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[Translated article] Impact of lower limb lengthening with telescopic nails on functionality and quality of life in patients with achondroplasia

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KEYWORDS
Achondroplasia;
Short stature;
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Health-related quality of life;
Satisfaction

Abstract
Introduction: The short stature characteristic of patients with achondroplasia can negatively affect health-related quality of life (HRQoL). Lower limb lengthening reusing telescopic intramedullary nails (TIMNs) offers an alternative to external fixators, with the potential to enhance functionality, self-esteem, and HRQoL, while reducing complication risks, which this study aims to evaluate.
Materials and methods: This retrospective study included nine patients with achondroplasia who underwent parallel transverse lengthening of femurs and/or tibias reusing a TIMN between 2015 and 2022. Functionality (Lower Extremity Functional Scale, LEFS), self-esteem (Rosenberg Self-Esteem Scale), and HRQoL (Short Form-12, SF-12, and EuroQol VAS) were assessed preoperatively and at least two years post-surgery. Complications (Clavien–Dindo–Sink classification) and patient satisfaction were also recorded.
Results: The median age was 13.5 years (IQR: 12.5–17.1), with a significant height increase of +19.9 cm ($p < 0.05$). Improvements were significant in functionality (LEFS, +4.6 points; $p < 0.05$), self-esteem (Rosenberg, +3.7 points; $p < 0.05$), and HRQoL (SF-12 physical, +8.9 points; $p < 0.05$; EQ-VAS, +20 points; $p < 0.05$). A total of 22 complications were reported in 32 treated bones, most classified as grade 2 or 3B, with no significant correlation to outcomes in functionality, HRQoL, or self-esteem outcomes ($p > 0.05$).

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Conclusions: Lower limb lengthening reusing TIMNs appears to improve functionality, HRQoL, and self-esteem in patients with achondroplasia compared to their preoperative status. High patient satisfaction and manageable complications were observed, with no negative impact on outcomes, laying the groundwork for future studies.

PALABRAS CLAVE
Acondroplasia;
Talla baja;
Cirugía de alargamiento;
Clavos intramedulares telescópicos;
Calidad de vida relacionada con la salud;
Satisfacción

Impacto del alargamiento de miembros inferiores con clavos telescópicos en la funcionalidad y calidad de vida de pacientes con acondroplasia

Resumen
Introducción: La talla baja característica de pacientes con acondroplasia puede afectar negativamente la calidad de vida relacionada con la salud (CVRS). El alargamiento de miembros inferiores reutilizando clavos intramedulares telescópicos (CIMT) ofrece una alternativa a los fijadores externos, con el potencial de mejorar la funcionalidad, autoestima y CVRS, mientras reduce el riesgo de complicaciones, objetivo principal de este estudio.
Material y métodos: Este estudio retrospectivo incluyó a 9 pacientes con acondroplasia que se sometieron a alargamiento paralelo transverso de fémures y/o tibias reutilizando un CIMT entre 2015 y 2022. Se evaluaron la funcionalidad (Escala de Función de Extremidad Inferior [LEFS]), la autoestima (Escala de Rosenberg) y la CVRS (*Short Form 12* [SF-12] y EuroQol VAS) preoperatoriamente y al menos a los 2 años poscirugía. Además, se registraron las complicaciones (sistema Clavien-Dindo-Sink) y la satisfacción.
Resultados: La mediana de edad fue de 13,5 años (RIC: 12,5-17,1), con un aumento significativo en la estatura de +19,9 cm ($p < 0,05$). Se observaron mejoras significativas en la funcionalidad (LEFS, +4,6 puntos; $p < 0,05$), autoestima (Rosenberg, +3,7 puntos; $p < 0,05$) y CVRS (SF-12 físico, +8,9 puntos; $p < 0,05$; EQ-VAS, +20 puntos; $p < 0,05$). En total, hubo 22 complicaciones en 32 huesos tratados, la mayoría clasificadas como grado 2 o 3B, sin correlación significativa con los resultados en funcionalidad, CVRS o autoestima ($p > 0,05$).
Conclusiones: El alargamiento de miembros inferiores con CIMT parece mejorar la funcionalidad, CVRS y autoestima en pacientes con acondroplasia en comparación con su situación preoperatoria. La satisfacción es alta y las complicaciones son manejables, sin impacto negativo en los resultados, sentando las bases para futuros estudios.

Introduction

Achondroplasia is the most common cause of non-lethal skeletal dysplasia, characterized by rhizomelic and disproportionate short stature. It is defined by short limbs, macrocephaly, and bone deformities, leading to significant functional and psychosocial complications.[1] The average height of adults with achondroplasia—130 cm in men and 124 cm in women[2]— together with associated skeletal comorbidities, significantly impacts daily quality of life. It imposes physical and architectural barriers, hinders social integration, and affects self-esteem.[3] In recent years, the development of medical treatments such as vosoritide has opened new possibilities for stimulating bone growth in these patients. Although data on its efficacy and safety with mid-term follow-up are available, its high cost, estimated at $320,000 annually (or $200,000 per centimetre of growth), limits accessibility and widespread use.[4,5]

Given these limitations, limb lengthening surgery remains a therapeutic option to increase height in patients with achondroplasia.[6] This procedure provides a more functional height, and improved body proportionality, and may also enhance self-esteem and health-related quality of life (HRQoL), as reported by patients themselves.[7,8] Several studies have shown that increased height facilitates mobility, reduces the need for physical adaptations, and promotes better social integration, thereby increasing personal and psychological satisfaction.[9] The introduction of telescopic intramedullary nails (TIMNs) has revolutionised limb lengthening, offering significant advantages over traditional external fixators,[10–12] such as a lower complication rate, greater patient comfort, and improved aesthetic perception, which translates into higher levels of satisfaction after surgery[13-17]. However, in patients with achondroplasia, whose bones are shorter, the use of TIMN is limited by their elongation capacity (maximum 5 cm), which is insufficient for the growth needs of these patients.

In 2022, the first study documenting the use of TIMN for lower limb lengthening in patients with achondroplasia was published, employing an innovative strategy that involved reusing the same device to perform two sequential lengthenings. This technique has shown promising results in terms

Figure 1 Example of a patient with achondroplasia from the series showing sequential radiographs during the femur and tibia lengthening procedure using two-stage telescopic intramedullary nails, resulting in a total height increase of 20 cm.

of local safety and efficacy.[18] Nonetheless, questions remain regarding the functional impact of the procedure, as well as on quality of life, self-esteem, and patient satisfaction, which are the central objectives of this study.

Methods

This retrospective study, conducted at a national paediatric orthopaedic referral centre, included all patients with achondroplasia who underwent bilateral transverse femoral and/or tibial lengthening by reusing a TIMN[18] between 2015 and 2022. Approval was obtained from the centre's Ethics Committee (no. R-0001/22). Exclusion criteria were prior lengthening surgery on the same bone, bone deformities that prevented intramedullary nailing, and incomplete medical records.

Surgical intervention and lengthening protocol

The surgical procedure and lengthening protocol have been described previously.[18] An initial lengthening of 5 cm was performed, followed by reusing the same nail, unlocking it, rewinding it, and relocking it for a second lengthening of up to an additional 5 cm, reaching a maximum total of 10 cm per bone (Fig. 1). All surgical procedures were performed by a team specialised in extremity reconstructive surgery, composed of two highly experienced orthopaedic surgeons (JAH and CMG). During the lengthening process, patients were evaluated by rehabilitation specialists and received formal physical therapy. Additionally, they were advised to perform daily home mobility exercises for the hip, knee, and ankle, with the goal of preventing contractures and optimising functional outcomes. A total of 9 patients were included in the study group: 7 underwent bilateral lengthening of both segments (femurs and tibias), while 2 patients underwent bilateral femoral lengthening only. A total of 32 bones were treated: 4 isolated femurs and 28 combined bilateral femoral and tibial procedures (non-simultaneous). Additionally, 3 patients underwent humeral lengthening using an external fixator. However, these procedures were not included in this analysis. The minimum follow-up for all patients was 2 years after the last intervention.

Assessment of results

Patients were evaluated preoperatively and at least two years after surgery. These evaluations were routinely performed in the clinics and included the following:

- Functionality was assessed using the Lower Extremity Function Scale (LEFS), which includes 20 questions on the ability to perform daily tasks.[19]
- The Rosenberg Self-Esteem Scale was used to measure patients' positive and negative feelings about their self-image and self-competence.[20]
- HRQoL was measured using the Short Form 12 (SF-12) Health Survey,[21] which measures the physical and mental components of health, as well as the EuroQol Visual Analogue Scale (EQ-VAS)[22] to measure perceived quality of life.
- Satisfaction was assessed using four qualitative questions, focusing on overall satisfaction with the procedure and results, willingness to undergo the procedure again, per-

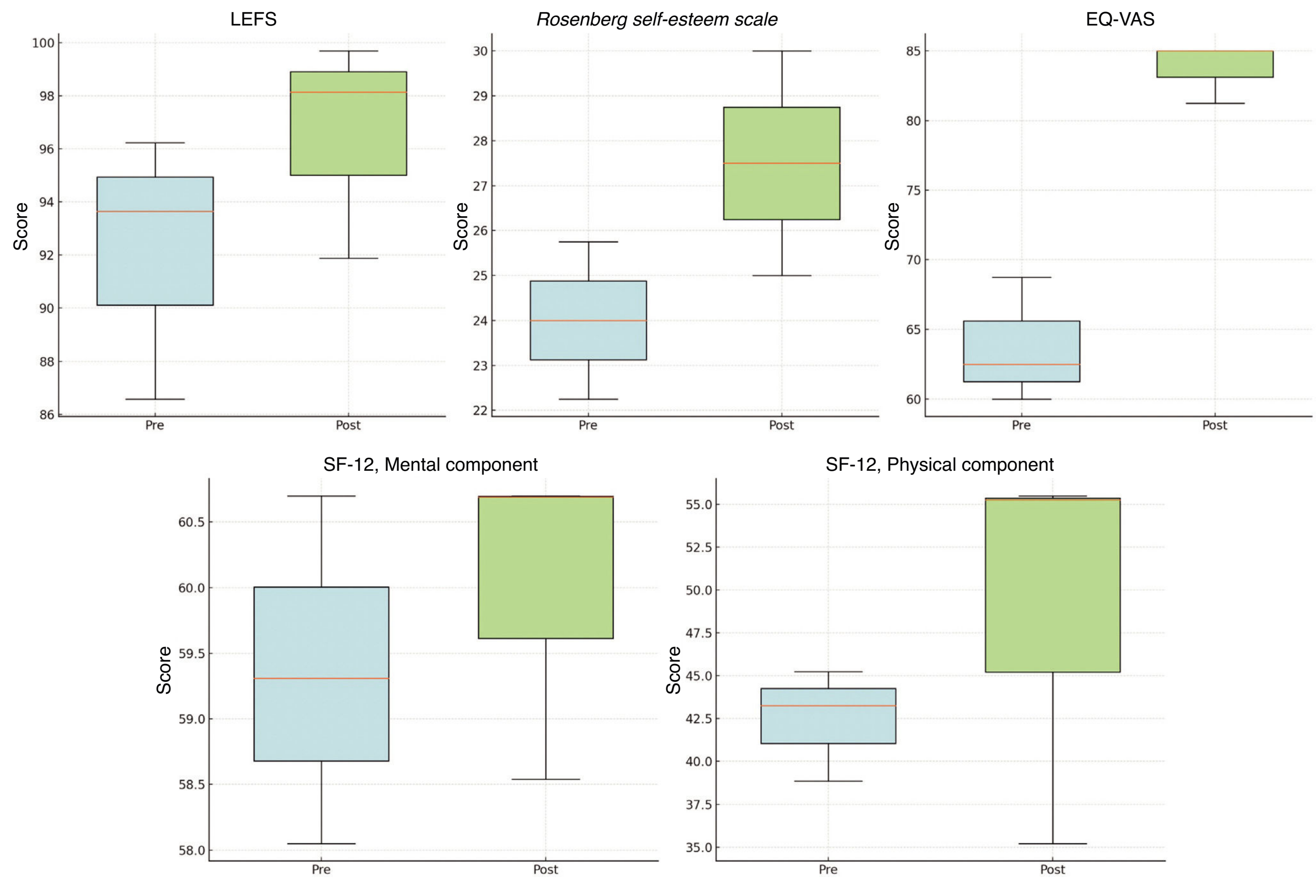

Figure 2 Box plots of pre- (in blue) and post- (in green) results on the LEFS, Rosenberg Self-Esteem Scale, EQ-VAS, and the physical and mental components of the SF-12.

ceived improvement in quality of life, and recommending the procedure to other patients. Patients were also asked whether they were now able to perform activities that were previously impossible due to their height, or whether they performed them with greater ease.

Additionally, anthropometric data, including weight (kg), height (m), and body mass index (BMI) (kg/m^2) before and after lengthening, were recorded. Complications were classified according to the modified Clavien–Dindo–Sink (MCD) system for orthopaedic procedures.[23]

Statistical analysis

All data were statistically analysed using SPSS version 23 software (IBM Inc., Chicago, IL). Continuous quantitative data were described as median and interquartile range (IQR), appropriate for small sample sizes, while categorical variables were presented as frequency and percentage values. The Wilcoxon signed-rank test was used to compare pre- and postoperative outcomes for functionality, HRQoL, self-esteem, and patient satisfaction. Likewise, the relationship between complications, classified according to the MCD system, and changes in the different assessment scales was assessed using Pearson's correlation coefficient. All tests were two-tailed, with a significance level set at $p = .05$.

Results

The median age of patients at the time of the first intervention was 13.5 years (IQR: 12.5–17.1 years), with 4 female and 5 male patients. Following the procedures, a significant increase in both weight and height was observed ($p < .05$), with the height increase being more pronounced. As a result, the BMI did not show a statistically significant change ($p > .05$) (Table 1). The median follow-up from the first intervention was 6 years (IQR: 5.3–7.7 years). At the end of the follow-up, the median age of the patients was 21 years (IQR: 18.5–25.9 years).

Functionality, self-esteem and quality of life

Significant improvements were observed in functionality, as assessed by the LEFS, after the procedure ($p < .05$) (Table 2, Fig. 2,). Self-esteem, assessed using the Rosenberg Self-Esteem Scale, also showed significant improvement, with an increase of 3.7 points (IQR: 2.0–4.0; $p < .05$) after the procedure (Table 2, Fig. 2). Similarly, HRQoL, measured using the SF-12 and the EQ-VAS, showed significant improvements.

Table 1 Pre- and postoperative anthropometric results.

Parameter	Pre-	Post-	Change	*p*
Weight (kg)	39.0 (30.2–51)	48.0 (36–55)	+9.0	<.05
Height (m)	121.0 (115–133)	140.0 (134–157)	+19.0	<.05
BMI (kg/m^2)	25.7 (20–38.5)	24.5 (17.9–27.9)	−1.22	>.05

Data are presented as median and interquartile range. Comparative analysis was performed using the Wilcoxon signed-rank test.
BMI: body mass index.

Table 2 Results from the different functionality scales, HRQoL and self-esteem.

	Pre-	Post-	Cambio	*p*
LEFS	85 (51.2–96.3)	97.5 (58.8–100)	+4.6	<.05
Rosenberg self-esteem scale	22 (22–26)	25 (24–30)	+3.7	<.05
SF-12, physical component	37.5 (28.7–46.3)	46.3 (35.2–55.5)	+8.9	<.05
SF-12, mental component	55.5 (55.3–60.5)	60.7 (57.8–62.4)	+.2	>.05
EQ-VAS	60 (60–70)	80 (65–85)	+15	<.05

Data are presented as median and interquartile range. Comparative analysis was performed using the Wilcoxon signed-rank test.
HRQoL: health-related quality of life; EQ-VAS: Euroqol Visual Analogue Scale; LEFS: Lower Extremity Function Scale; SF-12: Short Form 12.

On the physical component of the SF-12, the median score increased by 8.9 points (IQR: 6.0–12.3; $p < .05$), whereas the mental component showed a modest change of .2 points (IQR: −.1 to 4.0; $p > .05$). The EQ-VAS score improved significantly by a median of 15 points (IQR: 10–20; $p < .05$) (Table 2, Fig. 2).

Satisfaction

Overall patient satisfaction was high across all dimensions assessed. All indicated that they would be willing to undergo the procedure again and would recommend it to other patients in similar circumstances. Furthermore, all participants reported a significant improvement in their quality of life after lower limb lengthening. The activities they reported being easier to perform included reaching for objects on high shelves, asking for information at counters, climbing high curbs more easily, riding a bicycle, driving, and participating in sports such as basketball or volleyball. They also mentioned improvements in household tasks, such as accessing high cabinets and using previously inaccessible appliances, such as the microwave or the top shelves of the refrigerator.

Complications

A total of 26 complications were recorded in the 32 bones that underwent lengthening, representing a complication rate of 81.3%. Since 8 bones presented more than one complication, 53.1% of the bones suffered at least one complication. Of these, 5 were grade 1, 11 were grade 2, and 10 were grade 3B, with no grade 4 or 5 complications reported (Appendix B, Supplementary Table 1). No significant correlation was found between the occurrence of complications and changes in functionality, HRQoL, or self-esteem 2 years after the procedure (Table 3, Fig. 3). This suggests that, despite complications, patients did not experience a significant negative impact on their final outcomes.

Table 3 Correlation between the scales of results and the complications.

	Correlation	*p*
LEFS Change	.19	.77
Rosenberg self-esteem scale change	−.63	.26
SF-12, physical component change	.53	.36
SF-12, mental component change	.67	.21
EQ-VAS change	.29	.64

Analysis performed using Pearson's correlation coefficient. A value of 1 indicates a perfect positive correlation, −1 indicates a perfect negative correlation, and 0 indicates no linear correlation.
EQ-VAS: Euroqol Visual Analogue Scale; LEFS: Lower Extremity Function Scale; SF-12: Short Form 12.

Discussion

The results of this study demonstrate that lower limb lengthening with TIMN in patients with achondroplasia appears to improve functionality, self-esteem, and HRQoL in the medium term, with manageable complications that did not negatively impact outcomes. This is the first study to document these benefits using TIMN instead of external fixators, providing initial evidence and establishing a foundation for future studies.

Lower limb lengthening with TIMN appears to improve patients' functional capacity, as measured by the LEFS scale, facilitating daily activities with fewer adaptations. Previous studies have shown that greater height reduces physical barriers such as reaching high objects or walking long distances unaided.[8,24] Our patients also reported improvements in activities such as cycling, stepping up on curbs, or driving. This increase in height, by facilitating previously difficult or

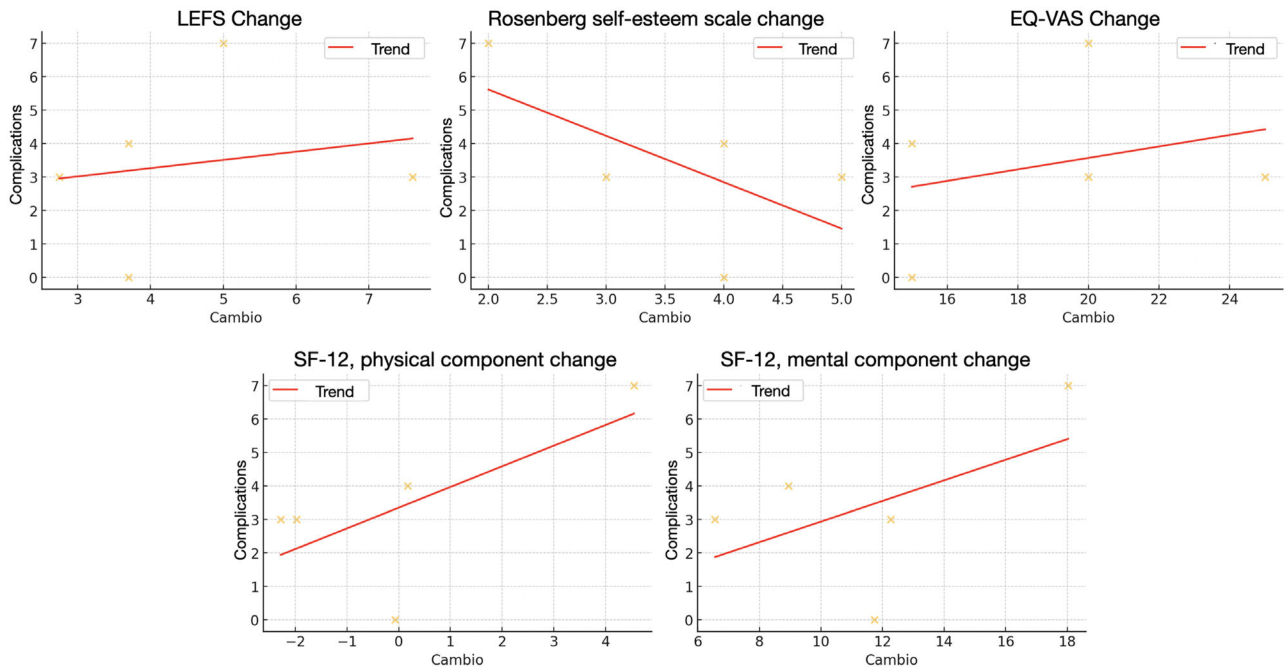

Figure 3 Scatter plots showing the non-statistically significant correlation between complications and changes on the various assessment scales. The trend lines (in red) indicate the direction of the relationship in each case.

impossible activities, contributed to greater independence and participation in social activities.[25,26]

HRQoL also improved significantly in our study, as physical and psychological barriers to daily living were reduced. Previous studies maintain that limb lengthening improves HRQoL in patients with achondroplasia[7,8,27] and that taller stature correlates with better HRQoL.[28] Increased height facilitates social integration and decreases the need for adaptations, allowing for fuller participation in environments designed for average-height individuals.[8,26] Validated questionnaires show that patients who undergo surgery report significantly higher HRQoL scores than those who do not, and compared to their own preoperative scores.[24,26]

Furthermore, increased height has a positive impact on self-image, improving confidence and reducing the perceived difference from peers, which facilitates greater social acceptance. Studies have shown that patients with increased height experience improvements in self-esteem as visible differences with average-height individuals are reduced.[7,29] Reducing the perception of difference facilitates more natural social integration, reduces feelings of insecurity, and mitigates the stigma associated with short stature.[8] Notably, this benefit is not limited to lower limbs, as significant improvements in self-esteem have also been observed after upper limb lengthening.[30]

TIMN lengthening is associated with greater satisfaction compared to external fixators, as its reduced visibility reduces emotional and social stress, improving emotional well-being and increasing satisfaction with the procedure.[15] Furthermore, the absence of pins that pierce the skin and muscles reduces the risk of infection and pain with mobilisation, facilitating more comfortable and effective rehabilitation and resulting in improved ranges of motion.[17,31] Overall, patients who undergo TIMN lengthening report a more positive experience and more satisfactory long-term results.[15]

Several studies have shown that TIMN lengthening reduces the risk of complications in non-achondroplastic populations.[16,17] In our study, although complications were observed in 53.1% of the 32 lengthened segments, most were manageable and did not affect mid-term functionality or HRQoL. No patients presented superficial or deep infections, skin problems, or clinically relevant length discrepancies, which contrasts with previous studies with external fixators, where these complications are more frequent and negatively affect HRQoL, postoperative satisfaction, and increase hospital readmissions.[32,33] In our series, one fracture was recorded upon nail removal, treated with re-nailing. Fractures of regenerated bone are more common with external fixators,[34,35] and some authors recommend using prophylactic intramedullary nails after external fixator removal.[36] The lower incidence of fractures with TIMN is attributed to the greater stability and alignment it provides, in addition to the comfort and less invasiveness that allow the device to remain in place during healing, reducing the risk of fractures.

Our study has some limitations. The small sample size limits generalizability to the entire achondroplasia population. Furthermore, the retrospective design introduces potential biases in data collection, and the lack of a control group limits comparisons with other treatment approaches, such as external fixators or non-lengthening. We did not perform a detailed analysis of anthropometric variables (e.g., body proportionality indicators or skeletal comorbidities), nor did we stratify height, weight, and BMI into standard deviations specific to achondroplasia. This may have provided more context and improved data interpretation. Furthermore, the use of generic questionnaires not specific to the achondroplasia population is another limitation, so the findings should be interpreted with caution. Finally, the 2-year follow-up period may not be sufficient to fully assess long-term complications or the sustainability of improvements in functionality, HRQoL, and self-esteem. These limitations highlight the need for prospective studies with a larger cohort, specific tools for the achondroplastic population[37] and longer-term follow-up to confirm these results and explore the long-term impact of these procedures.

Conclusions

Lower limb lengthening with TIMN in patients with achondroplasia appears to improve functionality, HRQoL, and self-esteem compared to the preoperative situation. Satisfaction is high, and complications are manageable, with no negative impact on outcomes, underscoring the safety and efficacy of TIMN as a technique for lower limb lengthening in these patients.

Level of evidence

Level of evidence IV.

Authorship

Substantial contributions to the conception or design of the study; or to the acquisition, analysis, or interpretation of data for it: MGO, JAH, CMG, JGF, RMEG, APQ.

Drafting the study or revising it critically for important intellectual content: MGO, JAH, CMG, JGF, RMEG, APQ.

Final approval of the version to be published: MGO, JAH, CMG, JGF, RMEG, APQ.

Agreement to be accountable for all aspects of the study, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: MGO, JAH, CMG, JGF, RMEG, APQ.

Informed consent

All the participants gave their informed consent prior to study participation.

Ethical approval

Institutional Review Board approval was obtained for this study (no. R-0001/22). This study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

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Conflict of interests

The authors have no conflicts of interest relevant to the content of this article to declare.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.recot.2025.04.012.

References

1. Pauli RM. Achondroplasia: a comprehensive clinical review. Orphanet J Rare Dis. 2019;14:1, http://dx.doi.org/10.1186/s13023-018-0972-6.
2. Merker A, Neumeyer L, Hertel NT, Grigelioniene G, Mäkitie O, Mohnike K, et al. Growth in achondroplasia: development of height, weight, head circumference, and body mass index in a European cohort. Am J Med Genet A. 2018;176:1723–34, http://dx.doi.org/10.1002/ajmg.a.38853.
3. Constantinides C, Landis SH, Jarrett J, Quinn J, Ireland PJ. Quality of life, physical functioning, and psychosocial function among patients with achondroplasia: a targeted literature review. Disabil Rehabil. 2022;44:6166–78, http://dx.doi.org/10.1080/09638288.2021.1963853.
4. Savarirayan R, Tofts L, Irving M, Wilcox WR, Bacino CA, Hoover-Fong J, et al. Safe and persistent growth-promoting effects of vosoritide in children with achondroplasia: 2-year results from an open-label, phase 3 extension study. Genet Med. 2021;23:2443–7, http://dx.doi.org/10.1038/s41436-021-01287-7.
5. Hoover-Fong J, Irving M, Bacino C, Charrow J, Prada C, Cormier-Daire V, et al. Persistence of growth-promoting effects in children with achondroplasia up to 7 years: update from phase 2 extension study with vosoritide [Poster presentation]. Genet Med Open. 2024;2:101041, http://dx.doi.org/10.1016/j.gimo.2024.101041.

6. Savarirayan R, Ireland P, Irving M, Thompson D, Alves I, Baratela WAR, et al. International Consensus Statement on the diagnosis, multidisciplinary management and lifelong care of individuals with achondroplasia. Nat Rev Endocrinol. 2022;18:173–89, http://dx.doi.org/10.1038/s41574-021-00595-x.
7. Kim SJ, Balce GC, Agashe MV, Song SH, Song HR. Is bilateral lower limb lengthening appropriate for achondroplasia? Midterm analysis of the complications and quality of life. Clin Orthop Relat Res. 2012;470:616–21, http://dx.doi.org/10.1007/s11999-011-1983-y.
8. Batıbay SG, Balcı Hİ, Bayram S, Chodza M, Göksoy Ş, Hürmeydan ÖM, et al. Quality of life evaluation following limb lengthening surgery in patients with achondroplasia. Indian J Orthop. 2020;54 Suppl. 1:39–46, http://dx.doi.org/10.1007/s43465-020-00127-1.
9. Ireland PJ, McGill J, Zankl A, Ware RS, Pacey V, Ault J, et al. Functional performance in young Australian children with achondroplasia. Dev Med Child Neurol. 2011;53:944–50, http://dx.doi.org/10.1111/j.1469-8749.2011.04050.x.
10. Cattaneo R, Villa A, Catagni M, Tentori L. Limb lengthening in achondroplasia by Ilizarov's method. Int Orthop. 1988;12:173–9, http://dx.doi.org/10.1007/BF00547160.
11. Lavini F, Renzi-Brivio L, de Bastiani G. Psychologic, vascular, and physiologic aspects of lower limb lengthening in achondroplastics. Clin Orthop Relat Res. 1990;250:138–42.
12. Aldegheri R, Dall'Oca C. Limb lengthening in short stature patients. J Pediatr Orthop B. 2001;10:238–47.
13. Paley D. Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. Clin Orthop Relat Res. 1990;250:81–104.
14. Fragomen AT, Kurtz AM, Barclay JR, Nguyen J, Rozbruch SR. A comparison of femoral lengthening methods favors the magnetic internal lengthening nail when compared with lengthening over a nail. HSS J. 2018;14:166–76, http://dx.doi.org/10.1007/s11420-017-9596-y.
15. Landge V, Shabtai L, Gesheff M, Specht SC, Herzenberg JE. Patient satisfaction after limb lengthening with internal and external devices. J Surg Orthop Adv. 2015;24:174–9.
16. Laubscher M, Mitchell C, Timms A, Goodier D, Calder P. Outcomes following femoral lengthening: an initial comparison of the Precice intramedullary lengthening nail and the LRS external fixator monorail system. Bone Joint J. 2016;98-B:1382–8, http://dx.doi.org/10.1302/0301-620X.98B10.36643.
17. Szymczuk VL, Hammouda AI, Gesheff MG, Standard SC, Herzenberg JE. Lengthening with monolateral external fixation versus magnetically motorized intramedullary nail in congenital femoral deficiency. J Pediatr Orthop. 2019;39:458–65, http://dx.doi.org/10.1097/BPO.0000000000001047.
18. Alonso-Hernández J, Galán-Olleros M, Miranda-Gorozarri C, Egea-Gámez RM, Palazón-Quevedo Á. Two-stage bone lengthening with reuse of a single intramedullary telescopic nail in patients with achondroplasia. J Pediatr Orthop. 2022;42:e616–22, http://dx.doi.org/10.1097/BPO.0000000000002133.
19. Binkley JM, Stratford PW, Lott SA, Riddle DL. The Lower Extremity Functional Scale (LEFS): scale development, measurement properties, and clinical application. North American Orthopaedic Rehabilitation Research Network. Phys Ther. 1999;79:371–83.
20. Rosenberg M. Society and the adolescent self-image. Princeton, NJ: Princeton University Press; 1965.
21. Ware JE, Keller SD, Kosinski M. SF-12: how to score the SF-12 physical and mental health summary scales. Health Institute, New England Medical Center; 1995.
22. EuroQol Group. EuroQol a new facility for the measurement of health-related quality of life. Health Policy. 1990;16:199–208.
23. Sink EL, Leunig M, Zaltz I, Gilbert JC, Clohisy J, Academic Network for Conservational Hip Outcomes Research Group. Reliability of a complication classification system for orthopaedic surgery. Clin Orthop Relat Res. 2012;470:2220–6, http://dx.doi.org/10.1007/s11999-012-2343-2.
24. Irving M, Savarirayan R, Arundel P, Polgreen L, Mohnike K, Ozono K, et al. Associations between height and health-related quality of life (HRQoL) and functional independence in children with achondroplasia. Genet Med. 2022;24 Suppl., http://dx.doi.org/10.1016/j.gim.2022.01.301.
25. Bedeschi MF, Mora S, Antoniazzi F, Boero S, Ravasio R, Scarano G, et al. The clinical management of children with achondroplasia in Italy: results of clinician and parent/caregiver surveys. J Endocrinol Invest. 2024;47:345–56, http://dx.doi.org/10.1007/s40618-023-02151-y.
26. Maghnie M, Semler O, Guillen-Navarro E, Selicorni A, Heath KE, Haeusler G, et al. Lifetime impact of achondroplasia study in Europe (LIAISE): findings from a multinational observational study. Orphanet J Rare Dis. 2023;18:56, http://dx.doi.org/10.1186/s13023-023-02652-2.
27. Leiva-Gea A, Delgado-Rufino FB, Queipo-de-Llano A, Mariscal-Lara J, Lombardo-Torre M, Luna-González F. Staged upper and lower limb lengthening performing bilateral simultaneous surgery of the femur and tibia in achondroplastic patients. Arch Orthop Trauma Surg. 2020;140:1665–76, http://dx.doi.org/10.1007/s00402-020-03360-3.
28. Matsushita M, Kitoh H, Mishima K, Yamashita S, Haga N, Fujiwara S, et al. Physical, mental, and social problems of adolescent and adult patients with achondroplasia. Calcif Tissue Int. 2019;104:364–72, http://dx.doi.org/10.1007/s00223-019-00518-z.
29. Moy N, Flynn D, Henriquez J, Connelly LB, Vale L, Paolucci F. Interventions for improving clinical outcomes and health-related quality-of-life for people living with skeletal dysplasias: an evidence gap map. Qual Life Res. 2023;32:2751–62, http://dx.doi.org/10.1007/s11136-023-03431-z.
30. Nakano-Matsuoka N, Fukiage K, Harada Y, Kashiwagi N, Futami T. The prevalence of the complications and their associated factors in humeral lengthening for achondroplasia: retrospective study of 54 cases. J Pediatr Orthop B. 2017;26:519–25, http://dx.doi.org/10.1097/BPB.0000000000000428.
31. Horn J, Grimsrud Ø, Dagsgard AH, Huhnstock S, Steen H. Femoral lengthening with a motorized intramedullary nail. Acta Orthop. 2015;86:248–56, http://dx.doi.org/10.3109/17453674.2014.960647.
32. Tillotson LO, Maddock CL, Hanley J, Arseneau GM, Bradley CS, Kelley SP. Femoral lengthening in children: a comparison of motorized intramedullary nailing versus external fixation techniques. J Pediatr Orthop. 2022;42:253–9, http://dx.doi.org/10.1097/BPO.0000000000002120.
33. Donaldson J, Aftab S, Bradish C. Achondroplasia and limb lengthening: results in a UK cohort and review of the literature. J Orthop. 2015;12:31–4, http://dx.doi.org/10.1016/j.jor.2015.01.001.
34. Launay F, Younsi R, Pithioux M, Chabrand P, Bollini G, Jouve JL. Fracture following lower limb lengthening in children: a series of 58 patients. Orthop Traumatol Surg Res. 2013;99:72–9, http://dx.doi.org/10.1016/j.otsr.2012.08.005.
35. Park KW, Garcia RA, Rejuso CA, Choi JW, Song HR. Limb lengthening in patients with achondroplasia. Yonsei Med J. 2015;56:1656–62, http://dx.doi.org/10.3349/ymj.2015.56.6.1656.

36. Rovira Martí P, Ginebreda Martí I, García Fontecha C. Prophylactic intramedullary rodding after femoral lengthening in patients with achondroplasia and hypochondroplasia. J Pediatr Orthop. 2024;44:e249–54, http://dx.doi.org/10.1097/BPO.0000000000002594.

37. Quitmann J, Giammarco A, Maghnie M, Napoli F, Di Giovanni I, Carducci C, et al. Validation of the Italian Quality of Life in Short Stature Youth (QoLISSY) questionnaire. J Endocrinol Invest. 2017;40:1077–84, http://dx.doi.org/10.1007/s40618-017-0667-1.