to-strenuous sports activity in patient self-reported ability scores

Variable	Univariate analysis		Multivariate analysis	
	β (standard error)	p value	β (standard error)	p value
Age	− 0.03 (0.38)	0.9285		
Sex				
Female				
Male	14.08 (5.05)	0.0066	13.25 (8.28)	0.1135
Height	0.41 (0.28)	0.1462	− 0.35 (0.43)	0.4213
Weight	0.17 (0.22)	0.4392		
BMI	0.04 (0.84)	0.9656		
Operation				
LON				
LATN	11.66 (4.91)	0.0199	8.86 (5.28)	0.0968
ISKD	− 4.74 (10.32)	0.6476	− 3.97 (10.09)	0.6949
Length	− 0.1 (0.22)	0.6538		
Problem				
0				
1	5.96 (4.63)	0.2017	6.62 (4.07)	0.1083
2	10.1 (6.43)	0.1199		
Obstacle				
0				
1	− 0.7 (5.01)	0.8893		
2	1.8 (19.76)	0.9276		
Percentage length	− 0.52 (0.61)	0.3951		

BMI, body mass index; LON, lengthening over intramedullary nail; LATN, lengthening and then nailing; ISKD, intramedullary skeletal kinetic distractor

Barker et al. reported a minor decrease in muscle strength and power in the quadriceps and hamstrings using a Kin-Com 125 isokinetic dynamometer, after femur or tibial lengthening procedures; however, they stated that the decreased strength did not have an adverse impact on the ability of patients to perform everyday functions at post-operative two years [16]. But, they did not differentiate between tibial and femoral lengthening. Similarly, Holm et al. reported no difference in pre- and two year post-operative isokinetic measurements using a Cybex 340 dynamometer (Cybex-Lumex Inc., Ronkonkoma, NY, USA), although their subjects were nine persons with short stature who had undergone bilateral femoral lengthening [23]. In this study, using data from a questionnaire completed by patients who had undergone bilateral tibial lengthening, we found that sports and life activity, as evaluated by SARS and IKDC, was decreased at one year post-operatively, and subsequently recovered to the pre-operative level at post-operative two years. One advantage of SARS is that it evaluates the frequency of exercise; hence, the recovery determined by SARS evaluation in this study reflects the ability of individuals to participate in sports, much as they did before surgery.

Regarding the recovery period for lengthening osteotomy, a six to 12-month healing period may be expected for 6–7 cm lengthening [1–3]. Park et al. reported a more rapid return to previous activity in the group that underwent LON, compared with a group that underwent the conventional Ilizarov procedure; however, even among this group, only 25 of 56 patients recovered within six months [2]. Barker et al. also found that muscle torque was decreased at six months after frame removal, with quadriceps and hamstrings recovering after one and two years [16]. In this study, SARS and IKDC scores were also improved at post-operative two years, relative to post-operative one year. But, there could be a long-term change after two years and long-term follow-up study should be followed.

To our knowledge, only one study has discussed patient-reported physical activity after cosmetic tibial lengthening [2]. In that study, 25% of each group of patients that had undergone Ilizarov and LON procedures were reported to have some difficulty participating in vigorous activities or strenuous sports. The study did not include the LATN procedure or intramedullary lengthening device, and sports activities were recorded only as ‘no limitation in any activity’ or ‘some limitation in vigorous activity’. The recovery of sports-related functions in this study was evaluated using SARS and IKDC. But, there was no consideration about the performance of sports in the SARS and IKDC was designed to evaluate the knee function, although this system has a question about the level of activity. If performance in sports activities or different

types of sports had been considered, the outcome of functional evaluation may have been different. In the patient self-reported ability scores, patients still had some difficulty participating in moderate-to-strenuous sports activities.

We attempted to identify patient-related or distraction-related factors associated with reduced performance in moderate-to-strenuous sports activities; however, none of the factors assessed exhibited significant relations. In univariate analysis, male patient and LATN procedure were related to the higher scores in moderate-to-strenuous sports activities. Male sex was predominant in our patient series, which may have introduced bias. In multivariate analysis, patient-related factors were not related to moderate-to-strenuous sports activities. Superior callus formation has been demonstrated in LATN compared with LON, and less pain and complications have been reported in internal lengthening nail [28, 29]; however, surgical technique was not related to the moderate-to-strenuous sports activities on multivariate analysis in this study. Williams et al. found that a high rate of distraction was associated with a greater loss of range of joint movement and elevated muscle fibre atrophy; however, in this series, the distraction rate was constant at 0.85–1 mm/day and was not associated with ability to participate in moderate-to-strenuous sports activities [18]. Kaljumäe et al. suggested that the percentage of lengthening correlated with the extent of motor unit recruitment in electromyography study including only femur [21]. But, only seven patients were included, and the surgery was done with one-stage lengthening, not gradual lengthening. Although the electromyography characteristics of muscles were not evaluated in this study, no relationship between sports function and percentage lengthening was identified by multiple regression analysis after an average 18.9% lengthening. After tibia lengthening, changes in electromyography and nerve conduction and decreased muscle strength have been reported as a consequence of osteotomy, or the lengthening procedure itself [16, 19, 20]. They suspected permanent damage to the muscles or nerves, because of the increased compartment pressure induced by osteotomy or lengthening. However, the effect of neuromuscular change to physical function had not been studied. Considering previous findings related to neuromuscular damage caused by limb-lengthening surgery, and the lack of a significant association between moderate-to-strenuous sports activity and factors related to the lengthening procedure in this study, we speculate that the observed difficulties in participation in moderate-to-strenuous sports may be attributable to the small changes in muscle power caused by the lengthening procedure itself. Nevertheless, activities of daily living and gentle sports were not affected by these changes in muscle power.

This study has several limitations. First, the IKDC and SARS were originally developed for orthopaedic sports medicine or knee disorders; hence, they may not fully reflect the physical status of patients after their lengthening procedures. However, the SARS evaluates the frequency of sports activities and IKDC can evaluate the level of activity. Second, adjacent joint problems during or after limb lengthening had been reported and we also experienced ten cases with knee contracture [30]. They recovered a full range of motion after physiotherapy, but long-term studies about the effect of limb lengthening to the joint should be followed. The patient self-reported physical ability score is a subjective tool and could be influenced by a patient's emotional condition, although we did not include patients with psychological problems or dysmorphic syndrome. However, scores of moderate-to-strenuous sports were correlated to IKDC. And in our opinion, the emotional change after cosmetic surgery should also be considered in evaluation of sports or daily activities, because changes in emotion related to sports could be an important factor.

In summary, daily activities and frequency of sports activities were fully recovered after cosmetic bilateral tibial lengthening using LATN, LON or ISKD, with a mean 18.9% lengthening at a rate of 0.85–1 mm/day in terms of SARS and IKDC. However, individuals who had undergone cosmetic lengthening may feel some limitation in moderate-to-strenuous sports until post-operative two years. The findings of this study should be considered before the decision to proceed with cosmetic tibial lengthening.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved by the institutional review board at our institution (4-2015-0722).

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Catagni MA (2005) Cosmetic bilateral leg lengthening: experience of 54 cases. J Bone Joint Surg Br 87:1402–1405. https://doi.org/10.1302/0301-620X.87B10.16468
2. Park HW, Yang KH, Lee KS, Joo SY, Kwak YH, Kim HW (2008) Tibial lengthening over an intramedullary nail with use of the ilizarov external fixator for idiopathic short stature. J Bone Joint Surg Am 90:1970–1978. https://doi.org/10.2106/JBJS.G.00897
3. Novikov KI, Subramanyam KN, Muradisinov SO, Novikova OS, Kolesnikova ES (2014) Cosmetic lower limb lengthening by ilizarov apparatus: what are the risks? Clin Orthop Relat Res 472:3549–3556. https://doi.org/10.1007/s11999-014-3782-8
4. Elbatrawy Y, Ragab IMA (2015) Safe cosmetic leg lengthening for short stature: long-term outcomes. Orthopedics 38(7):e552–e560. https://doi.org/10.3928/01477447-20150701-51
5. Motallebi Zadeh N, Mortazavi SH, Khaki S, Heidari K, Karbasi A, Ostad Rahimi S (2014) Bilateral tibial lengthening over the nail: our experience of 143 cases. Arch Orthop Trauma Surg 134:1219–1225. https://doi.org/10.1007/s00402-014-2069-6

6. Emara K, Farouk A, Diab R (2011) Ilizarov technique of lengthening and then nailing for height increase. J Orthop Surg (Hong Kong) 19: 204–8. doi: https://doi.org/10.1177/230949901101900215
7. Lee DH, Ryu KJ, Song HR, Han SH (2014) Complications of the intramedullary skeletal kinetic distractor (ISKD) in distraction osteogenesis. Clin Orthop Relat Res 472:3852–3859. https://doi.org/10.1007/s11999-014-3547-4
8. Rozbruch SR, Kleinman D, Fragomen AT, Ilizarov S (2008) Limb lengthening and then insertion of an intramedullary nail: a case-matched comparison. Clin Orthop Relat Res 466:2923–2932. https://doi.org/10.1007/s11999-008-0509-8
9. Burghardt RD, Manzotti A, Bhave A, Paley D, Herzenberg JE (2016) Tibial lengthening over intramedullary nails: a matched case comparison with Ilizarov tibial lengthening. Bone Joint Res 5:1–10. https://doi.org/10.1302/2046-3758.51.2000577
10. Guo Q, Zhang T, Zheng Y, Feng S, Ma X, Zhao F (2012) Tibial lengthening over an intramedullary nail in patients with short stature or leg-length discrepancy: a comparative study. Int Orthop 36: 179–184. https://doi.org/10.1007/s00264-011-1246-2
11. Calder PR, Laubscher M, Goodier WD (2017) The role of the intramedullary implant in limb lengthening. Injury 48:S52–S58. https://doi.org/10.1016/j.injury.2017.04.028
12. Sun X-T, Easwar TR, Manesh S, Ryu JH, Song SH, Kim SJ, Song HR (2011) Complications and outcome of tibial lengthening using the Ilizarov method with or without a supplementary intramedullary nail: a case-matched comparative study. J Bone Joint Surg Br 93: 782–787. https://doi.org/10.1302/0301-620X.93B6.25521
13. Xu WG (2017) Comparison of intramedullary nail versus conventional Ilizarov method for lower limb lengthening: a systematic review and meta-analysis. Orthop Surg 9:159–166. https://doi.org/10.1111/os.12330
14. Bhave A, Shabtai L, Woelber E, Apelyan A, Paley D, Herzenberg JE (2017) Muscle strength and knee range of motion after femoral lengthening. Acta Orthop 88:179–184. https://doi.org/10.1080/17453674.2016.1262678
15. Stanitski CL (2004) Limb lengthening for stature response to commentary. J Pediatr Orthop 24(5):593–594
16. Barker KL, Lamb SE, Simpson HRW (2010) Recovery of muscle strength and power after limb-lengthening surgery. Arch Phys Med Rehabil 91:384–388. https://doi.org/10.1016/j.apmr.2009.11.014
17. Watts J (2004) China' s cosmetic surgery craze. Lancet 363:9413–9413
18. Williams P, Simpson H, Kenwright J, Goldspink G (2001) Muscle fibre damage and regeneration resulting from surgical limb distraction. Cells Tissues Organs 169:395–400. https://doi.org/10.1159/000047907
19. Young NL, Davis RJ, Bell DF, Redmond DM (1993) Electromyographic and nerve conduction changes after tibial lengthening by the Ilizarov method. J Pediatr Orthop 13:473–477
20. Simpson AHRW, Halliday J, Hamilton DF, Smith M, Mills K (2013) Limb lengthening and peripheral nerve function—factors associated with deterioration of conduction. Acta Orthop 84:579–584. https://doi.org/10.3109/17453674.2013.859418
21. Kaljumäe U, Märtson A, Haviko T, Hänninen O (1995) The effect of lengthening of the femur on the extensors of the knee. An electromyographic study. J Bone Joint Surg Am 77:247–250
22. Makarov M, Birch J, Samchukov M (2009) The role of variable muscle adaptation to limb lengthening in the development of joint contractures: an experimental study in the goat. J Pediatr Orthop 29: 175–181. https://doi.org/10.1097/BPO.0b013e3181981fcf
23. Holm I, Steen H, Ludvigsen P, Bjerkreim I (1995) Unchanged muscle function after bilateral femoral lengthening. A prospective study of 9 patients with a 2-year follow-up. Acta Orthop Scand 66: 258–260. https://doi.org/10.3109/17453679508995537
24. Phillips KA (1999) Body dysmorphic disorder and depression: theoretical considerations and treatment strategies. Psychiatr Q 70: 313–331
25. Noyes FR, Barber SD, Mooar LA (1989) A rationale for assessing sports activity levels and limitations in knee disorders. Clin Orthop Relat Res 246:238–249
26. Higgins LD, Taylor MK, Park D, Ghodadra N, Marchant M, Pietrobon R et al (2007) Reliability and validity of the international knee documentation committee (IKDC) subjective knee form. Joint Bone Spine 74:594–599. https://doi.org/10.1016/j.jbspin.2007.01.036
27. Paley D (1990) Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. Clin Orthop Relat Res 250: 81–104
28. Ryu KJ, Kim BH, Hwang JH, Kim HW, Lee DH (2016) Reamed intramedullary nailing has an adverse effect on bone regeneration during the distraction phase in tibial lengthening. Clin Orthop Relat Res 474:816–824. https://doi.org/10.1007/s11999-015-4613-2
29. Alrabai HM, Gesheff MG, Conway JD (2017) Use of internal lengthening nails in post-traumatic sequelae. Int Orthop 41:1915–1923
30. Eidelman M, Jauergui JJ, Standard SC, Paley D, Hezenberg JE (2016) Hip stability during lengthening in children with congenital femoral deficiency. Int Orthop 40:2619–2625