**SYSTEMATIC REVIEW**

Cosmetic stature lengthening

**SYSTEMATIC REVIEW OF OUTCOMES AND COMPLICATIONS**

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**Aims**
To systematically review the outcomes and complications of cosmetic stature lengthening.

**Methods**
PubMed and Embase were searched on 10 November 2019 by three reviewers independently, and all relevant studies in English published up to that date were considered based on predetermined inclusion/exclusion criteria. The search was done using “cosmetic lengthening” and “stature lengthening” as key terms. The Preferred Reporting Item for Systematic Reviews and Meta-Analyses statement was used to screen the articles.

**Results**
A total of 11 studies including 795 patients were included. The techniques used in the majority of the patients were classic 3- or 4-ring Ilizarov fixator (267 patients; 33.6%) and lengthening over nail (LON) (253 patients; 31.8%), while implantable lengthening nail (ILN) was used in the smallest number of patients (63 patients; 7.9%). Mean end lengthening achieved was 6.7 cm (SD 0.6; 1.5 to 13.0), and the mean follow-up duration was 4.9 years (SD 2.1; 41 days to 7 years). Overall, the mean number of problems, obstacles, and complications per patient was 0.78 (SD 0.5), 0.94 (SD 1.0), and 0.15 (SD 0.2), respectively. The most common problem and obstacle was ankle equinus deformity, while the most common complications were deformation of the regenerate after end of treatment and subtalar joint stiffness/deformity.

**Conclusion**
Cosmetic stature lengthening provides favourable height gain, patient satisfaction, and functional outcomes, with low rate of major complications. Clear indications, contraindications, and guidelines for cosmetic stature lengthening are needed.

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**Keywords:** Stature lengthening, Cosmetic, Limb lengthening

**Article focus**
- Systematic review of the literature regarding cosmetic stature lengthening.
- What are the outcomes and complications of cosmetic stature lengthening?

**Key messages**
- Limb lengthening techniques can result in substantial height gain with high rate of patient satisfaction and favourable functional outcomes.
- Shorter treatment period and lower rate of problems, obstacles, and complications were noted with the use of implantable lengthening nail (ILN) technique.

**Strengths and limitations**
- This systematic review analyzed the outcomes and complications of different surgical techniques in cosmetic stature lengthening.
- The included studies are of low level of evidence (case series or retrospective reviews).
- The use of different limb lengthening techniques and devices on different bone segments, as well as the heterogeneity in reporting functional outcomes among the studies, make it difficult to generalize the results to one specific technique.
Introduction

Physical appearance and beauty have substantial value in our modern societies. People with short stature may, therefore, end up with considerable psychosocial disturbances, starting from adolescent age or even childhood.1,2

Limb lengthening is a commonly performed procedure for individuals with leg length discrepancy (LLD) as a result of acquired or congenital causes. When performed on both lower limbs, this procedure is referred to as stature lengthening. Stature lengthening is mainly done to improve the height of patients with dysplasia (e.g. achondroplasia).3,4 In the past few years, limb lengthening techniques have been utilized for cosmetic reasons.5-8 This is referred to as cosmetic limb lengthening or short stature lengthening. The aim of this is to improve patients’ self-esteem and ease their negative feelings regarding their short stature, in addition to improving their overall psychological and functional status.1,2,9,10

Regardless of the ethical concerns and controversies of cosmetic limb lengthening procedures, various techniques were applied for this purpose, including Ilizarov external fixation frames, lengthening over nail (LON), lengthening and then nail (LATN), and implantable lengthening nails (ILN).5-8,11-13 Multiple complications have been reported with the use of limb lengthening techniques for cosmetic indications, including pin site infections, nerve injuries, compartment syndrome, joints stiffness, and LLD.5-8,11-13 This has opened discussions among limb reconstruction experts about the indications and recommendations for cosmetic limb lengthening, but no formal consensus and guidelines have been made yet.14

In this study, we aim to systematically review the literature of cosmetic limb lengthening. We intend to assess the outcome and complications of applying the different limb lengthening techniques for cosmetic indications. We hypothesize that overall outcomes are favourable with regards to amount of height gained, and rate of substantial complications is low.

Methods

Search strategy. Three authors (YM, MA, DC) searched PubMed and Embase databases independently for relevant articles on 10 November 2019. The search was limited to English language only. The search terms “cosmetic lengthening” and “stature lengthening” were used. Although not indexed in PubMed and Embase, Journal of Limb Lengthening & Reconstruction was also searched for relevant articles since the journal is highly specialized in the topic of limb lengthening. The articles were screened based on the Preferred Reporting Item for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Inclusion and exclusion criteria. The following inclusion criteria were used in our systematic review: clinical studies; all level of evidence; limb lengthening done for constitutional or idiopathic short stature for cosmetic reasons; limb lengthening of the lower limbs; all lengthening techniques; and no restriction to date of publication. Studies were excluded if they met any of the following criteria: non-English articles; lengthening done for non-cosmetic indications; lengthening of the upper limbs; articles published in abstract form only; and review papers. In addition, articles about stature lengthening in general which included only few patients with cosmetic lengthening were excluded. This was because extraction of data specific to the cosmetic lengthening patients was not possible, and multiple attempts were made to contact the authors of these articles to get specific results of those patients, but the response and collaboration was extremely poor.

Data collection/extraction. The three authors (YM, MA, DC) screened the titles and abstracts of the included articles independently. To ensure completeness, articles were included in the full-text review stage if one of the three reviewers believed it should. More articles were excluded following full-text review. The three authors then independently retrieved data from the included studies in Microsoft Excel 2013 (Microsoft, Redmond, Washington, USA). The information was categorized into basic article information (e.g. title, authors, year of publication, journal, and country), patient background information and methodology details (e.g. sample size, sex, age, preoperative assessment, inclusion/exclusion criteria, and indication for surgery), surgical technique (e.g. segment lengthened and lengthening technique), and postoperative outcomes and complications (e.g. duration of follow-up, end lengthening achieved, external fixation period, external fixation index, consolidation index, rate of ILN distraction, functional/psychosocial...
| Study                              | Catagni et al 2005<sup>5</sup> | Elbatrawy and Ragab 2015<sup>12</sup> | Emara et al 2011<sup>11,16</sup> and 2017<sup>11,14</sup> | Guerreschi and Tsibidakis 2016<sup>17</sup> | Kocaoglu et al 2015<sup>6</sup> | Novikov et al 2014<sup>5</sup> | Novikov et al 2017<sup>18</sup> | Paley et al 2015<sup>7</sup> | Park et al 2008<sup>19</sup> | Park et al 2019<sup>13</sup> | Motallebi Zadeh et al 2014<sup>20</sup> |
|-----------------------------------|--------------------------------|--------------------------------------|----------------------------------------|------------------------------------|-------------------------------|-----------------------------|-----------------------------|-------------------------------|-----------------------------|----------------------------------|
| Number of patients               | 54                            | 50                                   | 32 (28 in 2017 study)                  | 63                                 | 32                            | 131                         | 70                          | 51                            | 44                          | 125                              |
| Sex, n                           | M: 32, F: 22                  | M: 35, F: 15                         | M: 26, F: 6                           | M: 36, F: 27                       | M: 24, F: 8                   | M: 65, F: 66                 | M: 44, F: 26                 | M: 45, F: 6                    | M: 24, F: 20                   | M: 85, F: 58                     |
| Mean age, yrs (range)            | 25.8 (17.0 to 47.0)           | 26.0 (17.0 to 46.0)                  | 27.0 (21.0 to 47.0)                   | 24.8 (17.0 to 48.0)                | 30.0 (16.0 to 62.0)           | 25.0 (14.0 to 68.0)          | 27.0 (16.0 to 52.0)           | 27.8 (15.0 to 51.0)            | 22.7 (18.0 to 34.0)             | 24.4 (16.0 to 55.0)              |
| Mean preoperative height, cm (range) | 153 (141 to 174)           | 164 (142.5 to 175)                  | 170 (160 to 176)                      | 152.6 (140 to 172)                 | 159 (130 to 174)             | 159 (130 to 174)           | 163.5 (143 to 181)           | 164.7 (150 to 180)            | 153.7 (140 to 163.1)           | 162.1 (144 to 175)              |
| Technique                        | Hybrid advanced ring fixator | Classic 3-ring Ilizarov             | LATN                                   | Hybrid advanced ring fixator       | Classic 3-ring Ilizarov       | LON                         | Classic 3-ring Ilizarov       | ILN/PRECICE<sup>★</sup>         | LON                          | LON                              |
| Bone segment                     | Tibia                         | Tibia                                | Tibia                                  | Tibia                             | Femur or tibia                | Femur or tibia               | Femur, tibia, or both        | Tibia                         | Femur, tibia, or both          | Tibia                            |
| Deformity corrected simultaneously | Varus (n = 2)                  | LLD (n = 1); varus (n = 6); varus and IR (n = 4) | None                                   | Eight patients had varus           | None                          | Varus (n = 9)                | None                        | Varus (n = 9)                  | None                          | None                            |
| Mean external fixation period, days (range) | 2.70 (210 to 540)         | 2.31 (166 to 369)                    | 9.6 (4.5 to 135)                      | 285 (210 to 540)                   | 85.9 (24 to 137)              | 215 (71 to 390)             | N/R                         | N/R                          | 372 (120 to 810); LON: 162.9 (90 to 300) |
| Mean external fixation index, day/cm (range)† | 34.2 (27.3 to 36.3)           | 11.4 (10.8 to 12.6)                  | N/R                                    | 11.2 (6.3 to 15.4)                 | 31 (12 to 78)                 | 39 (19 to 100)             | N/A                         | N/R                          | 66 (21 to 180); LON: 27 (12 to 45) |
| Mean maturation/consolidation index, day/cm (range) | 34.7 (29 to 49)             | 34.7 (29 to 49)                      | N/R                                    | 29.96 (15 to 38.6)                 | 19 (5.2 to 63)                | 23 (6 to 72)                | N/R                         | N/R                          | 63 (30 to 171); LON: 51 (27 to 81) |
| Mean end lengthening, cm (range)   | 7.0 (5.0 to 11.0)             | 6.9 (4.0 to 11.0)                    | 7.6 (3.5 to 12.0)                     | 7.2 (5.0 to 11.0)                  | 7.5 (2.0 to 13.0)             | 6.9 (2.0 to 13.0)           | 5.9 (1.5 to 10.0)            | 5.6 (1.7 to 8.0)              | 6.2 (2.5 to 8.4); LON: 5.9 (2.5 to 8.4); LON: 6.4 (3.5 to 8.0) |

Continued
### Table I. Continued

| Study                      | Catagni et al 2005<sup>5</sup> | Elbatrawy and Ragab 2015<sup>12</sup> | Emara et al 2011 and 2017<sup>15, 16</sup> | Guerreschi and Tsibidakis 2016<sup>17</sup> | Kocaoglu et al 2015<sup>8</sup> | Novikov et al 2014<sup>6</sup> | Novikov et al 2017<sup>18</sup> | Paley et al 2015<sup>7</sup> | Park et al 2008<sup>19</sup> | Park et al 2019<sup>13</sup> | Park et al 2019<sup>13</sup> | Motallebi Zadeh et al 2014<sup>20</sup> |
|---------------------------|--------------------------------|------------------------------------|---------------------------------------------|-------------------------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------------------|
| Mean follow-up duration   | 6.25 yrs (1 to 16)             | 7.6 yrs (5 to 12)                  | 38.7 mths (24 to 93) in 2011 study.         | Mean of 7 yrs in 2017 study               | 6.14 yrs (1 to 10)             | 73 mths (12 to 163)          | 5.75 yrs (1 to 14)             | 4.3 yrs (2 to 8)               | Until full consolidation      | Classic; 48 mths (35 to 62);  | LON: 40 mths (29 to 59)         |                                |
| (range)                   |                               |                                    |                                              |                                            |                               |                             |                               |                             | (exact duration not reported) |                          |                             |                                 |
| Satisfactory aesthetic    | Satisfactory aesthetic effect  | Clinical outcome score developed    | 94% satisfaction rate reported in 2011 study. | All satisfied                             | Functional score they developed:   | N/R                          | Patients satisfied (no specific number) | SARS and IKDC Subjective Form. | Overall return to activity is excellent. | SARS and IKDC Subjective Form. | Satisfactory mean score 8.7 (on a visual analogue scale consisting of 10 cm line) |                                 |
| effect in all. Clinical    | effect in all. Clinical        | by Catagni et al (2005): 49         | 94% satisfaction rate reported in 2011 study. | All satisfied                             | excellent (72), good (52),       | N/R                          | Patients satisfied (no specific number) | SARS and IKDC Subjective Form. | Overall return to activity is excellent. | SARS and IKDC Subjective Form. | Satisfactory mean score 8.7 (on a visual analogue scale consisting of 10 cm line) |                                 |
| outcome score they         | outcome score they developed:  | 94% satisfaction rate reported in   |                                              | All satisfied                             | satisfactory (6), poor (1).       | N/R                          | Patients satisfied (no specific number) | SARS and IKDC Subjective Form. | Overall return to activity is excellent. | SARS and IKDC Subjective Form. | Satisfactory mean score 8.7 (on a visual analogue scale consisting of 10 cm line) |                                 |
| developed:                | 49 excellent, 5 good          | 2011 study.                        |                                              | All satisfied                             | satisfaction: all satisfied except 1 | N/R                          | Patients satisfied (no specific number) | SARS and IKDC Subjective Form. | Overall return to activity is excellent. | SARS and IKDC Subjective Form. | Satisfactory mean score 8.7 (on a visual analogue scale consisting of 10 cm line) |                                 |
|                           |                               |                                    |                                              |                                            |                               |                             | Patients satisfied (no specific number) | SARS and IKDC Subjective Form. | Overall return to activity is excellent. | SARS and IKDC Subjective Form. | Satisfactory mean score 8.7 (on a visual analogue scale consisting of 10 cm line) |                                 |

*PRECICE Intramedullary Limb Lengthening System (NuVasive Specialized Orthopedics, San Diego, California, USA).
†External fixation index is the time (days/months) spent in external fixator for every centimetre gained; maturation/consolidation index is time (days/months) to consolidation per centimetre of distraction gap.
IKDC, international knee documentation committee; ILN, implantable lengthening nail; IR, internal rotation; ISKD, intramedullary skeletal kinetic distractor; LATN, lengthening and then nail; LLD, leg length discrepancy; LON, lengthening over nail; N/A, not applicable/available; N/R, not reported; SARS, sports activity rating scale; SF-36, 36-Item Short-Form Health Survey questionnaire
| Study                                      | Sample size, n | Technique                                      | Total problems, n | Number of problems per patient | Ankle valgus, n | Axial deviation, n | Behavioural problems/insomnia, n | Common peroneal nerve neuropathy, n | Deep vein thrombosis, n | Delayed consolidation, n | Equinus deformity, n | Fat embolism (suspected), n | Fractures, n | Hardware system error, n | Interlocking screw breakage, n | Knee flexion deformity/contracture, n | Knee subluxation, n | Muscle contracture (not specified if knee or ankle), n | Nail breakage, n | Pain, n | Pin tract infection, n | Foot rotation (ER/IR), n |
|-------------------------------------------|----------------|-----------------------------------------------|-------------------|--------------------------------|----------------|-------------------|-----------------------------------|-------------------------------|----------------------|--------------------------|-------------------|--------------------------|---------------|--------------------------|---------------------------|--------------------------|----------------|--------------------------|-----------------|-------|----------------|--------------------------|
| Catagni et al 2005¹                      | 54             | Hybrid advanced ring fixator                  | 26 (maximum)      | < 0.48                         | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Elbatrawy and Ragab 2015¹²²              | 50             | Classic 3-ring Ilizarov                       | 160 (at least)    | 1.20 (at least)                | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Emara et al 2011 and 2017¹³¹⁶             | 32             | LATN                                          | 60 (at least)     | 0.50                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Guerreschi and Tsibidakis 2015¹⁷         | 63             | Hybrid advanced ring fixator                  | 42                | 0.67                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Kocaoglu et al 2014⁶                      | 32             | Classic 3-ring Ilizarov                       | 23                | 0.17 (at least)                | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Novikov et al 2014¹⁴                    | 131            | Classic 3-ring Ilizarov                       | 22 (at least)     | 0.23                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Novikov et al 2017¹⁵                    | 70             | Classic 3-ring Ilizarov                       | 16                | 0.16                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Paley et al 2015²                        | 51             | ILN/PRECICE†                                   | 8 Classic: 19;    | 1.19                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Park et al 2008¹⁹                       | 44             | LATN (63); LON (50); ILN/ISKD (12)            | 164               | 1.31                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Park et al 2019¹³                       | 125            |                                                    | 211 (at least)    | 1.47                           | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |
| Motallebi Zadeh et al 2014²⁸             | 143            |                                                    |                    |                                | N/A            | N/A               | N/A                               | N/A                          | N/A                  | N/A                      | N/A               | N/A                      | N/A            | N/A                      | N/A                       | N/A                      | N/A         | N/A                      | N/A             | N/A   | N/A                  | N/A                       |

*Kocaoglu et al⁸ reported the number of each problem per patient (not segment).
†PRECICE Intramedullary Limb Lengthening System (NuVasive Specialized Orthopedics, San Diego, California, USA).
ER, external rotation; ILN, implantable lengthening nail; IR, internal rotation; ISKD, intramedullary skeletal kinetic distractor; LATN, lengthening and then nail; LON, lengthening over nail; N/A, not applicable/available.
Table III. Obstacles seen in patients who underwent cosmetic stature lengthening.5-8,11-13,16-20

| Study                  | Sample size, n | Technique                                      | Total obstacles, n | Number of obstacles per patient | Ankle valgus, n | Atrophic/hypotrophic regenerate, n | Common peroneal nerve neuropathy, n | Compartment syndrome, n | Cystic regenerate, n | Deformity/axial deviation of regenerate, n | Delayed consolidation, n | Distal migration of the fibula, n | Early collapse and/or deformation after hardware removal, n | Equinus deformity, n | Hardware system error, n | Haematoma, n | Incomplete corticotomy, n | Knee flexion deformity/contracture, n | Knee subluxation, n | Leg length discrepancy, n | Locking screw backout, n | Nail breakage, n | Osteomyelitis, n | Periprosthetic fracture, n | Park et al 200819 | Park et al 201918 | Mottaleb Zadeh et al 201420 |
|------------------------|----------------|-----------------------------------------------|--------------------|---------------------------------|----------------|-----------------------------------|------------------------------------|-------------------------|---------------------|----------------------------------------|-------------------------|-------------------------------|------------------------------------------------|----------------|--------------------------|-------------------------|---------------------------|----------------------|--------------------------|--------------------------|------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Catagni et al 20051    | 54             | Hybrid advanced ring fixator                  | 23                 | 0.43                            | N/A            | N/A                               | N/A                                | N/A                     | 1                   | N/A                                    | N/A                     | N/A                            | 19                                    | 19                       | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Elbatrawy and Ragab 201512 | 50             | Classic 3-ring Ilizarov                       | 72                 | 1.44                            | N/A            | N/A                               | N/A                                | N/A                     | 2                   | N/A                                    | N/A                     | N/A                            | 32                                    | 32                       | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Emara et al 2011 and 20171,14 | 32             | LATN                                           | 47                 | 1.47                            | N/A            | N/A                               | N/A                                | N/A                     | 4                   | N/A                                    | N/A                     | N/A                            | 33                                    | 33                       | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Guerreschi and Tsibidakis 201617 | 63             | Hybrid advanced ring fixator                  | 54                 | 0.86                            | N/A            | N/A                               | N/A                                | N/A                     | 2                   | N/A                                    | N/A                     | N/A                            | 10                                    | 10                       | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Kocaoglu et al 20158 * | 131            | Classic 3-ring Ilizarov                       | 28                 | 0.06 (at least)                 | N/A            | N/A                               | N/A                                | N/A                     | 2                   | N/A                                    | N/A                     | N/A                            | 70                                    | 70                       | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Novikov et al 20146     | 70             | Classic 3-ring Ilizarov                       | 47                 | 0.67                            | N/A            | N/A                               | N/A                                | N/A                     | 1                   | N/A                                    | N/A                     | N/A                            | 51                                    | 51                       | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Novikov et al 201718    | 51             | ILN/PRECICE†                                  | 12                 | 0.23                            | N/A            | N/A                               | N/A                                | N/A                     | N/A                  | N/A                                    | N/A                     | N/A                            | 125                                   | 125                      | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Paley et al 20157       | 44             | Classic 3- or 4-ring Ilizarov (n = 16)        | 13                 | 1.18                            | N/A            | N/A                               | N/A                                | N/A                     | 0                   | N/A                                    | N/A                     | N/A                            | 123                                   | 123                      | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Park et al 200819       | 44             | LATN (n = 63); LON (n = 33)                   | 123                | 0.86                            | N/A            | N/A                               | N/A                                | N/A                     | N/A                  | N/A                                    | N/A                     | N/A                            | 4                                    | 4                        | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Park et al 201918       | 125            | LON (n = 12)                                  | 123                | 0.86                            | N/A            | N/A                               | N/A                                | N/A                     | N/A                  | N/A                                    | N/A                     | N/A                            | 123                                   | 123                      | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |
| Motallebi Zadeh et al 201420 | 143           | LON (n = 12)                                  | 123                | 0.86                            | N/A            | N/A                               | N/A                                | N/A                     | N/A                  | N/A                                    | N/A                     | N/A                            | 123                                   | 123                      | N/A                    | N/A                     | N/A                    | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     | N/A                     |

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outcomes, and complications). External fixation index is the time (days/months) spent in external fixator for every centimetre gained, while the consolidation/maturation index is time (days/months) to consolidation per centimetre of distraction gap. The rate of distraction is the total length gained divided by total number of days of distraction of an ILN. Complications were classified based on Paley’s criteria into problems, obstacles, and complications.15 The primary outcome of this review was the number of end lengthening achieved, while number of complications per patients was the secondary outcome. It is, however, not possible to set a specific cut-off number of acceptable end lengthening gained since this depends on the patients’ expectations. Meta-analysis was not done due to the heterogeneity of the included studies; however, a qualitative assessment of the data was done. Since all the included studies are of level IV evidence (all are case series studies), individual study quality assessments were not performed.

Statistical analysis. The IBM SPSS Statistics 23.0 software (IBM, Armonk, New York, USA) was used to analyze the data. This was started with descriptive analysis of all variables, including frequencies, percentiles, means, SDs, and other basic statistics. The analysis of variance (ANOVA) test was used to test the association between polychotomous qualitative variable and normally distributed quantitative variables, while the Kruskal-Wallis test was used for quantitative variables that were not normally distributed. A p-value of < 0.05 was considered as the cut-off level of statistical significance.

Results

After removing the duplicates and limiting the results to English language only, the initial search yielded a total of 239 studies (Figure 1). A total of 181, 26, and 20 articles were excluded after title, abstract, and full-text review, respectively. Eventually, a total of 12 studies conducted in North America, Europe, Asia, and the Middle East were included for final analysis (Table I). One of the studies was a long-term follow-up of the same group of patients published earlier by the same senior surgeon in a previous publication, thus the data of these two studies were analyzed and presented as single study.11,16

The total number of patients was 795 (Table I). The male to female ratio was 1.6:1, and the mean age of the patients was 26.1 years (SD 1.9; 14 to 68). The mean preoperative height of the patients was 159.95 cm (130.00 to 181.00). The techniques used in the majority of the patients were classic 3- or 4-ring Ilizarov fixator (267 patients; 33.6%) and LON (253 patients; 31.8%); while ILN was used in the smallest number of patients (63 patients; 7.9%). Tibia was lengthened in all studies; however, three out of the 11 studies reported femur as the lengthening segment in some cases, and two out of the 11 studies lengthened both femur and tibia in some patients. A minority of patients (30 patients; 3.8%) underwent deformity correction at the same setting of limb lengthening. In cases who had external fixators, the mean external fixation period and mean external fixation index were 201.0 days (SD 99.7; 24.0 to 810.0) and 29.2 day/cm (SD 18.3; 6.3 to 180 day/cm), respectively. The mean maturation/consolidation index was 36.8 day/cm (SD 17.0; 5.2 to 171.0). Moreover, the mean end lengthening achieved was 6.7 cm (SD 0.6; 1.5 to 13.0), and the mean follow-up duration was 4.9 years (SD 2.1; 41 days to seven years). Overall, most of the patients were satisfied with the results and had excellent functional outcomes.

Tables II–IV demonstrate the problems, obstacles, and complications of cosmetic stature lengthening that were reported in the included studies. The most commonly reported problems were ankle equinus deformity and pin-track infection (Table II). Ankle equinus deformity was also the most common obstacle, where it was seen in 211 segments (Table III). On the other hand, deformation of the regenerate after end of treatment and subtalar joint stiffness/deformity were reported in 13 segments each, representing the most common complications of cosmetic stature lengthening (Table IV). Overall, the mean number of problems, obstacles, and complications per patient was 0.78 (SD 0.5), 0.94 (SD 1.0), and 0.15 (SD 0.2), respectively.

Table III. Continued

| Study           | Catagni et al 2005 | Elbatrawy and Ragab 2015 | Emara et al 2011 and 2017 | Guerreschi and Tsibidakis 2016 | Kocaoglu et al 2015 | Novikov et al 2014 | Novikov et al 2017 | Paley et al 2015 | Park et al 2008 | Park et al 2019 | Motallebi Zadeh et al 2014 |
|-----------------|-------------------|--------------------------|--------------------------|-------------------------------|-------------------|-------------------|-------------------|-------------------|-----------------|-----------------|--------------------------|
| Pin/wire bending/breakage, n | N/A               | N/A                      | 1                        | N/A                           | N/A               | 5                 | N/A               | N/A               | Classic: 38; LON: 22 | 6                | 55                       |
| Pin/wire slippage, n     | N/A               | N/A                      | 2                        | N/A                           | N/A               | N/A               | N/A               | N/A               | N/A             | N/A             | N/A                      |
| Premature consolidation, n | 1                 | N/A                      | N/A                      | 4                             | N/A               | 7                 | N/A               | N/A               | N/A             | N/A             | N/A                      |
| Ring breakage, n         | N/A               | N/A                      | 2                        | N/A                           | N/A               | 2                 | 1                 | 1                 | N/A             | 7               | N/A                      |

*Kocaoglu et al. 2015 reported the number of each obstacle per patient (not segment).
†PRECICE Intramedullary Limb Lengthening System (NuVasive Specialized Orthopedics, San Diego, California, USA).
ILN, implantable lengthening nail; ISKD, intramedullary skeletal kinetic distractor; LATN, lengthening and then nail; LON, lengthening over nail; N/A, not applicable/available.
Table V summarizes the outcomes and complications based on the lengthening technique used. The highest mean end lengthening achieved was seen with LATN technique (7.6 cm (3.5 to 12.0)), while the lowest was with ILN (5.6 cm (1.7 to 8.0)). Mean external fixation index was the lowest among the LATN group (11.4 day/cm (10.8 to 12.0)).

Table IV. Complications seen in patients who underwent cosmetic stature lengthening.5-8,11-13,16-20

| Study | Catagni et al 2005 | Elbatrawy and Ragab 2015 | Emara et al 2011 and 2017 | Guereschi et al 2016 | Kocaoglu et al 2015 | Novikov et al 2014 | Novikov et al 2017 | Paley et al 2015 | Park et al 2008 | Park et al 2019 | Motallebi Zadeh et al 2014 |
|-------|-------------------|--------------------------|--------------------------|---------------------|---------------------|-------------------|-------------------|-------------------|-----------------|-----------------|--------------------------|
| Sample size, n | 54 | 50 | 32 | 63 | 32 | 131 | 70 | 51 | 44 | 125 | 143 |
| Technique | Hybrid advanced ring fixator | Classic 3-ring Ilizarov | LATN | Hybrid advanced ring fixator | Classic 3-ring Ilizarov | LATN | Classic 3-ring Ilizarov | ILN/PRECICE† | Classic 3- or 4-ring Ilizarov (n = 16); LON (n = 50); ISKD (n = 28) | Classic: 8; LON: 1 | Classic: 0.50; LON: 0.04 |
| Total complications, n | 22 | 2 | 2 | 6 | 10 | 11 | 13 | 1 | 4 | 0.00 | 0.03 |
| Number of complications per patient, n | 0.41 | 0.04 | 0.06 | 0.09 | 0.31 | 0.08 | 0.19 | 0.02 | | |
| Common peroneal nerve palsy, n | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Deformation of regenerate after end of treatment, n | N/A | N/A | 1 | N/A | N/A | 4 | 7 | N/A | N/A | N/A | N/A |
| Delayed consolidation, n | 2 | N/A | 1 | N/A | N/A | N/A | N/A | N/A | N/A | Classic: 5; LON: 0 | 1 |
| Fascia lata/iliotibial band contracture, n | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 1 | N/A | N/A | N/A |
| Fracture through the regenerate, n | N/A | N/A | N/A | N/A | N/A | 1 | 2 | N/A | N/A | N/A | N/A |
| Foot drop requiring tendon transfer, n | N/A | N/A | N/A | N/A | 1 | N/A | N/A | N/A | N/A | N/A | N/A |
| Hardware (e.g. screws) irritation required removal, n | N/A | N/A | N/A | N/A | N/A | 7 | N/A | N/A | N/A | N/A | N/A |
| Impaired ankle dorsiflexion ( < 20°), n | 2 | N/A | N/A | N/A | N/A | 4 | 1 | N/A | N/A | Classic: 2; LON: 1 | N/A |
| Incomplete consolidation of the regenerate, n | N/A | N/A | N/A | N/A | N/A | N/A | 1 | N/A | N/A | N/A | N/A |
| Intraoperative fractures, n | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Knee subluxation, n | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Leg length discrepancy, n | 1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Residual axial deviation, n | 10 | 2 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Residual knee flexion deformity/ loss of knee extension, n | 2 | N/A | N/A | N/A | N/A | 1 | N/A | N/A | N/A | N/A | N/A |
| Scar revision, n | N/A | N/A | N/A | N/A | 2 | N/A | N/A | N/A | N/A | N/A | N/A |
| Subtalar joint stiffness/deformity, n | 5 | N/A | N/A | 6 | N/A | N/A | 1 | N/A | N/A | Classic: 1; LON: 0 | N/A |

*Kocaoglu et al. 2015 reported the number of each complication per patient (not segment). †PRECICE Intramedullary Limb Lengthening System (NuVasive Specialized Orthopedics, San Diego, California, USA). ILN, implantable lengthening nail; ISKD, Intramedullary skeletal kinetic distractor; LATN, lengthening and then nail; LON, lengthening over nail; N/A, not applicable/available.
while the highest was among the classic Ilizarov frame group (42.5 day/cm (SD 16.0)). In addition, lowest numbers of problems, obstacles, and complications per patient were all seen in the ILN group. None of these differences, however, were statistically significant.

**Discussion**

This systematic review of 795 patients reveals that limb lengthening techniques can result in substantial height gain with high rate of excellent patient satisfaction and functional outcomes, although some authors did not use validated instruments to assess outcomes. Shorter treatment period and lower rate of problems, obstacles, and complications were seen with the use of ILN technique. Overall, the rate of serious major complications was low for cosmetic limb lengthening; however, the treating surgeon should be experienced in managing minor problems and obstacles to avoid increasing the rate of serious complications and their consequences.

Short stature, although not considered as an illness when no underlying cause is present, might result in psychological and functional limitations to the individual.\(^{1,2,22-25}\) It can negatively impact many aspects of a person’s life, including career opportunity and success, interpersonal attraction, and mate selection.\(^{26-29}\) The majority of patients who seek cosmetic stature lengthening report a family concern or peer appraisal about their height in childhood.\(^2\) Being sensitized to height issues early in life have shown to affect a person’s life during adulthood.\(^{21}\) For males, short stature is more concerning, more stigmatizing, and less culturally accepted compared to females.\(^{23,26,28,29}\) As a result, more men than women seek stature lengthening as noted in this systematic review.

Cosmetic stature lengthening resulted in improved self-esteem and quality of life, and decreased distress and shyness levels.\(^{5,7,11,12,16-19}\) Most patients reported high satisfaction rate and felt they would recommend the surgery for others with short stature.\(^{5,6,17}\) Satisfaction, however, might not be predictable in patients with body dysmorphic disorder or dysmorphophobia.\(^30\) These patients experience a distressing and impairing preoccupation of an imagined appearance, and hence seek cosmetic surgery to alter their subjective perceived abnormal appearance. Preoperative psychological evaluation is, therefore, mandatory in patients seeking cosmetic limb lengthening to rule out psychiatric disorders and understand the patient’s personality and motivations. In addition to the psychological assessment, extensive preoperative counselling with the treating surgeon is a must. This should be done with an aim to determine whether the patient needs the surgery or not, to make him/her aware of the nature of the treatment and its possible complications, and to discuss and suggest other non-surgical options whenever possible.

Many patients who are counselled for cosmetic limb lengthening might not be good surgical candidates because they show features of dysmorphophobia, have unrealistic expectations of treatment outcomes, or show poor motivation in collaborating with long-term postoperative protocols. Some of those who are being rejected for surgery might go to centres or surgeons with minimal or no experience in limb lengthening techniques and end up with serious complications as noted by some authors.\(^6\) With the lack of clear indications and contraindications on when to offer this surgery to individuals with short stature, and the ethical controversies behind it, guidelines for cosmetic limb lengthening are needed.\(^{14}\) Guidelines should clearly explain at least: 1) indications and contraindications of the surgery; 2) preferred and acceptable lengthening technique; 3) level of training and experience of the surgeon needed to perform the surgery; 4) quality and setup of the facility where the surgery is being done; 5) preoperative counselling and psychological assessments needed; 6) definitions of acceptable outcomes; 7) protocols on how to manage common related complications; and 8) postoperative follow-up protocols.
Several limitations exist in the current study. The included studies have a low level of evidence (case series or retrospective reviews). Moreover, different limb lengthening techniques and devices have been used on different bone segments, making it difficult to generalize the results to one specific technique. Reporting outcomes varied between the included studies as well, with some studies missing important outcomes like maturation/consolidation index, and other studies using unvalidated outcome scores. This makes it difficult to compare functional outcomes in between the lengthening techniques used. Factors associated with poor satisfaction rate and outcomes were also not well-reported. Understanding the predictors of good outcomes would help the surgeons to select patients for cosmetic stature lengthening. The association between patients’ preoperative expectations in length gain, careful understanding of the possible complications that might occur with greater limb lengthening, and patient satisfaction of the outcome of this surgery needs to be studied in depth.

In conclusion, cosmetic stature lengthening provides favourable height gain, patient satisfaction, and functional outcomes, with a low rate of major complications. However, clear indications, contraindications, and guidelines for cosmetic stature lengthening are required.

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