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SYSTEMATIC REVIEW

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Aesthetic lower limb lengthening techniques: a systematic review of efficacy, complications, and patient satisfaction

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Abstract

Background Aesthetic limb lengthening (ALL) is a cosmetic procedure aimed at enhancing body symmetry and improving self-esteem through the gradual elongation of bones. Unlike functional limb lengthening, which addresses limb length discrepancies, ALL focuses on increasing limb length for aesthetic purposes. While functional limb lengthening has been extensively studied, a comprehensive analysis of ALL outcomes is needed. This systematic review evaluates the efficacy, complications, and patient satisfaction associated with different ALL techniques, including distraction osteogenesis and various external and internal fixation systems.

Methods A systematic search of PubMed, Embase, and Scopus was conducted up to July 2024 to identify relevant studies in English. Eligible studies included case series, cohort studies, and randomized controlled trials with at least 12 months of follow-up. Studies focusing on adult populations undergoing aesthetic limb lengthening were included. Data on limb lengthening achieved, bone healing rates, complications, and patient satisfaction were extracted and synthesized through narrative analysis. The methodological quality of studies was assessed using the MINORS criteria for non-randomized studies.

Results A total of 12 studies involving 760 patients were included. Most patients were male (67%), with an average age of 24.75 years. Techniques employed included the Ilizarov method, motorized internal lengthening nails (MILN), and combined methods like Lengthening And Then Nailing (LATN). The lengthening achieved ranged from 62 mm to 87 mm, with an average of 67 mm. Patient satisfaction rates ranged from 88.8 to 98%. Psychological outcomes showed improvements in body image and self-esteem. Functionally, most patients resumed normal activities with minimal joint limitations. However, common complications included infections, bone healing issues, joint deformities, and material-related complications.

Conclusion ALL offers high patient satisfaction and psychological benefits, with patients reporting improved body image and self-esteem. Despite these positive outcomes, complications such as infections and bone healing issues

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remain significant. Further research with rigorous study designs is needed to improve the safety and efficacy of ALL procedures.

Introduction

Limb length discrepancy (LLD) is a condition characterized by unequal lengths between the upper and lower limbs, which can profoundly impact an individual's physical appearance, functional abilities, and psychosocial well-being [1]. While functional limb lengthening techniques have long been utilized to address LLD and improve functional outcomes [2], aesthetic limb lengthening (ALL) has emerged as a distinct field to enhance body symmetry and improve patients' self-esteem through cosmetic interventions [3].

ALL techniques involve the gradual elongation of bones through various techniques [4, 5] like the application of external fixation devices [6], such as the Ilizarov apparatus or modern limb lengthening systems [4] (lengthening and then nailing (LATN) and lengthening over a nail (LON) and mechanical or motorized internal lengthening nails (MILN)). These procedures allow for controlled distraction and subsequent consolidation of the bone, resulting in increased limb length over time [4]. While functional limb lengthening techniques have been extensively studied and are well-documented [7], the specific considerations and outcomes related to ALL warrant further investigation.

This systematic review aims to comprehensively analyze the current literature on ALL, evaluate the efficacy of different techniques, identify potential complications, and assess patient satisfaction levels. By synthesizing existing evidence, we aim to offer valuable insights into the outcomes and challenges associated with ALL procedures. Key factors, including the amount of length gained, and the impact on joint function and range of motion, will be assessed to determine the effectiveness of different ALL techniques.

Numerous techniques and external fixation devices have been developed and utilized in aesthetic limb lengthening procedures. We will compare the different techniques and devices employed, considering their efficacy, safety profiles, complications, and patient-reported outcomes. By analyzing and comparing these approaches, we aim to identify the most effective techniques and devices for achieving optimal aesthetic outcomes while minimizing potential risks.

Moreover, as with any surgical intervention, ALL procedures carry potential risks and complications. Understanding and mitigating these risks are crucial for optimizing patient outcomes. We will evaluate the prevalence and types of complications associated with aesthetic limb lengthening techniques, including infection, delayed bone healing, nerve injury, joint stiffness, and hardware-related issues.

Finally, the psychological impact of limb length discrepancy can be substantial, affecting body image, self-confidence, and overall quality of life. ALL aims to address these psychosocial concerns by improving body symmetry and enhancing patients' self-perception. This review will also assess patient satisfaction levels following ALL procedures, evaluating subjective measures such as patient-reported outcomes, body image perception, self-esteem, and quality of life assessments. Understanding the impact of aesthetic limb lengthening on patients' psychological well-being is vital for comprehensive patient-centered care.

Materials and methods

Study design

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [8].

We conducted a comprehensive literature search of three electronic databases from their inception up to July 2024. The following search terms and their combinations were used with Boolean operators: "aesthetic", "bone lengthening", "limb reconstruction", "limb lengthening", "limb discrepancy", "distraction osteogenesis", "external fixation", "deformity treatment". The search was limited to articles published in English. This review protocol wasn't registered prior to conducting the systematic search.

Search strategy

A comprehensive and systematic literature search was conducted to identify relevant studies for inclusion. Three major electronic databases—PubMed, Embase, and Scopus—were queried using a structured search strategy that combined relevant keywords with controlled vocabulary terms (e.g., MeSH in PubMed, Emtree in Embase) to ensure a thorough retrieval of pertinent publications. The search strategy was customized to meet the specific indexing requirements and search functionalities of each database. To maximize the inclusiveness of the review, additional manual screening of the reference lists of selected studies and relevant systematic reviews was performed to identify potentially eligible articles not captured in the initial database search. The search results were imported into Rayyan (https://www.rayyan.ai), a web-based platform designed to facilitate systematic reviews. After automatic and manual removal of duplicate records, the retrieved studies underwent an initial

screening process based on predefined inclusion and exclusion criteria.

Eligibility criteria

Studies were included based on the following criteria:

i. Types of Studies: English studies such as case series, cohort studies, and randomized controlled trials (RCTs) reporting outcomes of aesthetic limb lengthening techniques were included. Review articles, case reports, conference abstracts, and animal studies were excluded. Additionally, articles published before the year 2000 were excluded.
ii. Participants: Studies involving adult populations undergoing esthetic limb lengthening procedures were included. Studies involving children were excluded.
iii. Interventions: Studies employing various aesthetic limb lengthening techniques, such as distraction osteogenesis and bone segment transport were included.
iv. Outcome Measures: Studies reporting relevant outcomes, including limb lengthening achieved, bone healing rates, complications, patient satisfaction, and psychosocial outcomes were included.
v. A minimum follow up period of 12 months was required.

Study selection

Two independent authors (R.G. and J.C.) screened the titles and abstracts of identified articles using Rayyan (https://www.rayyan.ai). Articles were assessed for elig ibility based on the predefined inclusion and exclusion criteria. Full-text articles of potentially eligible studies were retrieved and reviewed in detail. Any discrepancies between reviewers were resolved through discussion, and if consensus could not be reached, a third reviewer (Y.S.) was consulted to reach a final decision.

Data extraction

Data from eligible studies was extracted using a standardized data extraction form. The following information was collected: study characteristics (author, year, country), study design, participant demographics, sample size, aesthetic limb lengthening techniques employed, outcome measures assessed, follow-up duration, and reported results. Data extraction was performed independently by two authors (R.G. and J.C.), and any discrepancies was resolved through consensus.

Risk of bias and study quality assessment

The methodological quality and risk of bias of included studies was independently assessed by two reviewers using appropriate tools, such as the Methodological index for non-randomized studies (MINORS) for cohort studies and case series. Any discrepancies in the quality assessment were resolved through discussion or by consulting a third reviewer if needed.

Data synthesis and analysis

Due to anticipated heterogeneity in study designs and outcome measures, a meta-analysis was not planned. Instead, a narrative synthesis of the included studies was conducted. Data were organized and summarized in a tabular format, presenting the characteristics of the included studies, key findings, and outcomes of interest. Where appropriate, subgroup analyses and sensitivity analyses were performed to explore sources of heterogeneity and assess the robustness of the findings.

Complication categorization and analysis

Complications reported in the included studies were extracted and categorized based on the primary anatomical structure or clinical issue affected. Due to inconsistencies in how complications were reported—ranging from per-patient to per-segment or general mentions—we chose to report the number of mentions rather than per-patient incidence. Each complication was assigned to one of six categories: (1) Infections, (2) Bone-related, (3) Joint and tendon issues, (4) Material-related, (5) Neurological/vascular/other, and (6) Pain and discomfort. When complications could reasonably fall into multiple categories (e.g., equinus deformity), classification was based on the predominant anatomical or clinical context. This approach allowed for a standardized qualitative synthesis of complication types across heterogeneous studies.

Ethical considerations

As this systematic review involved the analysis of published data, ethical approval was not required.

Reporting

The findings of this systematic review were reported following the PRISMA guidelines. The results were presented clearly and concisely, supported by appropriate tables, figures, and descriptive summaries.

Results

Study selection

The initial literature search yielded a total of 1,288 articles from various databases. After removing duplicates, ineligible and other unfit records, 550 unique articles remained. Upon screening the titles and abstracts, 30 articles were deemed potentially relevant and were retrieved for full-text assessment. Ultimately, after applying the predetermined inclusion and exclusion criteria,

12 studies met the eligibility criteria and were included in the systematic review (Fig. 1; Table 1).

Study characteristics

The included studies consisted of 10 case series and 2 cohort studies. These studies were conducted in various countries, predominantly from Asia ($n = 5$) and Europe ($n = 4$). Sample sizes varied between 9 and 143 participants, with a total of 760 participants across all studies. Of these, only two studies were prospective, with the majority being retrospective. The studies were relatively recent, with the oldest published in 2005 and the most recent in 2020. As shown in Table 1.

Population and study design

The studies in this review involved a total of 760 patients. Participant ages ranged from 16 to 62 years, with a mean age of approximately 24.75 years. The studies included both retrospective and prospective designs, with follow-up periods ranging from a minimum of 14 months to a maximum of 16 years. The primary indications for limb lengthening were constitutional short stature ($n = 5$) or the desire for aesthetic improvement ($n = 7$), which aligns with the focus of this review on cosmetic limb lengthening procedures. As shown in Table 1.

Lengthening techniques and achieved length

Various limb lengthening techniques were used, including external systems such as the Ilizarov method ($n = 5$), and intramedullary systems like Motorized Internal Lengthening Nails (MILN), including Precice® ($n = 2$) and Fitbone® ($n = 1$), as well as mechanical devices like the Intramedullary Skeletal Kinetic Distractor (ISKD) ($n = 2$). Combinations of techniques, such as the Lengthening And Then Nailing (LATN) method ($n = 3$) and Lengthening Over a Nail ($n = 2$), were also employed. These techniques allowed for a mean lengthening ranging from 62 mm to 87 mm, with an average of 67 mm across all studies after weighting. Only four studies focused on femoral lengthening ($n = 43$ patients), while the remainder focused on tibial lengthening ($n = 717$ patients). Two studies included both femoral and tibial lengthening in the same individuals ($n = 7$ patients). The choice of technique often depended on the surgeon's preference, patient characteristics, and the anatomical area being treated (femur or tibia). Techniques and overall outcomes are summarized in Table 2.

Satisfaction, psychological and functional outcomes

Most studies reported excellent or good levels of patient satisfaction, with satisfaction rates ranging from 88.8 to 98%. Various validated scales were used to evaluate outcomes, including the Rosenberg Self-Esteem Scale (RSE), the Situational Inventory of Body-Image Dysphoria (SIBID), and the Multidimensional Body-Self Relations Questionnaire (MBSRQ), as reported by Assayag et al. Notably, this was the only study to compare these scores before and after the procedure. In other studies, satisfaction was categorized qualitatively (e.g., satisfied vs. unsatisfied) or using graded scales (e.g., extremely satisfied, moderately satisfied, or unsatisfied). Some studies also used quantitative scales ranging from 0 to 10 or 0 to 100%. Only two studies did not address psychological outcomes.

Functionally, the results were predominantly positive. Most patients did not experience significant limitations in the range of motion in adjacent joints (knee and ankle) and were able to resume normal daily activities. Different scales, such as the Sports Activity Rating Scale (SARS) and the International Knee Documentation Committee Subjective Knee Form (IKDC), were used to assess functional outcomes. Some studies, such as those by Park Hui Wan et al., also assessed mobility during the lengthening process, including the ability to perform outdoor activities independently. Satisfaction rates, psychological and functional outcomes are shown in Table 2.

Complications

Complications were a significant concern in aesthetic limb lengthening procedures. To allow for consistent synthesis across heterogeneous studies, complications were categorized by the primary anatomical structure or clinical domain affected and counted by number of mentions. Based on this approach, joint and tendon issues were the most frequently reported category, with 425 mentions. These included equinus deformity (restricted ankle dorsiflexion), knee and ankle contractures, Achilles tendon tightness, quadriceps and muscle contractures, and joint misalignments such as valgus or varus deviations. Infectious complications were reported 197 times, with pin-track infections being among the most common, reflecting the well-documented challenges of managing external fixation systems postoperatively. Although the majority were superficial, serious infections such as osteomyelitis were also noted ($n = 3$). Bone-related complications accounted for 100 mentions, including delayed or premature consolidation, regenerate deformities, bone atrophy, and nonunion. These issues often required additional interventions such as bone grafting, prolonging treatment duration and affecting overall outcomes. Material-related complications ($n = 82$) such as wire breakage, nail or screw failures, and issues with external fixation devices highlighted mechanical vulnerabilities associated with some techniques. Neurological and vascular complications were mentioned 43 times, including neurapraxia, temporary hypoesthesia, and cases of compartment syndrome ($n = 2$), all of which underscore the importance of careful monitoring during and after lengthening

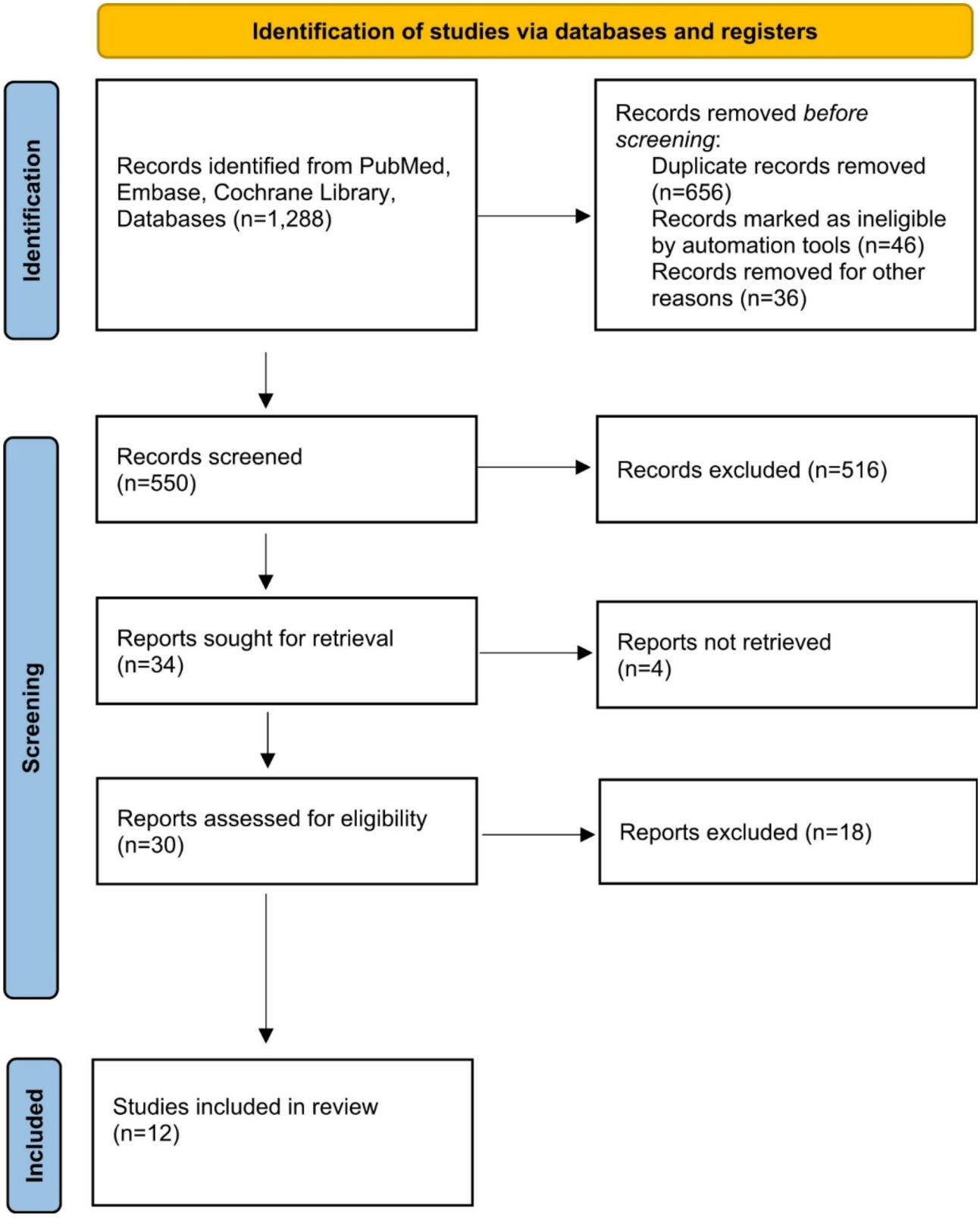

Fig. 1 PRISMA flow chart of the literature search

Table 1 Table of patients and study characteristics

Author (Year)	Study Design	Follow-up (year)	Patients (*n*)	Mean Age (year)	Sex	Diagnosis
Catagni et al. (2005)[9]	Prospective case series	Mean 6.25 (1–16)	54	25.8	32 M 22 F	Cosmetic leg lengthening
Park Hui Wan et al. (2008)[10]	Retrospective cohort study	Ilizarov method: Mean 4 (range 2.4–5.2) LON: Mean 3.3 (range 2.4–4.9)	44 Ilizarov method: 16 LON: 28	22.7	24 M 20 F	Constitutional short stature
Emara et al. (2011)[11]	Retrospective case series	Mean 3.23 (range 2–7.75)	32	25.8	26 M 6 F	Cosmetic leg lengthening
Elbatrawy et al. (2014)[12]	Prospective cohort study	Mean 7.6 (range 5–12)	52	26	36 M 16 F	Cosmetic leg lengthening
Novikov et al. (2014)[13]	Retrospective case series	Mean 6 (range 1–14)	131	25	65 M 66 F	Cosmetic leg lengthening
Motallebi Zadeh et al. (2014)[14]	Retrospective case series	Mean 1.16 (range 41days – 6.25 years)	143	26.6	85 F 58 F	Cosmetic leg lengthening
Kocaoglu et al. (2015)[15]	Retrospective case series	Mean 6.08 (range 1–13.6)	32	30	24 M 8 F	Cosmetic leg lengthening
Guerreschi et al. (2016)[16]	Retrospective case series	Mean 6.14 (range 1–10)	63	24.8	36 M 27 F	Constitutional short stature
Park Hoon et al. (2016)[17]	Retrospective case series	Mean 3.5 (range 2.17–5.9)	60	25	36 M 24 F	Constitutional short stature
Park Kun-Bo et al. (2018)[18]	Retrospective case series	> 2	125	24,4	N/A	Cosmetic leg lengthening
Havitcioglu et al. (2020)[19]	Retrospective case series	Mean 1.83	9	28.3	6 M 3 F	Constitutional short stature
Assayag et al. (2020)[20]	Retrospective case series	Mean 3.0 (range 1,24–7.96)	15	32.5	13 M 2 F	Constitutional short stature

procedures. Finally, pain and discomfort-related issues were noted 90 times, including general pain, insomnia, behavioral disturbances, and local soft tissue irritation.

A complete breakdown of all complications and their categorization is provided in Table 2.

Risk of bias and study quality assessment

The risk of bias in the included studies was assessed using the MINORS criteria. Most studies received scores between 7 and 13 on a scale of 16, with an average score of around 10, indicating several methodological limitations. These included a lack of prospective data collection, inadequate sample size calculations, and potentially insufficient follow-up. Only a few studies achieved higher scores, suggesting that much of the current literature may be biased, which limits the generalizability of the results (Supplement 1).

Discussion

ALL is a complex surgical procedure that is gaining popularity as an option for those who wish to increase their height for cosmetic reasons. This systematic review provides an in-depth analysis of the outcomes associated with this procedure, offering valuable insights for surgeons, patients, and researchers in the field.

The findings indicate that ALL is generally effective in significantly increasing leg length, with an average gain of about 67 mm across the various studies reviewed. This increase is considered satisfactory by most patients, who reported high satisfaction levels with the final result. Notably, the studies highlighted a significant improvement in patients' self-esteem, especially for those who previously suffered from constitutional short stature and its associated psychological implications. Several studies also reported a reduction in psychological distress, including symptoms of anxiety, depression, and shyness. Patients reported an improvement in their psychological well-being, with decreased distress related to their body image. These outcomes underscore the importance of considering not only physical results but also psychological ones when evaluating the success of the intervention. However, surgeons must manage patients' expectations, as limb lengthening may improve height but may not resolve all issues related to self-perception and self-esteem.

The most commonly used technique, the Ilizarov method and its variants, has proven reliable in achieving the desired length and in addressing potential intraoperative or postoperative complications. This technique was the most widely used, enabling an average lengthening of approximately 67 mm. Interestingly, the study by Havitcioglu et al. demonstrating the maximum mean lenghtening (87 mm) is also the one exposing a majority of femur lengthening (eight patients out of nine). The method, based on applying a circular external fixator, was chosen for its flexibility and ability to manage complications during the procedure. On the other hand, some studies employed intramedullary motorized nails such as the Precice system or the LATN method, which combines the use of intramedullary nails with distraction techniques, allowing for an average lengthening of about 6.4 cm. These methods offer advantages in terms

Table 2 Description of the procedures chosen and the outcomes. **LON**: lengthening over nail; **LATN**: lengthening and then nailing; **BIQLI**: body image quality of life inventory; **RSE**: Rosenberg self esteem; **SIBID**: situational inventory of body-image dysphoria; **MBSRQ**: the multidimensional Body-Self relations questionnaire; **ISKD**: intramedullary skeletal kinetic distractor; **1**: based on the axial deviation, restricted joint movement, pronation of the foot, leg-length discrepancy and scars; **2**: Catagni et al. classification [poor (0–4 points) = 0; patients; fair (5–9 points) = 0 patients; good (10 14 points) = 1 patient; and excellent (15–18 points) = 49 patients]; **3**: improvement in self-esteem, distress or shyness and quality of life; **4**: satisfied with the outcome of treatment, felt improvement of self-esteem, would undergo the procedure again, and would recommend it to another person having short stature; **5**: measured with the standard visual analog scale (**VAS**) at least 1 year after removal of external fixator. No satisfaction: 0 highest level of satisfaction: 10; **SARS**: sports activity rating scale; **IKDC**: international knee Documentation committee subjective knee form

Author (Year)	Segment	Technique	Mean lengthening (mm)	Psychological outcomes	Functional outcomes	Complications (case)
Catagni et al. (2005)[9]	Tibia	Ilizarov method	70	Satisfaction[2]: Excellent: 49 Good: 5 Aesthetic satisfaction: 70	NA	Atrophy of the new bone: 2 Early consolidation: 1 Collapse of regenerate with proximal varus: 1 Proximal anterior bowing and distal valgus: 2 Proximal anterior tibial bowing: 3 Distal varus: 2 Distal valgus: 5 Limitation of dorsiflexion of the ankle: 2 length discrepancy: 1 Superficial infection at the pin site: 26
Park Hui Wan et al. (2008)[10]	Tibia	Ilizarov method: 16 LON: 28	62 Ilizarov method: 59 LON: 64	*Overall satisfaction*: - Extremely satisfied: Ilizarov method: 2; LON: 6 - Moderately satisfied: Ilizarov method: 10; LON: 16 - No opinion: Ilizarov method: 2; LON: 4 - Moderately unsatisfied: Ilizarov method: 0; LON: 1 - Extremely unsatisfied: Ilizarov method: 2; B LON: 1	*Mobility during lengthening procedure*: - Outdoor activities without help possible: Ilizarov method: 7; LON: 24; - Only indoor activities possible: Ilizarov method: 9; LON: 4 *Physical activity at final follow-up*: - No limitations in any activity: Ilizarov method: 12; LON: 21 - Limitations in vigorous activities: Ilizarov method: 4; LON: 7 Time interval until return to previous activity: - <6 months: Ilizarov method: 10; LON: 25 - >6 months: Ilizarov method: 6; LON: 3	**Complication per segment**: Pin-track infection: 22 Wire breakage: 60 Screw breakage: 7 Axial deviation: 5 Delayed consolidation: 5 Premature consolidation: 9 Fibula migration: 4 Ankle valgus: 5 Knee and ankle contracture: 27 Neurapraxia: 7

Table 2 (continued)

Author (Year)	Segment	Technique	Mean lengthening (mm)	Psychological outcomes	Functional outcomes	Complications (case)
Emara et al. (2011)[11]	Tibia	LATN	76	Satisfaction (yes or no): 91% yes (week 6); 81% yes (after external fixator removal); 94% yes (year 1)	NA	Decreased range of ankle dorsiflexion: 32 Disconfort: 32 Knee flexion deformity: 9 Transient nerve neuropraxia: 3 Reversible angular deformities: 4 Rotational deformities: 1 Anterior knee pain: 8 Mild behavioural disturbances: 12 Revision Surgeries: 4
Elbatrawy et al. (2014)[12]	Tibia	Ilizarov method	69	Satisfaction[2]: Good: 1 Excellent: 49	NA	Loss of ankle dorsiflexion: 50 Pain: 35 Insomnia: 6 Behavioral changes: 3 Muscle contractures: 14 Superficial pin tract infection: 2 Tightness of Achilles tendon: 12 Mild misalignment: 16 Hypotrophic regenerate bone: 4 Cystic regenerate: 1 Large cyst: 1 Wire slippage: 1 Broken proximal ring: 1 Bilateral varus deformity: 1
Novikov et al. (2014)[13]	Tibia: 124 Tibia + Femur: 6 Femur: 1	Ilizarov Method	69	Satisfaction[4]: 130 out of 131 patients	NA	Pin tract infections: 5 Common peroneal neuropathy: 6 Equinus of the ankle: 12 Fixed flexion deformity of the knee: 14 Osteomyelitis: 3 Delayed consolisation: 6 Deformity of the regenerate: 9 Knee subluxation: 1 Delayed fracture: 1
Motallebi Zadeh et al. (2014)[13]	Tibia	LON (Ilizarov + Nail)	66.5	Satisfaction[5]: Median: 8.7 (1–10 scale)	NA	Pin tract infection: 65 Fracture pin: 39 Equinus deformity: 22 Achilles tendon lenghtening: 39 Nonunion: 3 prenature consolidation: 7 Nail breakage: 16 ibial fracture: 5 Compartment syndrone: 1

Table 2 (continued)

Author (Year)	Segment	Technique	Mean lengthening (mm)	Psychological outcomes	Functional outcomes	Complications (case)
Kocaoglu et al. (2015)[15]	Femur: 15 Tibia:17	LON (hybrid + Nail) LON (Ilizarov + Nail)	75	Emotional well being average: 68.72 (scale: 1-100) Role limitations due to emotional problems average: 87.87 (scale: 1-100)	Role limitations due to physical health: 77.45 Physical functioning: 87.25	Pin track infection: 21 Scar tissue: 2 Distal locking screw irritation: 7 compartment syndrome: 1 Deformity of regenerate while on fixator: 2 External fixator system not working properly: 1
Guerreschi et al. (2016)[16]	Tibia	Ilizarov method	72	Final aesthetic satisfaction: All patients stated that they would recommend the treatment to others of similar stature. 53 would have the surgery again; 10 were undecided (63 total)	Satisfaction[1]: Excellent: 88.8% Good: 7.9% Fair: 3.1% Maintaining of sportive Activity: satisfactory in all cases	Segments: Pin trac infection: 25 Proximal tibia procurvatus: 4 Proximal tibia recurvatus: 2 Distal tibia varus/valgus: 7 Limited ankle dorsal flexion: 4 Athrophic new bone: 2 Equinus foot: 42 Collapse of new bone: 5 Leg length discrepancy: 1 Early fibular consolidation: 4 Foot pronation: 6
Park Hoon et al. (2016)[17]	Tibia	LON	67	NA	NA	Valgus deviation proximal and distal (significant increase)
Park Kun-Bo et al. (2018)[18]	Tibia	LATN: 63 LON: 50 (Ilizarov + interlocking nail) ISKD: 12	63	NA	SARS: 71.5 vs. 65.2 (1 year) and 74.7 (2 years) IKDC: 84.1 vs. 66.8 and 83.9 Patient self-reported ability scores: 94.6 and 89.9 for daily living and light sports, respectively, and 68.1 for moderate-to-strenuous sports.	**Segments**: Pin-site infection: 28 Equinus contracture: 94 Temporary hypoesthesia: 26 Knee contracture: 10 Delayed consolidation: 6 Pin breakage: 6 Equinus contracture: 4 Axial deviation: 2 Impending compartment syndrome: 1
Havitcioglu et al. (2020)[19]	Femur Tibia	Precice®: 6 ISKD: 1 Fitbone®: 1 Precice®: 1	87	Satisfaction[3]: 9 out of 9 patients	NA	Proximal locking screw runaway: 1 Insufficient bone regeneration: 2 Quadriceps contracture: 1
Assayag et al. (2020)[20]	Femur: 12 Tibia + Femur: 1 Tibia: 2	Precice®: 14 LATN: 1	64	BIQLI: significant improvement (0.62 to 1.67) SIBID: significant improvement (1.3 to 1.02) MBSRQ: no significant change	NA	Femoral varus and procurvatum: 1 Premature consolidation: 2 Ankle equinus contractures: 2 Delayed consolidation: 6

of patient comfort and reduced treatment time. To clarify the advantages associated with combined lengthening techniques (such as LATN), previous literature suggests these methods can reduce external fixation duration, improve the bone consolidation index, and potentially enhance patient comfort by shortening external fixation exposure, which is generally considered uncomfortable for patients. For instance, Xu et al. (2017) demonstrated in their systematic review that LATN significantly reduced external fixation duration compared to conventional external fixation alone, consequently improving overall patient experience and potentially comfort [20]. However, within our systematic analysis, these specific parameters related to patient comfort and precise quantification of treatment duration reductions were not systematically reported. Therefore, future studies should explicitly measure and report patient comfort, treatment duration, and recovery parameters, enabling more robust and evidence-based conclusions regarding the comparative effectiveness and patient acceptability of these methods. A 2017 review [21] concluded that LATN, more than reducing the external fixation time could also improve the bone consolidation index. Also, by looking at the latest studies, it seems that the Ilizarov method tends to be reduced and the last research utilizing it for aesthetic purposes is dated from 2016.

The complications observed, such as bone deformities, early consolidation, and technical issues with fixation devices, highlight the need for careful planning and rigorous follow-up. Although these complications are manageable, patients must be informed of the potential risks before undergoing the procedure. Managing complications requires a multidisciplinary team experienced in limb lengthening techniques and the availability of resources for surgical correction if necessary. The complications were reported in terms of incidences across a number of patients or of limbs [10, 16, 18]. Therefore, the use of mentions was preferable in our results since the counting was disturbed leading to an estimation rather than exhaustive statistics. Also, one study [17] focused on tibial valgus deviation did not provide any precision on other complications underestimating the report of complications.

These issues, along with mild misalignments and insomnia, contribute to the overall patient experience and recovery timeline, underscoring the complexity of managing both the physical and psychological aspects of the procedure. The high number of reported complications—particularly joint and tendon issues—reflects the complex nature of aesthetic limb lengthening procedures and the physiological demands placed on soft tissues during gradual lengthening. Equinus deformity, contractures, and loss of dorsiflexion were among the most prevalent complications, suggesting a critical need for standardized and intensive rehabilitation protocols. Our decision to analyze complications by the number of mentions, rather than by per-patient frequency, was driven by the heterogeneity and inconsistencies in how complications were reported across studies. While this method does not permit direct calculation of incidence rates, it offers a standardized qualitative overview of the most common complication types. However, it should be noted that these figures represent mentions across studies, not necessarily distinct patients or events, and thus should be interpreted as indicators of relative frequency rather than precise prevalence. This analysis underscores the need for greater standardization in complication reporting. Future studies should clearly distinguish between patient-level and event-level data, provide denominator data (e.g., number of segments or procedures), and categorize complications using consistent definitions. Such efforts would greatly enhance the comparability and interpretability of findings in future systematic reviews and meta-analyses.

Overall, while limb lengthening can offer considerable benefits in achieving desired limb length or correcting deformities, the procedure carries a high risk of complications, particularly related to infections, bone healing, and material/device-related failures. Careful patient selection, thorough preoperative counseling, and diligent postoperative care are essential to minimizing these risks and improving outcomes.

From a functional standpoint, the available studies indicate optimal recovery among patients, with limited instances of loss of range of motion and an overall positive return to normal daily activities within a reasonable timeframe following the intervention. This outcome is encouraging, suggesting that with appropriate and consistent rehabilitation, patients can effectively maintain or even enhance the functionality of their lengthened limbs. Nevertheless, it is important to highlight that the assessment of functional outcomes was reported in only four out of the twelve studies included in this review, which considerably limits the robustness and generalizability of these conclusions. Given the relatively small number of studies addressing functional outcomes, these findings must be interpreted with caution. Future research should emphasize standardized functional outcome reporting across studies to allow for more comprehensive assessments. Additionally, acknowledging the demanding and prolonged nature of rehabilitation is crucial, as patient cooperation and adherence to rehabilitation protocols are essential in maximizing functional outcomes and minimizing potential long-term complications.

Emara et al. published two articles on the same study using LATN. The first article was published in 2011 [22] and focused on the physical outcomes of the procedure, and complications such as decreased range of ankle dorsiflexion and discomfort, among others. Therefore, a

second article was published in 2017 [23] on the same procedures. However, for clarity and consistency, the 2017 article was excluded from this review, as only 28 of the original 32 patients participated in the follow-up. This article aimed to assess long-term satisfaction and self-esteem outcomes, complementing the simple and short-term estimation of satisfaction conducted in 2011. The study used the Rosenberg Self-Esteem Scale (RSE), an overall satisfaction question, and additional specific yes/no questions administered before lengthening, one year after lengthening, and seven years after lengthening. The mean RSE score was significantly higher after one year but not after seven years. Regarding satisfaction, 20 of the 28 patients reported being satisfied at both the one- and seven-year follow-ups, while the remaining patients reported dissatisfaction as early as the one-year follow-up.

Aesthetic limb lengthening also raises important ethical issues. The elective nature of the procedure and the associated risks necessitate a thorough evaluation of the patient's motivations and expectations. Surgeons must ensure that patients have a clear and realistic understanding of the results that can be achieved, as well as the potential complications. Careful candidate selection and transparent communication are essential to avoid postoperative dissatisfaction and unnecessary complications. For these reasons, the decision to undergo this procedure should be made with caution, carefully weighing the potential risks and benefits. In our view, patients must receive detailed preoperative counseling and continuous support throughout the recovery process.

This systematic review provides an updated and detailed analysis of outcomes related specifically to elective, purely aesthetic limb lengthening, with particular emphasis on patient satisfaction and psychological outcomes. While previous systematic reviews have addressed various aspects of cosmetic limb lengthening, including complications and technical considerations, this review uniquely focuses on thoroughly evaluating patient-reported satisfaction, quality of life improvements, and emotional well-being [16, 24]. By synthesizing literature published up to July 2024 and emphasizing psychosocial dimensions, our work extends the existing evidence base and contributes additional insights into patient-centered outcomes, thus supporting informed decision-making and patient counseling in aesthetic limb lengthening procedures.

This study has some limitations that must be considered when interpreting the results. First, most of the included studies are retrospective case series, which are intrinsically subject to selection biases, confounding variables, and incomplete data, limiting the reliability of certain causal links between the surgical intervention and the outcomes observed. Moreover, the heterogeneity in methodologies, surgical techniques, follow-up protocols, and outcome measures prevented a meta-analysis of the findings. Due to the substantial heterogeneity across the included studies—in terms of surgical techniques, outcome definitions, follow-up durations, and reporting standards—we opted for a narrative synthesis rather than a quantitative meta-analysis. The variability in study design and reporting made statistical aggregation techniques, such as I^2 or subgroup comparisons, inappropriate and potentially misleading. While this limits direct comparability, it reflects the current state of the literature. Our findings highlight the urgent need for standardized reporting of outcomes and complications in future research to allow for more rigorous comparative analyses and potentially meaningful meta-analytic approaches.

Indeed, a further limitation is the inability to draw definitive conclusions on the best surgical technique for aesthetic limb lengthening due to the lack of sufficient comparative studies. A significant limitation of this systematic review is the relatively small sample size across studies, which may not allow for generalizable conclusions. The absence of RCTs, which provide the highest level of evidence, further restricts the robustness of the findings and the strength of the conclusions drawn from the available data. The lack of RCTs reflects the ethical and practical challenges inherent in conducting randomized studies in elective aesthetic procedures yet underscores the need for more rigorous and controlled research designs. As with all cosmetic procedures, key outcomes to investigate include the safety of the procedure and patient satisfaction. Therefore, future well-designed prospective comparative studies using standardized outcome measures are essential to assess patient satisfaction, improvements in self-esteem, and quality of life. Additionally, future research should examine and compare potential functional impairments and muscle weakness that may arise after the procedure. Finally, a cost analysis of the available techniques could provide valuable information for the decision-making process. A further methodological limitation of this review is related to how complication incidence was assessed. Due to significant heterogeneity and inconsistencies in complication reporting across the included studies, we reported complications based on the number of mentions rather than a per-patient or per-segment frequency. Although the total number of patients or limb segments was known, complications were often aggregated without precise attribution to individual cases. This approach limits the precision of quantitative conclusions about complication rates. Future research should adopt standardized complication reporting methods to facilitate more accurate, patient-specific analyses and reliable comparisons across studies. Another limitation of this systematic review is the inclusion of only English-language articles, potentially

introducing language bias by excluding relevant studies published in other languages. However, English is the predominant language of international scientific communication, and including literature in multiple languages was beyond the scope and feasibility of this review.

While this review highlights important findings, it also reveals significant limitations in the existing literature that hinder more advanced forms of data synthesis. The wide variability in study designs, outcome definitions, follow-up durations, and reporting formats precluded the use of pooled estimates or meta-analytic techniques. To address this in future research, the development and adoption of standardized reporting protocols and core outcome sets specific to aesthetic limb lengthening are essential. Establishing consistent metrics for complications, functional recovery, and psychological outcomes would greatly enhance the comparability of studies and facilitate meaningful pooled analyses or meta-analyses. Such methodological harmonization would ultimately improve the quality of evidence available to guide both clinical decision-making and patient counseling.

Despite these limitations, aesthetic limb lengthening holds great promise, but only if supported by an adequate body of literature about its safety, low risk, and effectiveness.

This review provides a useful overview of the outcomes of aesthetic limb lengthening, highlighting the need for more rigorous and standardized future studies. Efforts should focus on prospective studies with long-term follow-up, including appropriate control groups and the use of uniform evaluation criteria, to improve the understanding of the risks and benefits associated with this procedure.

Conclusion

In conclusion, aesthetic limb lengthening significantly increases height and improves patients' psychological well-being, establishing itself as an effective procedure for those seeking cosmetic enhancements. However, thorough risk assessment and careful management of expectations, along with rigorous postoperative follow-up, are essential to ensure optimal outcomes and minimize complications.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05808-x.

Supplementary Material 1

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Conceptualization, R.G., D.K. and J.C.; methodology, R.G., J.C. and Y.M.S.; investigation, R.G., J.C., and Y.M.S.; data curation, J.C. and Y.M.S.; writing—original draft preparation, R.G., J.C., Y.M.S. and Y.B.; writing—review and editing, R.G., Y.B., and Y.M.S.; supervision, G.M.P. and L.M. All authors reviewed the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
As this study is a systematic review of previously published data, ethical approval and consent to participate were not required. All data analyzed were obtained from publicly available sources, and no new data involving human participants were collected for this research.

Consent for publication
Not applicable. This manuscript does not contain any individual person's data in any form, including images, videos, or case details, requiring consent for publication.

Competing interests
The authors declare no competing interests.

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