NATIONAL INSTITUTE FOR HEALTH AND CARE EXCELLENCE

INTERVENTIONAL PROCEDURES PROGRAMME

Interventional procedure overview of intramedullary distraction for lower limb lengthening

People can have different length legs from birth, or because of disease or injury. In this procedure, under general anaesthesia, a bone in the shorter leg is cut surgically and a metal lengthening device (distractor) is put inside the bone (intramedullary) across the cut bone. It may be done to a bone in the upper or lower leg. After the operation, the device is gradually lengthened while new bone forms across the cut, so increasing the length of the bone. There are different techniques used to lengthen the distractor depending on the device used. The process of lengthening and healing takes several months, during which partial weight bearing is possible. The main aim is to lengthen the leg and reduce disability.

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Abbreviations

Word or phrase	Abbreviation
Confidence interval	CI
Iliotibial band	ITB
Intramedullary skeletal kinetic distractor	ISKD
Intramedullary	IM
Limb reconstruction system	LRS
Lengthening and then nailing technique	LATN
Limb length discrepancy	LLD
Lengthening over the nail	LON
Mean difference	MD
Non-randomised study	NRS
Not reported	NR
Risk difference	RD
Randomised controlled trial	RCT
Visual analogue score	VAS

Introduction

The National Institute for Health and Care Excellence (NICE) prepared this interventional procedure overview to help members of the interventional procedures advisory committee (IPAC) make recommendations about the safety and efficacy of an interventional procedure. It is based on a rapid review of the medical literature and professional opinion. It should not be regarded as a definitive assessment of the procedure.

Date prepared

This overview was prepared in June 2021.

Procedure name

- intramedullary distraction for lower limb lengthening

Professional societies

- British Limb Reconstruction Society
- British Orthopaedic Association
- British Society for Children's Orthopaedic Surgery

Description of the procedure

Indications and current treatment

People may have different or deficient limb lengths because of trauma or infection (acquired) or, more rarely, because of hypoplasia or dysplasia of the femur or tibia (congenital). Unequal leg length can cause a limp and limit functional ability.

Lengthening of an abnormally short lower limb can be done using an external fixation device. This exerts force along the long axis of the bone to induce new bone formation (distraction osteogenesis). Potential problems with external fixation include: infection of the pin tracts, pain, hip and knee subluxation or dislocation, angulation, bone deformity and neighbouring joint stiffness. People may also find that external fixation devices are impractical and aesthetically unacceptable. Often, once the external fixation is removed, the new bone is augmented by either an internal plate fixation or an IM nail.

What the procedure involves

IM distraction systems are used for managing fractures. Once inserted and fixed they can be mechanically lengthened over time using different technique. The aim is to lengthen the bone in a controlled manner.

With this procedure, under general anaesthesia, an osteotomy is done while avoiding damage to the periosteum and its blood supply. The adjustable IM nail-like device is then implanted into the IM space. Its proximal and distal sections are then fixed to the relevant section of the bone with sterile locking screws. Once implanted and fixed, the device can be adjusted in length to provide an appropriate amount of compression and allow bony alignment at the osteotomy site. It exerts a force along the long axis of the bone, which stimulates new bone formation (distraction osteogenesis) in the gap, causing bone lengthening. Over days, weeks or months, sequential distractions are used to produce the target limb length.

Different devices achieve distraction in different ways. For example, some work mechanically by releasing a preloaded spring or using a motor driven extension. Others are non-invasive and use an electromagnetic external device.

Soon after the procedure, with help from the therapy team, people are able to partially weight bear. The IM device then remains implanted until bone consolidation is complete. When there is radiological evidence of adequate bone consolidation across the gap, full weight bearing is possible. The device is then usually removed using standard surgical techniques.

Efficacy summary

Mean lengthening achieved

In a systematic review of 10 studies comparing 3 methods of lower limb lengthening, patients who had external fixation alone (in 2 studies) had a greater increase in lengthening (mean 60 mm) than those who had external fixation with an IM nail (5 studies, mean 54 mm) or an IM nail alone (3 studies, mean 44 mm; Brewster 2010).

In a systematic review and meta-analysis of 4 studies comparing LATN with the conventional Ilizarov method for limb lengthening, patients who had LATN gained no more length than those who had the conventional procedure. The pooled results (from 2 studies) showed that there was no statistically significant difference in length gained between the 2 treatment groups (MD = −0.30, 95% CI, −0.72 to 0.12; p=0.16, I^2=80%; Xu 2017).

In a Canadian Agency for Drugs and Technologies in Health (CADTH) report of 3 NRS on lower limb lengthening with a magnetically driven IM nail, 2 studies (Laubscher 2016, Szymczuk 2017) reported that mean lengthening was higher in the LRS external fixation group than in the magnetically driven IM nail group (Laubscher 2016: 59.7 mm compared with 51.4 mm; Szymczuk 2017: 5.55 cm compared with 4.75 cm, p=0.052) but did not achieve statistical significance. One study (Hammouda 2017) reported that there was no statistically significant difference in the mean lengthening between the magnetically driven IM nail group and the mechanically activated ISKD group (5.6 cm compared with 5.2 cm, p=0.35). The lengthening goal was achieved in most patients and in all treatment groups in the 3 studies (Young 2017).

In a systematic review of 15 studies on mechanically activated ISKD for bone lengthening in the femur or tibia, 9 studies reported that the mean lengthening achieved in patients ranged from 31 mm to 49 mm across the studies. Lengthening goals were not explicitly stated in this systematic review (Nageeb 2014).

Mean lengthening time

In the systematic review of 10 studies, the mean time to lengthening was less in patients who had IM nail alone (18 days/cm) than those who had external fixation with IM nail (23 days/cm) or external fixation alone (46 days/cm; Brewster 2010).

Percentage of limbs in which target lengthening was achieved

In the systematic review of 15 studies, 8 studies reported that target lengthening was achieved in 89% to 100% of operated limbs. Two studies reported that target lengthening was achieved in 35% to 100% of limbs (Nageeb 2014).

Mean lengthening rate (mm/day)

In the systematic review of 15 studies, 5 studies reported that the mean lengthening rate ranged from 0.62 mm/day to 1.9 mm/day (Nageeb 2014).

In a retrospective cohort study of 56 patients, the rate of distraction was statistically significantly higher with magnetically driven IM nails (39 limbs,1.0 mm/day) than with LON (20 limbs, 0.8 mm/day) for femoral lengthening ($p<0.001$; Fragomen 2018).

LLD

In the retrospective cohort study of 56 patients, patients in the IM nail group had a lower mean postoperative residual LLD (difference between desired length and final length) than those in the LON group (0.3 mm compared with 3.6 mm, $p=0.007$; Fragomen 2018).

Bone healing (mean distraction and consolidation or healing index)

In the systematic review and meta-analysis of 4 studies, patients who had the LATN procedure had better consolidation indices than those who had the conventional Ilizarov method. Pooled analysis of 3 studies showed that there was a statistically significant difference in the consolidation indices between the 2 groups (MD = −19.97; 95% CI, −21.59 to −18.35; $p<0.00001$, $I^2=100\%$; Xu 2017).

In the systematic review of 15 studies, 3 studies reported that the mean consolidation time ranged between 80 to 152 days. The mean consolidation index across 7 studies ranged between 2.2 mm/day to 12.7 mm/day and the mean distraction index across 6 studies ranged between 0.2 mm/day to 1.7 mm/day (Nageeb 2014).

In the CADTH report, 1 study (Szymczuk 2017) reported that distraction index (0.7 mm/day compared with 0.7 mm/day, $p=0.99$) and consolidation index (34.77

cm/day compared with 29.33 cm/day, p=0.08) were similar in the magnetically driven IM nail group and LRS external fixation groups. Also, 1 study (Laubscher 2016) reported that the mean healing index was statistically significantly shorter in the magnetically driven IM nail group than the LRS external fixation group (31.3 days/cm compared with 47.1 days/cm, p<0.001; Young 2017).

In the retrospective cohort study of 56 patients, time to union was statistically significantly shorter in the IM nail group than that in the LON group (3.3 months compared with 4.5 months, p=0.001. Also, bone healing index was not statistically significant different between the groups (1.0 month/cm compared with 1.4 month'/cm, p=0.101; Fragomen 2018).

In a retrospective matched pair analysis of 34 patients, the distraction index was statistically significantly different in the mechanically activated ISKD group than in the motorised IM nail (Fitbone) group (0.99 mm/day compared with 0.55 mm/day, p=0.001). Also, the mean weight bearing index differed statistically significantly between the mechanically activated ISKD group and the motorised IM nail (Fitbone) group (32 days/cm compared with 52 days/cm, p=0.001;Thaller 2020).

Mean time to full weight bearing

In the systematic review of 15 studies, 3 studies reported that mean time to full weight bearing ranged from 1 week to 20.5 weeks (Nageeb 2014).

In the CADTH report, 1 study (Laubscher 2016) reported that mean time to full weight bearing was statistically significantly shorter in the magnetically driven IM nail group than the LRS external fixation group (3.6 months compared with 4.8 months, p=0.02; Young 2017).

Range of motion

In the CADTH report, 2 studies (Szymczuk 2017, Laubscher 2016) reported that the range of motion was not statistically significantly better in the magnetically driven IM nail group than in the LRS external fixation groups. In 1 study (Szymczuk 2017), range of motion was better retained at the end of lengthening and at consolidation (p<0.001) in the magnetically driven IM nail group than in LRS external fixation group. In 1 study (Laubscher 2016), there was a higher rate of preservation of knee range of movement after lengthening in the magnetically driven IM nail group (100%) than in the LRS external fixation group (92% [12/13]; p value not reported; Young 2017).

In the retrospective cohort study of 56 patients, knee flexion at the end of distraction was greater in IM nail group than in the LON group (103 degrees compared with 89 degrees, p=0.006), but this difference was no longer seen after 1 year (123 degrees compared with 119 degrees, p=0.464; Fragomen 2018).

External fixation index

In the systematic review and meta-analysis of 4 studies, patients who had LATN had better external fixation indices than those who had the conventional Ilizarov method. The pooled results (from 3 studies) showed a statistically significant difference in the external fixation index between the 2 treatment groups (MD −50.21, 95% CI, −51.83 to −48.59; p<0.00001; I^2 = 99%; Xu 2017).

Patient reported outcomes (measured by patient interviews)

In the CADTH report, 1 study (Laubscher 2016) reported that, after treatment, patients interviewed in the magnetically driven IM nail group were more satisfied with the cosmetic appearance of their scar after femoral lengthening, experienced less pain (as measured with the mean VAS score) and were more able to do activities of daily living throughout lengthening than patients in the LRS external fixation group (Young C 2017).

Safety summary

Overall complications

The overall complication rate was 34% (332/983) in a systematic review of 41 studies of externally controlled (motorised or magnetically driven) IM bone lengthening nails. Of these, 3% (28/983) were type 3B complications (with new pathology or permanent sequelae), 5% (45/983) were type 3A complications (not achieving the lengthening goal), 15% (146/983) were type 2 complications (with substantial change in treatment) and 11% (113/983) were type 1 complications (with minimal intervention). The overall complication rate per bone segment was 46% for studies reporting the use of an externally controlled motorised IM nail and 31% for studies reporting the use of an externally controlled magnetically driven IM nail (Frost 2021).

The complication rate in the mechanically activated ISKD group was not statistically significantly higher than in the magnetically driven IM nail cohort (39% [3/13] compared with 23% [7/18], p=0.45) in an NRS (Hammouda 2017) included in the CADTH report. In the same report, in another NRS (Szymczuk 2017), adverse events classified as ‘problems’ were statistically significantly lower in the magnetically driven IM nail group than in the LRS external fixation group (8 compared with 32, p<0.001; Young 2017).

Complications in the magnetically driven IM nail cohort were lower than in the LON cohort (18% [7/39] compared with 45% [9/20], p=0.027) in the retrospective cohort study of 56 patients (Fragomen 2018).

Device-related complications

Device-related complications were seen in 12% (122/983) of segments in the systematic review of 41 studies. These were mainly related to the distraction mechanism (in 5%, 45/983), mechanical strength (in 5%, 44/983, 2 of these were type 3B complications) and attachment failure in 3% (33/983) of bone segments. One per cent (13/983) of segments failed to achieve the planned lengthening goal because of device-related type 3A complications (Frost 2021).

Hardware malfunction complications ranging from 6% to 33% were reported in 7 studies in the systematic review of 15 studies. Runaway nails (uncontrolled rapid lengthening of more than 1.5 mm/day) ranging from 8% to 100% were reported in 10 studies. Non-distracting or difficult-to-distract nails (defined as 'nails that fail to distract in-situ despite increasing the activity level and manually rotating the lower extremities by the patients themselves or with assistance from family members') ranging from 2% to 50% were reported in 9 studies. Jammed nails were reported in 1% to 33% of operated limbs (in which the lengthening mechanism jammed as a result of implantation procedure) in 3 studies (Nageeb 2014).

Bone-related complications

In the systematic review and meta-analysis of 4 studies, pooled analysis (3 studies) showed that there was no statistically significant difference in refracture between the LATN group and the conventional method group (RD = -0.02, 95% CI –0.06, 0.01; p=0.21, I^2=69%). Pooled analysis (3 studies) showed that there was no statistically significant difference in axial deviation between the LATN group and the conventional method group (RD = -0.10, 95% CI –0.15, –0.05; p=0.22, I^2=57%; Xu 2017).

Complications related to bone regeneration were seen in 8% (78/983) of bone segments in the systematic review of 41 studies. These were mainly due to premature consolidation in 2% (19/983) of segments, or delayed healing in 5% (46/78) of segments. Other causes include secondary malalignment in 3 fractures in 8 segments and other reasons in 2 segments. Four of these complications were type 3B (with new pathology or permanent sequelae) and 7 were type 3A complications (not achieving the lengthening goal; Frost 2021).

Insufficient bone regeneration causing delayed healing or non-union (needing additional surgical procedures to achieve union) are other common complications reported in the systematic review of 15 studies. This ranged from 8% to 38% across 6 studies. Premature consolidation (ranging from 7 to 36%) was reported in 5 studies. Non-union (ranging from 1% to 33%) was reported in 4 studies. Angular deformity was reported in 2 patients in 1 study (Nageeb 2014).

Joint-related complications

In the meta-analysis of 4 studies, pooled analysis (3 studies) showed that there was a statistically significant difference in joint contracture between the LATN

group and the conventional method group (RD = –0.04, 95% CI–0.10, 0.02; p=0.0003, I^2=69%; Xu 2017).

Joint-related complications were reported in 6% (61/983) of segments in the systematic review of 41 studies. These included contractures in 5% of segments (53/983), joint subluxation in 6 segments, and dislocation or pain in 1 segment each (Frost 2021).

Joint contractures were reported in 2 patients in 1 study included in the systematic review of 15 studies (Nageeb 2014).

Infections

In the systematic review and meta-analysis of 4 studies, the pooled analysis of 4 studies showed that there was a statistically significant difference in pin tract infection between the LATN procedure and the conventional method group (RD = −0.13; 95% CI, −0.19 to 0.06; p=0.0002, I^2=79%) (Xu 2017). The pooled analysis of 3 studies showed that there was no statistically significant difference in IM infection between the LATN and the conventional method group (RD = 0.05, 95% CI –0.01, 0.11; p=0.11, I^2=56%; Xu 2017).

Infection rates were lower for the IM nail alone group (0%) than the external fixation alone group (39%) and external fixation with IM nail group (6.9%) in the systematic review of 10 studies. There were more superficial pin tract infections (36%) and fewer deep infections (3%) in the external fixation alone group. In the external fixation with IM nail group, there were more deep infections (6%) and fewer superficial pin tract infections (1%) (Brewster 2010).

Complications such as pin site or superficial infections were reported less frequently with externally controlled magnetically driven IM nail lengthening than with LRS external fixation in 2 non-randomised studies included in the CADHT report (Young C 2017).

Infections were reported in fewer than 1% of bone segments (8/983) in the systematic review of 41 studies with externally controlled motorised or magnetically driven IM bone lengthening nails. These included superficial soft tissue infection in 3 operated segments, deep soft tissue infection in 1 limb and osteomyelitis in 4 segments (3 type 3A and 1 type 3B complications; Frost 2021).

Infections (superficial in 2 operated limbs and deep in 1 limb) were reported in 3 included studies in the systematic review of 15 studies (Nageeb 2014).

Soft tissue complications

Soft tissue related complications were reported in 1% (13/983) of segments in the systematic review of 41 studies. These included pain in 5 segments (type 1), skin

problems in 3 segments (type 1 and 2), and other complications in 5 segments, of which 2 were compartment syndrome problems (with new pathology or permanent sequelae; Frost 2021).

Compartment syndrome was reported in 1 patient in a study included in the systematic review of 15 studies (Nageeb 2014).

Vascular complications

Vascular complications were reported in 1% (10/983) of segments in the systematic review of 41 studies with externally controlled motorised or magnetically driven IM bone lengthening nails. These included 6 type 3B complications (vascular damage in 1, deep vein thrombosis in 4 and arteriovenous fistula of the posterior tibial artery decompensated during tibial lengthening in 1) and 4 type 1 complications (haemorrhage in 2 and other complications in 2 segments; Frost 2021).

Neurological complications

Neurological complications were reported in less than 1% of segments (8/983) in the systematic review of 41 studies with externally controlled motorised or magnetically driven IM bone lengthening nails. These included paraesthesia in 5 segments (of which 1 was a type 3A complication) (Frost 2021).

Other complications

Other complications (6 patient related, 11 surgical related and 1 other) were reported in 2% (18/983) of segments in the systematic review of 41 (Frost 2021).

Anecdotal and theoretical adverse events

In addition to safety outcomes reported in the literature, professional experts are asked about anecdotal adverse events (events which they have heard about) and about theoretical adverse events (events which they think might possibly occur, even if they have never happened). For this procedure, we received no questionnaires.

The evidence assessed

Rapid review of literature

The medical literature was searched to identify studies and reviews relevant to IM distraction for lower limb lengthening. The following databases were searched, covering the period from their start to 14.04.2021: MEDLINE, PREMEDLINE, EMBASE, Cochrane Library and other databases. Trial registries and the Internet

were also searched. No language restriction was applied to the searches (see the literature search strategy). Relevant published studies identified during consultation or resolution that are published after this date may also be considered for inclusion.

The inclusion criteria were applied to the abstracts identified by the literature search. Where selection criteria could not be determined from the abstracts the full paper was retrieved.

Inclusion criteria for identification of relevant studies

Characteristic	Criteria
Publication type	Clinical studies were included. Emphasis was placed on identifying good quality studies. Abstracts were excluded where no clinical outcomes were reported, or where the paper was a review, editorial, or a laboratory or animal study. Conference abstracts were also excluded because of the difficulty of appraising study methodology, unless they reported specific adverse events that were not available in the published literature.
Patient	Patients with limb length deficiency of any aetiology.
Intervention/test	IM distraction (or distraction osteogenesis) for lower limb lengthening (implants can either be mechanically activated nails, motorised nails, or magnetically driven nails).
Outcome	Articles were retrieved if the abstract contained information relevant to the safety and/or efficacy.
Language	Non-English-language articles were excluded unless they were thought to add substantively to the English-language evidence base.

List of studies included in the IP overview

This IP overview is based on 2,255 patients from 5 systematic reviews, 1 retrospective cohort study and 1 retrospective matched case series.

Other studies that were considered to be relevant to the procedure but were not included in the main summary of the key evidence are listed in the appendix.

Summary of key evidence on intramedullary distraction for lower limb lengthening

Study 1 Brewster MB (2010)

Study details

Study type	Systematic review
Country	UK
Study period	Search period NR. Databases searched: PubMed; additional studies were identified from reference lists of included studies.
Study population and number	n=619 patients who had limb lengthening (10 studies: 3 prospective case series, 2 retrospective case series, 3 retrospective reviews, 1 retrospective matched case series, 1 prospective non-randomised cohort study). 3 methods of lengthening were compared: 1. external fixation alone (n=335, 2 studies) 2. IM nail alone (n=54, 3 studies) 3. IM nail with external fixation (n=230, 5 studies)
Age and gender	NR
Study selection criteria	Inclusion criteria: studies in English, limited to humans, on limb lengthening involving the tibia or femur, with a minimum of 10 bones, reporting lengthening of bone achieved and timing of lengthening and infection data. Exclusion criteria: lengthening using Taylor special frames were excluded due to prolonged, complex correction process involved. Studies with inadequate raw data available to recalculate lower limb results were excluded.
Technique	1. external fixation alone (n=335, 2 studies) 2. IM nails alone (n=54, 3 studies) 3. IM nail with external fixation (n=230, 5 studies)
Follow up	Varied across studies and between comparator groups.
Conflict of interest/source of funding	No conflicts of interest were declared. Authors declared that no funding was received for this study.

Analysis

Follow-up issues: length of follow up was varied and not consistent in the included studies and between treatment groups.

Study design issues: search was done in only 1 database; study selection criteria were described but lacked details on screening and critically appraisal of included studies. The majority of the included studies were retrospective comparisons and susceptible to bias. Confounding factors were not considered when

comparisons were made and outcomes were analysed. There is variation in reporting data across studies and data on infection rates were limited. Mean scores were calculated.

Study population issues: patient population and demographic characteristics were clearly stated but they were diverse. 4 papers included some patients who had concurrent angulation corrections.

Key efficacy findings

- Number of patients analysed: 619

Study details	Median follow up, months (range)	Lengthening method	Median lengthening index, days/cm (range)	Mean length increase, mm (range)	Infection rates %
External fixation with IM nail					
Lee 1997 retrospective review	37 (24-59)	14 external fixations	50 (36-76)	40 (37-78)	29% pin tract infections
	30 (24-42)	7 external fixations + IM nail	14 (13-18)	48 (36-60)	0
Huang 1997 prospective cohort	27 (24-80)	59 external fixations	57 (31–134)	37 (30–80)	0 deep infections
		12 external fixations +IM nail	20 (12–29)	40 (32–50)	8% deep infections
Wang 1999 retrospective review	73 (30-100)	23 external fixations	41 (6-80)	67 (30-145)	30% pin tract infections
	48	1 external fixation + IM nail	28	63	0
Paley 1997 retrospective matched case series	44 (24-72)	32 external fixations	51	58 (20-130)	3% nail removal for infection
	34 (24-60)	32 external fixations + IM nail	21	52 (20-130)	3% pin removal
Kocaoglu 2004 retrospective case series	44 (26-62)	42 external fixations + IM nail	31.2	63 (25-115)	Pin tract infections unspecified; 2.5 pins removed for infection
External fixation alone					
Maffuli 1996 Retrospective review	>12	281 external fixations	35.3 (26-43)	93 (30-80)	62-78% pin tract infections 5% pin removal 1 case of osteomyelitis
Catagni 2005 prospective case series	75 (12-192)	54 external fixations	41	70 (50-110)	48.2% pin tract infections, some nails removed
IM nail alone					
Baumgart 1997	>24	12 motorised IM nail	12.4 42 healing index	NR	0

prospective case series					
Singh 2006 retrospective case series	36 (12-48)	22 motorised IM nail	28.5 (18.8–70.9)	40 (27–60)	0
Cole 2001 prospective case series	28 (12-48)	20 ratcheted IM nail	12 (6-25)	49 (29-110)	0

Mean lengthening index, days/cm

	Mean lengthening index, days/cm	**Mean length increase, mm (range)**
External fixation alone (2 studies)	45.9	60
IM nail alone (3 studies)	17.6	44
External fixation with IM nail (5 studies)	22.8	54

Key safety outcomes

Complications

	External fixation alone	**IM nail alone**	**External fixation with IM nail**
Superficial infections, %	36.2	0	1.4
Deep infections, %	2.5	0	5.5

Study 2 Xu WG (2017)

Study details

Study type	Systematic review and meta-analysis
Country	China
Study period	Search period: inception to 22 May 2015 Databases searched: Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, EMBASE, and the ISI Web of Knowledge. References of included studies were searched for additional studies, grey literature was also identified. Further internet searches were done from articles from Congress, such as those of the European Federation of National Associations of Orthopaedic Sports Traumatology and British Orthopaedic Association Annual Congress.
Study population and number	n=212 patients (354 limbs) who had lower limb lengthening (4 studies: 1 RCT), 2 clinical controlled trials and 1 retrospective cohort study) lengthening and then nailing (LATN [94 patients, 183 limb]) versus conventional Ilizarov method (118 patients,171 limbs) number of tibiae: LATN (n=142), conventional method (n=187)
Age and gender	Age range between 22 to 30 years.
Study selection criteria	Inclusion criteria: clinical controlled trials (RCT or non-RCT); patients having leg lengthening operations with 1 group having the LATN method and 1 group having the conventional Ilizarov method; and reported surgical outcomes (external fixation index, percentage length increase, consolidation index, and incidence of complications).
Technique	Intervention: longitudinal osteotomy combined with the LATN or LON technique. After the desired length was achieved, the fixator was removed and 2 distal interlocking screws were inserted; partial weight bearing was continued until full consolidation. Comparator: in the conventional Ilizarov technique the fixator was removed when there was a radiographic confirmation of 3 cortices in the regenerate column of both anterio–posterior and lateral X-ray images, and then the individual could try to bear weight fully.
Follow up	Varied across studies and between comparator groups.
Conflict of interest/source of funding	No conflicts of interest were declared. Authors declared that no funding was received for this study.

Analysis

Follow-up issues: length of follow up was varied and not consistent in the included studies and between treatment groups.

Study design issues: comprehensive searches were done; study selection was done independently by authors and any disagreements were resolved by consensus. Quality assessment of RCT was assessed using the Cochrane collaboration's tool for assessing risk of bias and the non-RCTs were assessed using a methodological index for NRS (MINORS) form. The RCT had a low risk of bias and the non-RCTs had a high

risk of bias (inadequate information on the randomisation methods and blinding methods). Authors of the studies were contacted for missing data or further information. Meta-analysis was performed.

Very few studies were included in the review. Studies were heterogenous in terms of indications, devices used, and the surgical techniques used for limb lengthening).

Key efficacy findings

- Number of patients analysed: 212 patients (354 limbs)

External Fixation Index between LATN and conventional method (3 studies)

The pooled results (from 3 studies) demonstrated a significant difference in the external fixation index between the 2 treatment groups (MD −50.21, 95% CI, −51.83 to −48.59; p < 0.00001; I^2 = 99%). So, patients who had LATN procedure had better external fixation indices than those who had the conventional procedure.

Length gained between LATN and conventional methods (2 studies)

The pooled results (from 2 studies) demonstrated that there was no significant difference in length gained between the 2 treatment groups (MD = −0.30, 95% CI, −0.72 to 0.12; p=0.16, I^2=80%). Therefore, patients who had LATN procedure gained no more length than those who had the conventional procedure.

Consolidation Index between LATN and conventional methods (3 studies)

Pooled analysis (from 3 studies) showed a statistically significant difference in the consolidation indices between the 2 groups (MD = −19.97; 95% CI, −21.59 to −18.35; p<0.00001, I^2=100%). Therefore, patients who had the LATN procedure had better consolidation indices than those who had the conventional procedure.

Key safety outcomes

Adverse events between LATN and conventional methods (4 studies)

Adverse event	**LATN Method (n)**				**Conventional method (n)**			
	Rozburch 2008	**Guo 2012**	**Lan 2013**	**El Husseini 2013**	**Rozburch 2008**	**Guo 2012**	**Lan 2013**	**El Husseini 2013**
Pin tract infections	1	8	2	5	1	11	11	9
IM infection	1	0	0	3	0	0	0	0
Refracture	0	-	0	0	0	-	0	3
Axial deviation	-	0	0	0	-	1	8	5
Joint contracture	0	-	6	1	0	-	8	6
Delayed consolidation	-	1	-	3	-	2	-	0
Total	**2**	**9**	**8**	**12**	**1**	**14**	**27**	**23**

Pin tract infections
Pooled analysis (of 4 studies) showed that there was a significant difference in pin tract infections between the LATN group and the conventional method group (RD = −0.13; 95% CI, −0.19 to 0.06; p=0.0002, I^2=79%). Therefore, patients who had the LATN procedure had fewer pin tract infections than those who had the conventional procedure.

IM infection
Pooled analysis (of 3 studies) showed that there was no statistically significant difference in IM infection between the LATN group and the conventional method group (RD = 0.05, 95% CI –0.01, 0.11; p=0.11, I^2=56%).

Refracture
Pooled analysis (of 3 studies) showed that there was no significant difference in refracture between the LATN group and the conventional method group (RD = -0.02, 95% CI –0.06, 0.01; p=0.21, I^2=69%).

Axial deviation
Pooled analysis (of 3 studies) showed that there was no significant difference in axial deviation between the LATN group and the conventional method group (RD = -0.10, 95% CI –0.15, –0.05; p=0.22, I^2=57%).

Joint contracture
Pooled analysis (of 3 studies) showed that there was a significant difference in joint contracture between the LATN group and the conventional method group (RD = –0.04, 95% CI–0.10, 0.02; p=0.0003, I^2=69%).

Study 3 Nageeb MA (2014)

Study details

Study type	Systematic review
Country	Egypt
Study period	Search was done between August to November 2012. Databases searched: PubMed, Ovid Medline, Ovid Full Text, Springer link, EBSCO Medline, Science Direct, ISI Web of Knowledge, and Google Scholar. References of included articles and previous reviews and meta-analyses were reviewed to identify additional relevant articles.
Study population and number	n=440 patients (484 operated limbs: femora 222; tibiae 43) 15 studies (case series) Causes of LLD needing ISKD implantation: trauma (n=185), congenital (n=162), cosmetic (n=29), infection (n=14), tumour (n=9), burn, polio, knee arthrodesis (1 each), and other causes (n=31).
Age and sex	mean age ranging from 24 years to 40 years 173 male and 101 female patients.
Study selection criteria	Inclusion criteria: peer reviewed studies (prospective, retrospective, cross-sectional, or interventional) published in the English language, reporting ISKD implantation in the femur or tibia of skeletally mature patients, with extractable data about the study population and outcomes. Exclusion criteria: studies in languages other than English; animal studies; studies describing lengthening techniques using devices other than ISKDs; and unpublished data and abstracts.
Technique	ISKD bone lengthening in femora and tibiae. Tibial lengthening reported in 5 studies Femoral tibial lengthening in 12 studies
Follow up	Mean follow up ranged from 14 to 76 months
Conflict of interest/source of funding	The authors declare that they have no financial or non-financial conflicts of interest.

Analysis

Follow-up issues: follow up was reported in only 8 studies and varied across studies.

Study design issues: comprehensive search was done; 2 reviewers independently reviewed abstracts to identify relevant studies and any disagreements were resolved by consensus. Quality assessment of included studies was done using a checklist of potential sources of bias. Only 6 studies stated inclusion and exclusion criteria and 8 reported the consolidation and distraction indices. Blinding was not possible and there was no allocation concealment in all studies. Studies were too heterogenous and there is no standardised reporting so a narrative synthesis was done.

Study population issues: studies included different groups of patients; 2 studies did not report which limbs were operated.
Other issues: authors state that the patient's level of activity may not be homogeneous and may be responsible for the variability in daily lengthening.

Key efficacy findings

Number of patients analysed: 440

Clinical outcomes

Clinical outcome	Data are presented as n (%), n (range), or mean ± SD.	Study
Mean time to full weight bearing (week)	1	Cole 2001
	10 (7-14)	Hankemeier 2004
	20.5	Kucukayya 2011
Mean lengthening achieved (mm)	49 (29-110)	Cole 2001
	31 (26-40)	Hankemeier 2004
	46 (15-80)	Simpson 2009
	42.8 ± 12.9 (25-70)	Kenawey 2011
	31 (0-60)	Pappanna 2011
	35 (21-75)	Wang and Edwards 2012
	38 (20-52)	Kucukayya 2011
	40.8 (10-80)	Schiedel 2011
	43 ± 16 (2-10)	Kenawey 2011
Mean lengthening rate (mm/day)	0.82 (0.4-1.7)	Cole 2001
	1.2 ± 0.4 (0.7-2.8)	Kenawey 2011
	0.62	Pappanna 2011
	in 10 patients:1.9 (1.43-2.56) In 2 patients:0.84 (0.75-0.93)	Mahboubian 2012
	1	Kenawey 2011
% of limbs in which satisfactory lengthening was achieved	4 (100%)	Hankemeier 2004
	32 (97%)	Simpson 2009
	37 (100%)	Kenawey 2011
	2 (66%)	Pappanna 2011
	16 (100%)	Wang and Edwards 2012
	8 (89%)	Kucukayya 2011
	88 (53-100%)	Mahboubian 2012
	63 (91%)	Schiedel 2011
	168 (93%)	Burghardt 2011
	57 (100%)	Kenawey 2011

Mean consolidation time (days)	80 (51-111)	Hankemeier 2004
	152 (77-365)	Wang and Edwards 2012
	133 (56-477)	Schiedel 2011
Mean consolidation index (mm/day)	2.9 (1.8-4.1)	Hankemeier 2004
	3.6 ± 0.9 (1.8-6.3) (n=29)	Kenawey 2011
	12.66	Pappanna 2011
	4.87 (2.78-11.2)	Wang and Edwards 2012
	2.2 (1.2-3.5)	Kucukayya 2011
	9.09 (1.26-51.6)	Mahboubian 2012
	3.39 (2.37-9.54)	Schiedel 2011
Mean distraction index (mm/day)	1.2 (0.9-1.8)	Hankemeier 2004
	1.1 ± 0.3 (n=29)	Kenawey 2011
	0.63 (0-1.25)	Pappanna 2011
	0.2-2.5	Wang and Edwards 2012
	1.0 (0.1-2.5)	Schiedel 2011
% of patients in whom additional surgical procedures were performed	3 (75%)	Hankemeier 2004
	7 (78%)	Kubiak 2007
	3 (100%)	Pappanna 2011
	6 (38%)	Wang and Edwards 2012
	2 (22%)	Kucukayya 2011
	30 (43%)	Schiedel 2011

Mean time to patient discharge: ranged from 7-10 days (in 3 studies).

Key safety findings

Complications with ISKD procedures

	% (n, ISKDs)	Study	Number of patients	Number of inserted ISKDs
Infection				
Deep	(1/12)	Mahboubian 2012	11	12
Superficial	(1/3)	Pappanna 2011	3	3
	1.75 (1/57)	Kenawey 2011	53	57
Compartment syndrome	(1/57)	Kenawey 2011	53	57
Insufficient bone regenerate (causing delayed union)	21 (12/57)	Kenawey 2011	53	57
	8.3 (1/12)	Mahboubian 2012	11	12
	9 (3/33)	Simpson 2009	30	33
	21.6 (8/37)	Kenawey 2011	35	37
	33.3 (1/3)	Pappanna 2011	3	3

	37.5 (6/16)	Wang and Edwards 2012	16	16
Runaway nail (uncontrolled rapid lengthening of > 1.5 mm per day)	21.2 (7/33)	Simpson 2009	30	33
	18.9 (7/37)	Kenawey 2011	35	37
	9.09 (1/11))	Kubiak 2007	9	11
	33.3 (1/3)	Pappanna 2011	3	3
	31.2 (5/16)	Wang and Edwards 2012	16	16
	1	Reynders 2009	1	1
	44.4 (4/9)	Kucukkaya 2011	9	9
	8.33 (1/12)	Mahboubian 2012	11	12
	15.78 (9/57)	Kenawey 2011	53	57
	10 (4/41)	Thonse 2005	41	41
Jammed nail (lengthening mechanism jammed)	0.7 (1/210)	Burghardt 2011	180	242
	33.3 (1/3)	Pappanna 2011	3	3
	27.2 (3/11)	Kubiak 2007	9	11
Difficult to distract nails^	24.2 (8/33)	Simpson 2009	30	33
	2.7 (1/37)	Kenawey 2011	35	37
	33.3 (1/3)	Pappanna 2011	3	3
	18.7 (3/16)	Wang and Edwards 2012	16	16
	10.1 (7/69)	Schiedel 2011	69	69
	1.65 (4/210)	Burghardt 2011	180	242
	1.75 (1/57)	Kenawey 2011	53	57
	50(1/2)	Vitale 2006	2	2
	20 (8/41)	Thonse 2005	41	41
Premature consolidation	36.3 (4/11)	Kubiak 2007	9	11
	33.3 (1/3)	Pappanna 2011	3	3
	11.1 (1/9)	Kucukkaya 2011	9	9
	8.3 (1/12)	Mahboubian 2012	11	12
	7.01 (4/57)	Kenawey 2011	53	57
Non-union	33.3 (1/3)	Pappanna 2011	3	3
	11.1 (1/9)	Kucukkaya 2011	9	9
	8.3 (1/12)	Mahboubian 2012	11	12
	1.2 (3/210)	Burghardt 2011	180	242
Angular deformity	12.5 (2/16)	Wang and Edwards 2012	16	16
Joint contracture	3.5 (2/57)	Kenawey 2011	53	57
Hardware malfunction	10 (2/20)	Cole 2001	18	20
	6.06 (2/33)	Simpson 2009	30	33

	33.3 (1/3)	Pappanna 2011	3	3
	6.2 (1/16)	Wang and Edwards 2012	16	16
	8.3 (1/12)	Mahboubian 2012	11	12
	8.9 (6/69)	Schiedel 2011	69	69
	6.2 (15/210)	Burghardt 2011	180	242
Technique abandoned	33.3 (1/3)	Pappanna 2011	3	3
	33.3 (4/12)	Mahboubian 2012	11	12
	10.1 (7/69)	Schiedel 2011	69	69

^Non-distracting nails were defined as nails that fail to distract in situ despite increasing the activity level and manually rotating the lower extremities by the patients themselves or with assistance from family members.

Study 4 Young C (2017)

Study details

Study type	Systematic review
Country	Canada
Study period	Search period: January 2012 to November 2017 Databases searched: MEDLINE, The Cochrane Library, University of York Centre for Reviews and Dissemination (CRD) databases, Canadian and major international health technology agencies; a focused internet search was also done.
Study population and number	n=112 patients who had limb lengthening with the Precice IM limb lengthening system or alternative limb lengthening system (LRS external fixation system or ISKD) (3 NRS/retrospective reviews) 1. Szymczuk [2017, US]: n=62 patients with congenital femoral deficiency, with or without fibular hemimelia, who had femoral lengthening (30 Precice IM nail and 32 LRS monoliteral external fixation) 2. Hammouda [2017, US]: n=28 skeletally immature patients who had a reamed IM lengthening nail inserted through the greater trochanter (31 femurs, 13 in Precice group and 18 in ISKD group). 3. Laubscher [2016, UK]: 22 skeletally mature patients that had femoral lengthening procedures (33 femurs, 20 in Precice group and 13 in LRS external fixation group)
Age and gender	1. Szymczuk 2017: mean age 15.4 years in Precice group and 9.4 years in LRS external fixation group; 24 male and 38 female 2. Hammouda 2017: age 7 to 17 years; 17 male and 11 female 3. Laubscher 2016: age 15 to 57 years; 11 male and 11 female
Study selection criteria	Inclusion criteria: published studies (health technology assessments, systematic reviews, meta-analyses, RCTs, NRS, and guidelines), in humans, limited to English language; patients who have growth disturbances secondary to trauma or congenital abnormalities, post-traumatic growth arrests, congenital deformity, infection, bone loss, tumours, non-unions, or achondroplasia; correction of lower or upper limb deformities in adults and children with Precice IM limb lengthening system; reporting clinical benefit (e.g., rate of lengthening, overall lengthening, range of motion, gait, pain, functional ability) and Harms (e.g., femoral fissure, spontaneous bony section, transient palsy, pain, fracture, mechanical failure, poor bone formation, lengthening at an inappropriate rate, fat embolisation, deep vein thrombosis, respiratory distress syndrome, equinus ankle deformity). Exclusion criteria: duplicate publications, studies published before 2012, uncontrolled, single-arm trials were excluded.
Technique	Intervention: Precice magnetically motorised IM nail was used for femoral lengthening. Comparators: external fixation using the LRS (2 studies, Szymczuk [2017] and Laubscher [2016]). ISKD (Hammouda 2017).
Follow up	Varied across studies and between compactor groups.

	Szymczuk 2017: mean 86 years and 4.47 years for the Precice and the LRS external fixation groups Hamaoudda 2017: 1.9 years and 4.6 years for the Precice and ISKD groups Laubascher 2016: 14.7 months and 28.8 months for the Precice and LRS fixation groups
Conflict of interest/source of funding	No conflicts of interest were declared. Authors of 1 study (Hammouda 2017) declared financial support from device companies (Precice technologies, Ellipse technologies).

Analysis

Follow-up issues: length of follow up was varied and not consistent in the included studies and between treatment groups.

Study design issues: systematic review followed preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. comprehensive search was done; studies were screened and selected by 1 reviewer. Included studies had small sample sizes (ranging from 22 to 62 patients), lacked randomisation, patients were unblinded to treatments, and were critically appraised using the Downs and Black checklist. All 3 studies were retrospective comparisons and susceptible to bias. Confounding factors were not considered when comparisons were made and outcomes were analysed. Patient selection criteria, interventions, outcomes were explicitly described in included studies.

Study population issues: patient population and demographic characteristics were clearly stated but they were diverse (in terms of aetiology and age) between comparisons and studies. All studies considered patients having femoral lengthening only.

Key efficacy findings

- Number of patients analysed: 112

Hammouda 2017	**Outcomes**	**Precice (n=13 segments)**	**ISKD (n=18 segments)**	**P value**
	Mean lengthening achieved, cm (range)	5.6 (3-6.7)	5.2 (3.8-6.5)	0.35
Szymczuk 2017	**Outcomes**	**Precice (n=30)**	**LRS external fixation (n=32)**	**P value**
	Lengthening goal, cm (range)	4.97 ± 1.43	5.58 ± 1.82	0.15
	Lengthening goal achieved % (n)	87 (26/30)	88 (28/32)	NR
	Mean lengthening achieved, cm (range)	4.75 ± 1.40	5.55 ± 1.74	0.052
	Distraction index, mm/day (±SD)	0.7 ± 0.18	0.7 ± 0.17	0.99
	Consolidation index, cm/day (±SD)	34.77 ± 11.23	29.33 ± 12.68	0.08

	Range of motion degrees, (± SD)	Extension	Flexion	Extension	Flexion	P value
	Preoperative	0.8±3.1	127.7±22.9	0.47±2.18	123.3±12.2	0.35
	Post distraction	0.93 (± 3.3)	96.3 (± 28.2)	-0.6 (± 4.3)	69.9 (± 30.2)	0.0007
	Post consolidation	-0.4 (± 2.1)	121.5 (± 23.1)	0.74 (± 4.9)	81.3 (± 30.1)	< 0.0001
	Final follow up	-0.4 (± 2.0)	119.6 (± 16.5)	-0.7 (± 4.8)	120.2 (± 19.9)	0.90
Laubscher 2016	**Outcomes**	**Precice (n=20)**		**LRS external fixation (n=12)**		**P value**
	Planned lengthening achieved % (n)	100 (20/20)		92 (12/13)		NR
	Mean lengthening, mm (range)	51.4 (25-68)		59.7 (50-70)		NR
	Mean lengthening rate, mm (range)	0.93 (0.67-1.09)		0.83 (0.55-1.13)		NR
	Preservation of knee range of motion % (n)	100 (20/20)		92 (12/13)		NR
	Mean healing index, cm/day (range)	31.3 (21.1-43.0)		47.1 (34.4-67)		<0.001
	Mean time to full weight bearing, months (range)	3.6 (2-7)		4.8 (3-7)		0.02

Patient reported outcomes (measured by patient interviews), Laubscher 2016

Outcome	Precice (n=20)	LRS external fixation (n=13)	P value
Cosmetic appearance of scars, mean score* (range)	3.0 (1-5)	7.5 (6-10)	<0.001
Pain, mean VAS score (range)	during lengthening: 4.4 (1-7.5) during consolidation: 2.2 (1-6)	during lengthening: 8.1(5-10) during consolidation: 5.3 (3-7)	<0.001 <0.001
Ability to perform daily activities of living, n (%)	90 (18/20)	38 (5/13)	NR
Choose to have treatment again, n (%)	100 (20/20)	68 (9/13)	NR

*0 being best and 10 being worst

Key safety outcomes

Complications

Hammouda 2017	Precice (n=13 segments)	ISKD (n=18 segments)	P value

Complication rate % (n)	23 (3/13)		39 (7/18)		0.45
Szymczuk 2017	**Precice (n=30)**		**LRS external fixation (n=32)**		**P value**
Adverse events*	**Total events**	**Affected segments**	**Total events**	**Affected segments**	**P value**
Problems % (n)	25.8 (8)	23.3 (7)	55.2 (32)	62.5 (20)	<0.001
Obstacles % (n)	61.3 (19)	36.7 (11)	34.5 (20)	31.3 (10)	0.66
Complications % (n)	12.9 (4)	13.3 (4)	10.3 (6)	15.6 (5)	0.99
Total	31	60 (18)	58	81.3 (26)	0.07

*Authors classified adverse events as problems, obstacles, or complications.

Study 5 Frost MW 2021

Study details

Study type	Systematic review
Country	Denmark
Study period	Search done in 2019 and updated in March 2020. Databases searched: PubMed, EMBASE, and the Cochrane Library. Additional studies were identified from reference lists of included studies.
Study population and number	n=782 patients; 983 bone segments (813 femurs ([n 40 studies] and 170 tibiae [in 28 studies]) 41 studies (26 case series, 6 cohort studies, 1 case-control study and 8 case reports) Indications for lengthening (in accordance with the modified Stricker and Hunt classification): 208 with congenital shortening (in 22 studies), 305 with acquired limb shortening (in 29 studies), 111 with short stature (in 14 studies), 158 with unidentified aetiology.
Age and gender	Age range 8-74 years (in 39 studies) 384 were male (in 29 studies), 34 were female (in 33 studies) and 164 were unidentified.
Study selection criteria	Inclusion criteria: published studies (RCTs, prospective and retrospective cohort studies, case-control studies, case series, and case reports with less than 5 segments), conducted in humans in both English and German with no limit on publishing date; studies on bone lengthening (with FITBONE and/or PRECICE nails) on lower extremities, with descriptions of complications (origin, severity, and management) or a statement of no complications. Exclusion criteria: cross-sectional studies or different study designs, duplicate studies, other operation types (studies reporting bone transport treatment, nails used for compression), other indications (no involvement of lower extremities, stump lengthening), other nail types, insufficient description of complications.
Technique	Magnetically driven (PRECICE) and externally controlled motorised (FITBONE) IM nails were used for lower limb lengthening. 214 FITBONE nails (in 15 studies), 747 PRECICE nails (in 27 studies), 22 either FITBONE or PRECICE nails.
Follow up	Varied across studies.
Conflict of interest/source of funding	No conflicts of interest were declared. Study was funded by the authors' institution.

Analysis

Study design issues: systematic review was done according to meta-analysis of observational Studies in epidemiology (MOOSE) guidelines; comprehensive search was done and 2 reviewers independently reviewed, selected studies, evaluated and graded complications. Any disagreements were resolved by consensus. There were no standardised reporting methods in studies. Complications were assessed in relation to segments lengthened and according to origin (8 main groups and 33 sub-groups) and severity (graded according to

modified Black classification 2015 into 4 types) to achieve consistent reporting. Some complications that were not well described might have been downgraded. The Oxford Centre for Evidence-Based Medicine-Levels of Evidence 2009 grading of Harm was used to assess the level of evidence in the included studies. Studies were quality assessed using validated scores (MINORS and Murad et al) and the level of evidence was low. The primary outcome was the risk of type 3B complications resulting in a new pathology or permanent sequelae.

Study population issues: patient population and demographics were diverse.

Key safety findings

- Number of patients analysed: 782 (983 segments)

Complications (categorised **according to origin** (8 groups (soft tissue, joint, vascular, bone, neurological, infection, device-related, others) **and severity:** type 1 (minimal intervention); type 2 (substantial change in treatment); Type 3A (failure to achieve planned lengthening due to a complication); and Type 3B (resulted in new pathology or permanent sequelae).

14 complications could not be categorised due to missing descriptions.

	Severity				
	Grade 1	**Grade 2**	**Grade 3A**	**Grade 3B**	**Total**
Total number of complications, n	113	146	45	28	332
Complications per segment, %	11	15	5	3	34
Complications per segment using Precice nail %					31
Complications per segment using Fitbone nail %					46
Complications per patient, %	14	19	6	4	42
Groups					
Soft tissue, n					**13**
Skin	2	1			3
Pain	5				5
Others	2	1		2*	5
Soft tissue complications per segment %					1
Joint, n					**61**
Pain	1				1
Contracture	19	24	5	5	53
Subluxation				6	6
Dislocation				1	1
Joint complications % of segments					6
Vascular, n					**10**
Vascular damage				1	1
Deep vein thrombosis				4	4
Haemorrhage/haematoma	2				2
Others	2			1 AV^	3

IP overview: intramedullary distraction for lower limb lengthening

Vascular complications per segment %					1
Bone, n					**78**
Premature consolidation		15	4		19
Delayed healing	16	27	2	1	46
Secondary alignment		1		2	3
Fracture		6	1	1	8
Others	1	1			2
Bone complications per segment %					8
Neurology					8
Paraesthesia	2	2	1		5
Others	3				3
Neurology complications per segment %					0.8
Infection, n					**8**
Superficial soft tissue	2	1			3
Deep soft tissue		1			1
Osteomyelitis			3	1	4
Infection complications per segment %					0.8
Device related, n					**122**
Distraction mechanism	16	20	9		45
Mechanical strength	25	14	3	2	44
Attachment failure	8	24	1		33
Device related complications per segment %					12
Others, n					**18**
Patient (request to stop lengthening procedure)			6		6
Surgical (intra-articular nail placement causing irritation and residual deformity)		3	7	1	11
Others			1		1
Others, complications per segment %					1.8

*compartment syndrome

^ arteriovenous fistula of the posterior tibial artery decompensated during tibial lengthening and an embolisation procedure had to be performed.

6% (11/177) of complications occurred intraoperatively (n=5) or perioperatively (n=6) before the start of distraction, and 94% of complications (166/177) occurred during distraction (in 85 segments), or after the end of distraction (in 81 segments).

Subgroup analysis of complications was not possible between nail types due to low numbers. Authors state that studies with fewer than 20 patients had more complications per segment compared with studies with more than 40 patients.

Study 6 Fragomen AT (2018)

Study details

Study type	Retrospective cohort study
Country	USA
Recruitment period	LON (2005-9) Magnetic remote controlled IM nail (2012- 14)
Study population and number	n= 56 patients who had femoral or lower limb lengthening . (35 patients with IM nail lengthening (40 femurs) and 21 with LON technique (22 femurs) Indications for lengthening: • posttraumatic incident (malunion): 12 in IM nail group, 11 in LON group • congenital: 11 in IM nail group, 1 in LON group • metabolic: 4 in IM nail group, 2 in LON group • short stature: 7 in IM nail group, 3 in LON group.
Age and gender	IM nail group: mean 29.7 years; LON group: 32.4 years IM nail group: 78% (31/40) male; LON group: 90% (18/20) male
Study selection criteria	Inclusion criteria: Exclusion criteria: patients with active infection or irregular bone diameter or deformity that would prevent insertion of an IM device.
Technique	LON technique used an antegrade nailing method. First IM nail is inserted and external fixator (frame) is applied with pin insertion. Then at the end of lengthening phase, the nail is locked and the fixator is removed. Magnetically driven IM lengthening nail is done with a Precice nail. Both antegrade and retrograde nailing approaches are used. The ITB is released in these patients and also extended posteriorly to include the lateral intramuscular septum. All patients were given anticoagulants for 4 weeks. Physical therapy focused on ambulation with weight bearing restrictions. Weight bearing as tolerated was allowed for LON patients and for IM nail patients, it was dependent on the nail diameter. In both groups IM nails were removed after 1 year.
Follow up	LON group: minimum follow up was 13 months (average, 27 months; range, 13–38 months) IM nail group: 21 months (average, 31 months; range, 21–43 months).
Conflict of interest/source of funding	Authors declare that they have no conflicts of interest. Some authors received fees from the company outside the submitted work.

Analysis

Follow-up issues: 2 patients in the LON group (n=22) were lost to follow up 3 to 4 months after removal of the external frame and 1 patient in the IM nail group (n=35) was lost to follow up after postoperative visit.

Study design issues: study was conducted according to the strengthening the reporting of observational studies in epidemiology (STROBE) guidelines. Patients in the 2 cohorts were retrospectively identified from registry. All procedures were performed by 2 trained surgeons. Lengthening technique (osteotomy, IM canal reaming, and IM nail) were similar in both methods except the ITB release in the IM nail technique and external fixator in the LON group. Data were collected retrospectively from medical records and radiographs. Regenerate assessment was performed by only 1 observer.

Study population issues: patient population, demographics and pre-evaluation were similar between the groups but there were more patients with congenital femoral shortening in the IM nail group.

Key efficacy findings

- Number of patients analysed: 56
  59 limbs (39 IM nail group versus 20 LON group)

	IM nail group (39 limbs)	LON (20 limbs)	P value (between groups)
Pre-operative LLD (mm)	26.8±23.5	43.3±20.4	0.007
Femur length distracted (mm)	38.0±16.8	40.5±22.9	0.666
mean postoperative LLD^ (accuracy, mm)	0.3±1.6	3.6±7.0	0.007
Rate of distraction (mm/day)	1.0±00	0.8±0.2	<0.001
Bone healing index* (months/cm)	1.0±0.5	1.4±0.8	0.101
Time to union^^ (months)	3.3±1.0	4.5±1.7	0.001
Regenerate quality (measured with modified Li score)			
Homogenous, %	35±88	14±70	0.082
Heterogenous, %	5±12	4±20	0.565
Sparse	0	2±10	0.188

^ difference between desired length and final length.
^^ defined as the time at which there was bridging bone on 3 of 4 cortices on the AP and lateral femur radiographs.

* rate at which bone heals after lengthening.

Knee range of motion

	IM nail group (39 limbs)	LON (20 limbs)	P value (between groups)
Knee extension			
Pre-operative	0.4±2.8	-0.5±3.6	0.385
Distraction	1.8±5.4	2.7±4.4	0.481
Postoperative	0.5±1.6	0.9±5.7	0.739
P value (within group)	0.239	0.070	
Knee flexion			
Pre-operative	125.9±9.52	122.2±8.9	0.426
Distraction	103.3±25.2	88.8±20.0	0.006
Postoperative	122.6±14.9	119.2±11.5	0.464
P value (within group)	0.000	0.000	
Knee arc of motion			
Pre-operative	125.5±9.5	116.3±29.9	0.145
Distraction	101.5±26.9	80.0±30.7	0.002

Postoperative	122.0±16.0	111.9±30.8	0.112
P value (within group)	0.000	0.000	

Key safety findings

Complications

Complications	**IM nail group (39 limbs)**	**LON (20 limbs)**
Total	**18% (7/39)**	**45% (9/20) (p=0.027)**
Number of events	**n**	**n**
Delayed union	1	0
LLD (over-lengthening, treated by reversing the motor for 4 days)	1	1
Varus deformity of regenerate	2	1
IM nail fracture/breakage (changed nail)	1	0
Premature consolidation (1 with varus deformity)	2	0
Unplanned surgeries	5	4
Skin dehiscence (around pin site)	0	1
Excessive pain	0	3
Knee flexion contracture	0	1

Study 7 Thaller 2020

Study details

Study type	Retrospective matched comparative case series
Country	Germany
Recruitment period	1999-2011
Study population and number	n=34 patients who had femoral or lower limb lengthening with IM limb lengthening devices (ISKD®; Fitbone®). (17 patients with ISKD versus 17 with Fitbone) site: 4 proximal femoral, 7 distal femoral, and 6 proximal tibial
Age and gender	Age range 14-63 years; 11 male, 23 female
Study selection criteria	Inclusion criteria: patients in both groups meeting 5 criteria were matched. Criteria include similar surgical technique and pre and postoperative treatment protocol, site of osteotomy (proximal femur, distal femur or proximal tibia), simultaneous realignment of the mechanical axis, amount of lengthening (maximum variation 10%), age (maximum variation 20%). Exclusion criteria: subsequent lengthening of another bone, implant failure due to malpractice by the patient or accidental trauma, or nicotine abuse during lengthening.
Technique	Lower limb lengthening with IM limb lengthening devices (ISKD®; Fitbone®).
Follow up	Mean 2.5 years (range 1.3–7.0) years
Conflict of interest/source of funding	None, no financial support received.

Analysis

Study design issues: small, matched pair analysis; surgeries were all performed by 1 surgeon with the same technique and managed with equivalent pre and postoperative treatment protocols. Complications were rated according to Paley's classification for external lengthening.

Study population issues: aetiology was not included in the matching criteria.

Key efficacy findings

- Number of patients analysed: 34

	ISKD nail group (n=17)	Fitbone nail group (n=17)	P value (between groups)
Distraction index, mm/day (range)	0.99 (0.55-1.67)	0.55 (0.14-0.92)	0.001
Mean weight bearing index, day/cm	32 (16.4-64)	51.6 (25.8-95)	0.001

Differences between the 3 osteotomy sites independent from group 1 or 2 were not significant (p= 0.875).

There was only 1 ISKD patient who had a distraction index of more than 1.5 mm/day and none in the fitbone group.

Key safety findings

Complications

Complications	ISKD group (n=17)	Fitbone (n=17)
Implant related, n	**4^**	**11^^**
pain (treated with peridural catheter or analgesic)	3	
accelerated nail (treated with peridural catheter and had 3 additional blocking screws to increase the friction)	1	
early consolidation treated by re-osteotomy	2	
thrombosis of the popliteal vein	1	
Superficial wound infection	1	
Defect in external controller		1
Back tracking of the nail (distraction index<0.5mm/day)		7
Temporary peroneal nerve irritation	2	3
Periostitis		1
Equinus foot (treated with physiotherapy)	2	1
Loosening of interlocking bolts (retightening or exchanged)		3
Broken interlocking bolt	1	
insufficient regenerate by following cancellous bone grafting		2
osteophyte needing removal		1

^1 accelerated nail, 2 early consolidations, 1 broken bolt.

^^ 1 defect controller, 7 back tracking, 3 loosening of interlocking bolts.

Validity and generalisability of the studies

- Several IM limb lengthening devices with variation in techniques (mechanically activated nails, motorised nails, and magnetically driven nails) are used for distraction and stimulating lower limb lengthening and all these are considered in this review.

- There are no RCTs comparing the use of IM limb lengthening nails alone for lower-limb lengthening with current standard of care/conventional lengthening procedures (external fixation devices).

- 5 systematic reviews are included in this overview and evidence is mainly based on NRS, case series and case reports that are prone to a number of biases. NRS compared IM nail lengthening with LON or with external fixation. There were differences in the time of follow up and no standardised reporting methods were used in studies.

Existing assessments of this procedure

There were no published assessments from other organisations identified at the time of the literature search.

Related NICE guidance

There is currently no NICE guidance related to this procedure.

Additional information considered by IPAC

Professional experts' opinions

Expert advice was sought from consultants who have been nominated or ratified by their professional Society or Royal College. The advice received is their individual opinion and is not intended to represent the view of the society. The advice provided by professional experts, in the form of the completed questionnaires, is normally published in full on the NICE website during public consultation, except in circumstances but not limited to, where comments are considered voluminous, or publication would be unlawful or inappropriate. No

professional expert questionnaires for IM distraction for lower limb lengthening were submitted.

Patient commentators' opinions

NICE's Public Involvement Programme will send questionnaires to NHS trusts for distribution to patients who had the procedure (or their carers). When NICE has received the completed questionnaires, these will be discussed by the committee.

Company engagement

A structured information request was sent to 2 companies who manufacture a potentially relevant device for use in this procedure. NICE received 2 completed submissions. These was considered by the IP team and any relevant points have been taken into consideration when preparing this overview.

Issues for consideration by IPAC

- Lengthening of bones other than the tibia and femur is not considered in the overview.
- It is unclear from the evidence whether (and when) removal of device after lengthening and consolidation is recommended.
- One company representative informed that 'the ISKD system is older technology that they have decided to stop actively marketing and is very much superseded by FITBONE®'.
- Some of the other IM nails are also no longer available (Phenix nail, Albizzia nail, Bliskunov nail).

References

1. Brewster MBS, Mauffrey C, Lewis AC et al. (2010) Lower limb lengthening: is there a difference in the lengthening index and infection rates of lengthening with external fixators, external fixators with intramedullary nails or intramedullary nailing alone? A systematic review of the literature. European Journal of Orthopaedic Surgery and Traumatology, 20:103–108.
2. Xu WG (2017) Comparison of intramedullary nail versus conventional Ilizarov method for lower limb lengthening: a systematic review and meta-analysis. Orthopaedic Surgery; 9 (2):159-66.
3. Nageeb MA, Mohamed A, Muhammad AT et al. (2014) Is the intramedullary skeletal kinetic distractor a safe measure for bone lengthening? A systematic review. Journal of Orthopaedics, Trauma and Rehabilitation. 18, 69-79.
4. Young C and Adcock L (2017) PRECICE intramedullary limb lengthening system: a review of clinical effectiveness. Ottawa: CADTH. (CADTH rapid response report: summary with critical appraisal).
5. Frost MW, Rahbek O, Traerup J et al. (2021) Systematic review of complications with externally controlled motorized intramedullary bone lengthening nails (FITBONE and PRECICE) in 983 segments. Acta Orthopaedica; 92 (1): 119–126.
6. Fragomen AT, Kurtz AM, Barclay JR et al. (2018) A comparison of femoral lengthening methods favors the magnetic internal lengthening nail when compared with lengthening over a nail. HSSJ,14:166–176.
7. Thaller PH, Frankenberg F, Degen N, et al. (2020) Complications and effectiveness of intramedullary limb Lengthening: A Matched Pair Analysis of Two Different Lengthening Nails. Strategies Trauma and Limb Reconstruction;15 (1):7–12.

Literature search strategy

Databases	Date searched	Version/files
Cochrane Database of Systematic Reviews – CDSR (Cochrane Library)	14/04/2021	Issue 4 of 12, April 2021
Cochrane Central Database of Controlled Trials – CENTRAL (Cochrane Library)	14/04/2021	Issue 4 of 12, April 2021
International HTA database (INAHTA)	14/04/2021	-
MEDLINE (Ovid)	14/04/2021	1946 to April 13, 2021
MEDLINE In-Process (Ovid)	14/04/2021	1946 to April 13, 2021
MEDLINE Epubs ahead of print (Ovid)	14/04/2021	April 13, 2021
EMBASE (Ovid)	14/04/2021	1974 to 2021 April 13

Literature search strategy

The following search strategy was used to identify papers in MEDLINE. A similar strategy was used to identify papers in other databases.

1 orthopedic fixation devices/ or external fixators/
2 ((Intramedullar* or internal* or implant*) adj4 (lenghten* or distract*)).tw.
3 ISKD.tw.
4 intramedullary skeletal kinetic distractor.tw.
5 ((orthoped* or external*) adj4 fixat*).tw.
6 ilizarov technique/ or osteogenesis, distraction/
7 (albizia* or albizzia).tw.
8 or/1-7
9 Bone Malalignment/
10 Bone Lengthening/
11 or/9-10
12 exp Femur/
13 Tibia/
14 Femur*.tw.
15 Tibia*.tw.
16 femora.tw.
17 or/12-16
18 11 and 17
19 ((leg or lower limb or femora* or femur* or tibia*) adj4 (lengthen* or elongat*)).tw.
20 Leg Length Inequality/
21 leg lengt* inequal*.tw.
22 or/19-21
23 18 or 20
24 8 and 23
25 fitbone.tw.
26 illzarov.tw.
27 precice.tw.

28 or/25-27 (47)
29 24 or 28 (995)
30 Animals/ not Humans/
31 29 not 30
32 limit 31 to ed=20190801-20210430

Appendix

The following table outlines the studies that are considered potentially relevant to the IP overview but were not included in the summary of the key evidence. It is by no means an exhaustive list of potentially relevant studies.

Additional papers identified

Article	Number of patients/follow up	Direction of conclusions	Reasons for non-inclusion in summary of key evidence section
Acharya A, Guichet JM (2006) Effect on knee motion of gradual intramedullary femoral lengthening. Acta Orthop Belg 72, 569-577.	Case series N=27 patients had bilateral simultaneous femoral lengthening using Albizzia nails. Mean follow up was 28.6 months.	The mean gain was 6.2 cm. No significant difference was noted between the mean preoperative and final knee flexions (148.3° vs. 148.4°) and the mean preoperative and final knee extensions (2.3° vs. 3.4°). All patients were flexing to at least 120° and only 1 patient had a flexion deformity over 5°.	Larger studies included in the summary of key evidence.
Accadbled F, Pailhé R, Cavaignac E et al. (2016) Bone lengthening using the Fitbone motorized intramedullary nail: the first experience in France. Orthop Traumatol Surg Res; 102(2): 217-22.	Prospective case series N=23 patients had 26 limb lengthening (15 in femur and 11 in tibia) using IM limb lengthening systems (Fitbone and Precice) Mean follow up was 3.4 years (range: 2–5.3 years)	Limb lengthening obtained in 23 cases (88%) and the mean lengthening was 45.3 ± 18 mm (range: 20–80 mm). The mean time to healing was 277 ± 167 days (range: 86–638 days). The mean healing index was 73 ± 57 days/cm for the femurs and 83.5 ± 65 days/cm for the tibias. The	Study included in systematic review added to the summary of key evidence.

		mean complication rate was 15.4%.	
Al-Sayyad MJ. (2012) Lower limb lengthening and deformity correction using the Fitbone motorized nail system in the adolescent patient. J Pediatr Orthop Part B; 21(2): 131-6.	Prospective case series N=10 patients had leg lengthening with a motorised IM lengthening device (the Fitbone System) 9 femoral nails and 5 tibial nails	leg lengthening combined with correction of the mechanical axis alignment seen in 3 patients. The consolidation index was 24 days/cm. No bone or soft tissue infections noted. 1 patient had irritation and pain from the antenna system after lengthening and recovered after antenna removal.	Study included in systematic review added to the summary of key evidence.
Burghardt RD, Herzenberg JE, Specht SC, et al. (2021) Mechanical failure of the Intramedullary Skeletal Kinetic Distractor in limb lengthening. J Bone Joint Surg Br; 93:639e43.	Case series (retrospective) n=180 patients (had 242 lower-limb segments using the ISKD.	15 ISKDs in 12 patients (13 limbs) failed mechanically (overall failure rate of 6.2%), with device fracture in 10/15 failures. 2 nails in 1 patient failed to lengthen and had to be replaced. The manufacturer detected an error in the assembly of the nail, which prompted a wide recall. 1 nail jammed after being forcefully inserted, and 2 nails failed to lengthen fully. Lengthening was achieved in all 12 patients, although 3 needed a second operation to exchange a defective nail for a new, functioning device.	Study included in systematic review added to the summary of key evidence.
Bafor A, Duncan ME, Iobst CA. (2020)	Retrospective case series	The pixel value ratio is a reliable method	More relevant studies

Evaluating the utility of the Pixel value ratio in the determination of time to full weight-bearing in patients undergoing intramedullary limb lengthening. Strategies Trauma Limb Reconstr;15(2):74–78.	N= 42 patients had unilateral lengthening of the femur for LLD using the PRECICE nail. Follow up ranged from 4 to 35 months.	to objectively assess the state of healing of the regenerate bone during distraction osteogenesis. There were no adverse effects when subjects commenced full weight-bearing when 3/4 cortices had a PVR of at least 0.93.	included in the summary of key evidence.
Burghardt RD, Paley D, Specht SC et al. (2012) The effect on mechanical axis deviation of femoral lengthening with an intramedullary telescopic nail. J Bone Joint Surg Br; 94 (9): 1241–5.	Case series (retrospective) N=24 patients (27 femoral lengthening using the ISKD)	The mean lengthening achieved was 4.4 cm (1.5 to 8.0). In 26 of 27 limbs, the mechanical axis shifted laterally by a mean of 1.0 mm/cm of lengthening (0 to 3.5). In one femur that was initially in varus, a 3 mm medial shift occurred during a lengthening of 2.2 cm	Larger studies included in the summary of key evidence.
Calder PR, McKay JE, Timms AJ et al. (2019) Femoral lengthening using the Precice intramedullary limb-lengthening system. Bone Joint J; 101-B (9): 1168-76.	Case series (retrospective) N=92 (107 femoral lengthening operations (73 antegrade nails and 34 retrograde nails inserted.	This study confirms excellent results in femoral lengthening with antegrade and retrograde Precice nails. There is a trend for better healing and less restriction in hip and knee movement following antegrade nails. Minor implant complications included locking bolt migration, deformity of the nail u(in 1),delayed union (in 3),	Study included in systematic review added to the summary of key evidence.

		surgical intervention for joint contracture (in 5).	
Cosic F, Edwards E. (2020) PRECICE intramedullary nail in the treatment of adult leg length discrepancy. Injury 51,1091–1096.	Case series N=21 patients had lengthening with PRECICE IM nail (17 femoral and 4 tibial) . Mean follow up 15.1 months.	All patients achieved correct lengthening (mean gain 36.5 mm). All patients consolidated their regenerate bone (mean 268 days). Mean femoral consolidation index was 6.5, mean tibial consolidation index was 16.1 (p=0.002). 6 patients had delayed consolidation of regenerate bone. 19%(4/21) patients suffered a complication, with 1 implant failure.	Study included in systematic review added to the summary of key evidence.
Dinçyürek H, Kocaoğlu M, Eralp IL et al. (2012) Functional results of lower extremity lengthening by motorized intramedullary nails. Acta Orthop Traumatol Turc; 46(1): 42-9.	Case series N=14 patients (11 femoral and 4 tibiae) had limb lengthening using motorised IM femoral nails (Fitbone). Mean follow up was 33.5 (range: 7 to 88) months.	Functional scores were excellent for 12 patients. Complications such as dysfunction of the distraction mechanism in 2, restricted transient knee motion in 4, and delayed consolidation in 4 were noted. Other complications included valgus deformities and superficial infections surrounding the antenna of the IM nail, as well as femur fractures at the proximal end of the nail.	Study included in systematic review added to the summary of key evidence.
Fragomen AT, Rozbruch R. (2017) Retrograde magnetic	Review	The phenomenal bone healing ability for the retrograde	Review

internal lengthening nail for acute femoral deformity correction and limb lengthening. Expert review of medical devices, 4 (10): 811–820.		Precice nail after femoral osteotomy for lengthening, even after acute deformity correction, is recognised. The few failures that have occurred appear to be attributable to excessive loading of the femur and implant during a vulnerable time of bone healing. Further studies with more uniform outcome criteria need to be conducted to better standardise user's experiences. The higher 1-time cost of the implant is offset by the reduced number of surgeries needed when compared with the gold standard of lengthening-over-nail-technique, and patients return to work sooner due to the ability to wear normal clothing and the reduction in pain throughout the entire lengthening process.	
Fragomen AT, Rozbruch R. (2016) Lengthening of the femur with a remote-controlled magnetic intramedullary nail-retrograde technique. JBJS Essential Surgical Techniques, 6(2): e20(1-15).	Surgical technique is described.	retrograde approach is used for special occasions.	Surgical technique.

Gigi, R., Hemo, Y., Danino, B. et al. (2021) Changes in the femoral osteotomy level coefcient and neck shaft angle during limb lengthening with an intramedullary magnetic nail. Archives of orthopaedic and trauma Surgery, doi: 10.1007/s00402-020-03740-9. Online ahead of print.	Case series (retrospective) n= 30 patients with 31 femoral lengthening procedures with the PRECICE antegrade IM lengthening nail. Trochanteric entry points were used in 24 femurs, and piriformis entry points in 7 femurs. Average follow up was 10.15 months.	The osteotomy level co-efficient (OLC) ranged from 0.16 to 0.34. The average postoperative neck shaft angle (NSA) significantly reduced from 133.5º to 128.5º p=0.000]. There was no correlation between the OLC and the change in the NSAs. The trochanteric entry points have a greater tendency to reduce the NSA compared to the piriformis entry points.	More relevant studies added to the summary of key evidence.
Hammouda AI, Jauregui JJ, Gesheff MG et al. (2017) Treatment of post-traumatic femoral discrepancy with PRECICE magnetic-powered intramedullary lengthening nails. J Orthop Trauma; 31(7): 369-74.	Case series (retrospective) N=17 patients with post-traumatic femoral shortening had femurs lengthened with Precice nail. Mean follow up was 2.2 years	16patients achieved the planned lengthening, a mean of 3.8 cm. Regenerate consolidation occurred at a mean of 119 days The mean consolidation index was 32 d/cm. 3 patients (18%) experienced complications.	Study included in systematic review added to the summary of key evidence.
Hidden KA, Dahl MT, Ly TV. (2020) Management of a Broken PRECICE Femoral Nail at an Ununited Distraction Osteogenesis Site. A Case Report. JBJS The Journal of Bone and Joint Surgery, Case Connect;10:e0267	Case report A 20-year-old man with a right lower extremity fibular hemimelia treated with PRECICE femoral nail lengthening presented with a broken magnetic nail and a displaced fracture through an ununited distraction osteogenesis site.	Using a combination of techniques, the broken implant was removed while maintaining the achieved limb length and preserving the native biology without bone grafting.	Implant removal reported in studies included in the summary of key evidence.

Havitcioglu H, Gursan O, Isin Y. (2020) Cosmetic bilateral leg lengthening using intramedullary nail experience of 9 cases. J Orthop; 20: 232-5.	Retrospective case series N=9 patients with short stature had IM nail lengthening for cosmetic purposes (16 femoral and 2 tibial segments) Mean follow up was 22 ± 11 months	The mean lengthening gained in all was 8.7 cm; healing index with normal bone healing was 46.8 ± 16 months/ cm. Complications included insufficient bone regeneration (n = 2), quadriceps contracture (n = 1), proximal locking screw runaway (n = 1).	Study included in systematic review added to the summary of key evidence.
Hawi N, Kenawey M, Panzica M et al. (2015) Nail–medullary canal ratio affects mechanical axis deviation during femoral lengthening with an intramedullary distractor. Injury, 46: 2258–2262.	Retrospective case series N=20 patients had unilateral femoral-lengthening procedures using IM distractors. Analysed pretreatment and posttreatment radiographs.	Compared to the preoperative axis, the mechanical axis shifted medially in 7 patients (varisation group) and laterally in 13 patients (valgisation group). The nail–medullary canal ratio significantly differed between groups ($p < 0.001$), being <85% in the varisation group and >85% in the valgisation group. The nail–medullary canal ratio should be considered during preoperative planning.	More comprehensive studies included in the summary of key evidence.
Horn J, Grimsrud Ø, Dagsgard AH et al. (2015) Femoral lengthening with a motorized intramedullary nail: a matched-pair comparison with external ring fixator lengthening in 30 cases.	Case control study N=30 femoral lengthening (15 with a motorised IM nail (Fitbone) compared with 15 lengthening with an external ring fixation.	Mean lengthening was 35 mm in the nail group and 38 mm in the fixator group. The mean radiographic consolidation index in the Fitbone group, at 1.5 months/cm, was better than the mean value for the	Study included in systematic review added to the summary of key evidence.

Acta Orthop; 86(2): 248-56.		fixator group 1.9 months/cm (p=0.01). Knee ROM was better in the nail group during the lengthening, after 6 weeks, and 6 months (p<0.001). A larger number of complications were seeb in the fixator group than in the nail group.	
Horn J, Hvid I, Huhnstock S et al. (2019) Limb lengthening and deformity correction with externally controlled motorized intramedullary nails: evaluation of 50 consecutive lengthenings. Acta Orthop; 90(1): 81-7.	Retrospective case series N=47 patients (50 lengthenings -34 Precice and 16 Fitbone devices) ≥ 12 months follow up.	Lengthening was achieved in all but 2 patients. 5 patients who had simultaneous axial correction showed minor residual deformity. The consolidation index was 1.2 months/cm in the femur and 2.5 months/ cm in the tibia. 2 femoral fractures occurred in retrograde femoral lengthenings after consolidation due to substantial trauma. There were 8 complications, all correctable by surgery.	Study included in systematic review added to the summary of key evidence.
Iliadis AD, Palloni V, Wright J et al. (2021) Pediatric lower limb lengthening using the PRECICE nail: our experience with 50 cases. J Pediatr Orthop; 41: e44–e49.	Retrospective case series n= 42 paediatric and adolescent patients treated with IM lengthening for lower LLD using the PRECICE and STRYDE IML nails (50 procedures, 43 femoral and 7 tibial nails).	Mean achieved lengthening was 46.5 mm. Mean percentage lengthening was 12.6%. Nail accuracy was 96% and reliability 90%. Average distraction rate was 0.92 mm/d for femur and 0.64 mm/d for tibias. Consolidation index	More comprehensive studies included in the summary of key evidence.

		was 28 d/cm and 39 d/cm, respectively. Time from completion of lengthening to independent full weight-bearing was 45 days and 34.2 days, respectively. Bone and functional scores were favourable and PROMS demonstrated high patient satisfaction. No significant complications were seen.	
Karakoyun O, Sokucu S, Erol MF et al. (2016) Use of a magnetic bone nail for lengthening of the femur and tibia. J Orthop Surg; 24(3): 374-8.	Case series (retrospective) N=23 patients with trauma and other reasons had limb lengthening with 27 precice nails (femur 21, tibia 6) Mean follow up was 20.72 months.	The mean lengthening was 48.20 mm, and the mean acute angular correction was 15.5º. The mean time to full weight-bearing was 5.15 months, and the mean consolidation index was 1.12 months/cm. The mean maturation index was 0.78 months/cm. 1 patient had nail breakage during the consolidation phase. The nail was replaced, 8 patients had over-lengthening and the nails were driven back to the desired length.	Study included in systematic review added to the summary of key evidence.
Karakoyun Ö, Küçükkaya M, Erol MF. (2015) Does lengthening after acute correction negatively affect bone healing during distraction	Case series (retrospective) Group 1 (9 patients, 9 femora) had lengthening IM distraction	Acute correction had no negative effect on bone healing after distraction osteogenesis using new-generation IM distraction devices.	Study included in systematic review added to the summary of key evidence.

osteogenesis? Acta Orthop Traumatol Turc; 49(4): 405-9.	devices after acute correction. Group 2 (13 patients, 16 femora) had lengthening using IM distraction devices. Group 3 (12 patients,13 femora) had lengthening ≥4 cm with lengthening and the retrograde nailing method (LORN) following acute correction.	We suggest that the negative impact on healing and the prolonged consolidation index in patients having LORN may be due to impaired periosteal blood supply due to fixator pins.	
Kenawey M, Krettek C, Liodakis E et al. (2011) Insufficient bone regenerate after intramedullary femoral lengthening: risk factors and classification system. Clin Orthop Relat Res; 469:264e73.	Case series N= 35 patients (with 37 ISKD femoral lengthening procedures) Follow up 12 months	The average length gain was 42.8 ± 12.9 mm. Distraction problems with the ISKD were related mostly to internal malfunction of the lengthening mechanism (in 8). A distraction rate greater than 1.5 mm/day should be avoided in femoral IM lengthening. Smoking should be a contraindication for femoral lengthening.	Larger studies included in the summary of key evidence.
Kenawey M, Krettek C, Liodakis E et al. (2011) Leg lengthening using intramedullary skeletal kinetic distractor: results of 57 consecutive applications. Injury; 42:150e5	Case series N=53 patients (femoral = 45 and tibial = 12) had lengthening procedures using ISKD nail. Mean follow up was 23±12 months.	Emphasises the rule of distraction rates above 1.5 mm/day in the development of insufficient bone regenerate. Distraction problems with these nails are due to dysfunction within the ratcheting mechanism, which may be related to the diameter of the nail. New designs for mechanically	Study included in systematic review added to the summary of key evidence.

		activated nails with a better control mechanism for the distraction rate are needed.	
Kirane YM, Fragomen AT, Rozbruch SR. (2014) Precision of the PRECICE internal bone lengthening nail. Clin Orthop Relat Res; 472 (12): 3869-78.	Case series (retrospective) N=24 patients had femoral and/or tibial lengthening procedures using the PRECIC nail for varied aetiology. Mean14 follow up was weeks	Mean total lengthening was 35 mm with an accuracy of 96% and precision of 86%. All patients achieved target lengthening with minimal unintentional effects on bone alignment. The knee and ankle ROM were minimally affected. Implant failure by a non-functional distraction mechanism in 1, premature consolidation in 1 patient, delayed bone healing in 2, delayed equinus contracture in 2 and toe clawing in 1 were reported.	Study included in systematic review added to the summary of key evidence.
Krieg AH, Speth BM, Foster BK. (2008) Leg lengthening with a motorized nail in adolescents: an alternative to external fixators? Clin Orthop Relat Res; 466(1): 189-97.	Case series (prospective) N=8 had leg lengthening with a motorised IM lengthening device (Fitbone).	In 6 patients, leg lengthening was combined with successful correction of the mechanical axis alignment. The consolidation index averaged 26 days/cm. No bone or soft tissue infections were seen.	Study included in systematic review added to the summary of key evidence.
Krieg AH, Lenze U, Speth BM (2011). Intramedullary leg lengthening with a motorized nail: indications, challenges, and outcome in 32	Case series (retrospective) N=32 had limb lengthening with IM motorised nail (fitbone) -femur 21, tibia 11	Leg lengthening was successful in 30/32 cases. No intraoperative complications were seen. The consolidation index was significantly	Study included in systematic review added to the summary of key evidence.

patients. Acta Orthop; 82(3): 344-50.		different (p=0.04) between femoral lengthening (mean 35 days/cm) and tibial lengthening (mean 48 days/cm). 10 complications noted and 4 were implant-associated.	
Küçükkaya M, Karakoyun Ö, Sökücü S et al. (2015) Femoral lengthening and deformity correction using the Fitbone motorized lengthening nail. J Orthop Sci; 20(1): 149-54.	Case series (retrospective) N=22 patients with femoral shortening and deformity (had 25 Fitbone lengthening nail). Follow up was 30.8 months.	The mean lengthening was 5.8 (range 2–14) cm. The degree of acute angular correction was 9° (5–22°) in 9 cases. The time to full weight-bearing was 5.9 months. The consolidation index was 1.07 (0.75–1.62) months/cm. Complete consolidation was obtained in all cases except 2.	Study included in systematic review added to the summary of key evidence.
Karakoyun O, Kucukkaya M, Sokucu S (2014). Intramedullary skeletal kinetic distractor in lower extremity lengthening. Acta Orthop Traumatol Turc; 48 (3): 307-312.	Case series N=12 patients (10 femoral and 2 tibial lengthening with ISKD)	IM extensible nails decrease the risk of joint contractures and infection. This procedure can be well tolerated by the patients and they can return to their daily activities earlier.	Larger studies included in the summary of key evidence.
Kariksiz M, Karakoyun O. (2019) Limb lengthening with one Precice nail over its capacity. Saudi Med J; 40(10): 1058-62.	Case report N=37-year-old patient with a 14 cm LLD was treated with a Precice nail.	This surgical technique can be used safely and satisfactorily in cases with more shortness as we can correct the extremity length discrepancy using only 1 nail.	Study included in systematic review added to the summary of key evidence.
Laubscher M, Mitchell C, Timms A et al. (2016) Outcomes following femoral	Case series (retrospective)	Femoral lengthening with the Precice femoral nail achieved excellent	Study included in systematic review and CADTH report

lengthening: an initial comparison of the Precice intramedullary lengthening nail and the LRS external fixator monorail system. Bone Joint J; 98-B(10): 1382-8.	N=22 patients had femoral lengthening (15 precice lengthening nail versus 7 patients, 13 LRS external fixator system)	functional results with fewer complications and greater patient satisfaction when compared to LRS external fixation.	added to the summary of key evidence.
Lee HD, Ryu KJ, Song HR et al. (2014) Complications of the Intramedullary Skeletal Kinetic Distractor (ISKD) in Distraction Osteogenesis. Clin Orthop Relat Res, 472: 3852–3859.	Case series N=19 patients (35 lengthening segments-(26 femurs, 9 tibias) ISKD Follow up was 15 months (mean, 26 months; range, 15–38 months) after first-stage surgery.	Rate control was not achieved with the ISKD nail for femoral and tibial lengthenings, complications were relatively common, and among these patients, pain levels were high. Complications occurred in 10 patients (53%) with decreased ankle ROM during distraction, 4 with delayed bone healing, and 1 with mechanical device failure during distraction. Based on our findings, we believe that surgeons should avoid use of this nail.	Larger studies included in the summary of key evidence.
Lee DH, Kim S, Lee JW et al. (2017) A comparison of the device-related complications of intramedullary lengthening nails using a new classification system. Biomed Res Int. 2017:8032510	115 segments of lower limb lengthening using IM lengthening nails (35 ISKD, 34 PRECICE1, and 46 PRECICE2)	Most common complications were distraction mechanism issues (type 1) in ISKD and mechanical strength related ones (type 2) in PRECICE1 and PRECICE2. Sixty percent (21/35) of ISKD had device-related problems. In PRECICE1 group, 8.8% (3/34) had	Study included in systematic review added to the summary of key evidence.

		device-related problems, and 8.8% (3/34) showed device-related obstacle. In PRECICE2, 44% (20/46) had device-related problems.	
Lecoanet P, Legallois Y, Ribes C et al. (2020) Medium-term evaluation of leg lengthening by ISKD® intramedullary nail in 28 patients: Should we still use this lengthening system? Orthopaedics & Traumatology: Surgery & Research 106, 1433–1440	Case series (retrospective) N=28 patients with limb-lengthening by ISKD nails (24 femoral and 4 tibial). Mean follow up was 75 months.	Lengthening was achieved in 79% of cases, for a mean lengthening of 34.5 mm. Mean lengthening and consolidation indices were respectively 0.94 mm/day and 105 days/cm. Length discrepancy showed significant correction, with improvement in functional scores ($p < 0.01$). The overall complications rate was 68%, 76% of which were specific to the ISKD® nail.	Larger studies included in the summary of key evidence.
Mahboubian S, Seah M, Fragomen AT, et al. (2012) Femoral lengthening with lengthening over a nail has fewer complications than intramedullary skeletal kinetic distraction. Clin Orthop Relat Res; 470: 1221e31.	Case series (retrospective) N=11 patients had 12 ISKD procedures 21 patients had LON procedures (22 femoral lengthenings) ISKD average follow up was 76 months (range, 62–93 months) Lengthening over nail (average 27 months; range, 13–38 months).	No difference in achieving the lengthening goals between the 2 procedures. LON technique for femoral lengthening is associated with fewer complications than the ISKD.	Study included in systematic review added to the summary of key evidence.
Mazeau P, Assi C, Louahem D et al. (2012)	Case series	Bone consolidation was achieved faster	More comprehensive

Complications of Albizzia femoral lengthening nail: an analysis of 36 cases. Journal of Pediatric Orthopaedics B, 21:394–399.	N=36 patients with femoral lengthening using the Albizzia nail for various indications. Follow up average was 5.8 years.	than with external fixation. The patient's comfort during lengthening as well as the speed of functional restoration also improved. In 3 cases, the program failed, in 6 the lengthening was achieved with a second procedure, and 8 patients needed 1 ratcheting or more under general anaesthesia.	studies included in the summary of key evidence.
Morrison T, Sontich J.(2016) Premature consolidation with resultant implant failure using PRECICE femoral nail lengthening. JBJS Case Connect; 6(2): E2.	Case report describes a failure to lengthen with the PRECICE femoral nail and the subsequent steps taken to determine the root cause.	This failure represents the first reported case of malfunction of the PRECICE femoral nail distraction mechanism since its 2013 redesign.	Study included in systematic review added to the summary of key evidence.
Nasto LA, Coppa V, Riganti S et al. (2020) Clinical results and complication rates of lower limb lengthening in paediatric patients using the PRECICE 2 intramedullary magnetic nail: a multicentre study. J Pediatr Orthop B; 29, 6: 611-617.	Retrospective case series N=26 patients had limb lengthening using the Precice 2 system Follow up was more than 6 months.	average achieved lengthening was 44.4 ± 11.6mm. Average distraction and consolidation indexes were 11.9 ± 2.1 days/cm and 25.1 ± 8.1 days/cm, respectively. Nail accuracy and reliability were 91.1% , 88.5%, respectively. 5 joint contractures, 1 femur fracture and 1hip joint subluxation, 1 deep infection and 1 nail running back) were reported.	Study included in systematic review added to the summary of key evidence.
Paley D, Harris M, Debiparshad K et al.	Retrospective case series	Successful lengthening was	Study included in systematic

(2014) Limb lengthening by implantable limb lengthening devices. Tech Orthop; 29 (2): 72-85.	N=48 patients had treatment of LLD (unilateral) and short stature (bilateral) with Precice nails (n=65) at different locations .	achieved in all patients. There were numerous distraction and hardware complications. Despite these, implantable limb lengthening appears to be the direction for the future.	review added to the summary of key evidence.
Paley D, Debiparshad K, Balci H et al. (2015) Stature lengthening using the precice intramedullary lengthening nail. Tech Orthop; 30 (3): 167-82.	Retrospective case series N=51 patients 116 bone segments lengthened using Precice nails (P1 and P2).	All patients consolidated the distraction gap of the femurs and/or tibias without additional surgery. All returned to previous activities including sports. There were 7/58 (12.1%) implant failures for P1 and 1/58 (1.7%) for P2. The P2 had the lowest complication rate with the best overall reported results.	Study included in systematic review added to the summary of key evidence.
Pappana M, Monga P, Wilkes R. (2011) Promises and difficulties with the use of femoral intra-medullary lengthening nails to treat limb length discrepancies. Acta Orthop Belg, 77, 788-794.	Case series N=8 femoral lengthening procedures performed in adults using intra-medullary lengthening nails (Albizzia nails 5, ISKD 3). Average follow up was 26.5 months	Target lengthening was achieved in 6/8 femurs with an average of 38.77 mm length gained. The distraction index (length gained per day) was 0.58 on average and the consolidation index average was 5039 days/cm. Premature consolidation was noted in 4 cases, runaway acute lengthening in 1 patient; prominent metalwork in 4 patients and a bent nail were frequent obstacles.	Larger studies included in the summary of key evidence.

Paley D (2015) PRECICE intramedullary limb lengthening system. Expert Rev. Med. Devices 12(3), 231–249.	Review	PRECICE IM limb lengthening system reported and published results in over 250 cases has been excellent with less pain and lower complication rates than with external fixation methods or previous implantable nail systems.	Review
Richardson SS, Schairer WW, Fragomen AD et al. (2019) Cost comparison of femoral distraction osteogenesis with external lengthening over a nail versus internal magnetic lengthening nail. Journal of the American Academy of Orthopaedic Surgeons. 27, 9: e430-436.	retrospective review comparing femoral lengthenings using either LON (n = 19) or MLN (n = 39).	No difference was seen in the length of femoral distraction. Patients treated with MLN had fewer surgeries (3.1 versus 2.1; P , 0.001) and had a shorter time to union (136.7 versus 100.2 days; p=0.001). Total costs were similar ($50,255 versus $44,449; p=0.482), although surgeon fees were lower for MLN ($4,324 versus $2,769; p=0.001).	Costs out of remit
Rozbruch R, Fragomen AT (2016) Lengthening of the femur with a remote-controlled magnetic intramedullary nail- antegrade technique. JBJS Essential Surgical Techniques, 6(1): e2(1-11).	Surgical technique described.	antegrade technique is the first choice for lengthening.	Surgical technique.
Schiedel FM, Pip S, Wacker S, et al. (2011) Intramedullary limb lengthening with the Intramedullary Skeletal Kinetic Distractor in the	69 unilateral ISKD lengthenings (58 femora and 11 tibiae).	Successful femoral lengthening was achieved in 52 of the 58 patients (90%). However, successful tibial lengthening was only achieved in	Study included in systematic review added to the summary of key evidence.

lower limb. J Bone Joint Surg Br; 93:788e92.	Mean follow up was 16 months (6-49)	5 of 11 patients (45%).	
Schiedel F M, Vogt B, Tretow HL et al. (2014) How precise is the PRECICE compared to the ISKD in intramedullary limb lengthening? Reliability and safety in 26 procedures. Acta Orthop; 85 (3): 293-8.	Prospective case series N=24 patients with PRECICE IM limb lengthening system (26 procedures)	24/26 nails obtained 37 mm lengthening. There were 2 nail breakages, 1 in the welding seam and 1 because of a fall that occurred during consolidation. 15 cases had implant-associated problems, 5 had obstacles and 4 had complications.	Study included in systematic review added to the summary of key evidence.
Simpson AH, Shalaby H, Keenan G (2009). Femoral lengthening with the Intramedullary Skeletal Kinetic Distractor. J Bone Joint Surg Br; 91:955e61.	Case series N=30 (33 femoral lengthening with ISKDs)	Lengthening was achieved in 32/33 limbs. Problems encountered included difficulty in achieving length in 8 femora (24%) and uncontrolled lengthening in 7(21%).	Study included in systematic review added to the summary of key evidence.
Shabtai L, Specht SC, Standard SC et al. (2014) Internal lengthening device for congenital femoral deficiency and fibular hemimelia. Clin Orthop Relat Res; 472 (12): 3860-8.	Case series (prospective) N=18 patients with congenital limb shortening (21 bone segments lengthened using Precice nails) Mean follow up was 14 months	satisfactory joint motion during treatment in most patients. Lengthening was achieved in an accurate, controlled manner, and all patients reached their goal length. Complications remain a concern, as is the case with all approaches to this complex patient population. Both future comparative studies and longer-term follow up are needed.	Study included in systematic review added to the summary of key evidence.
Singh S, Lahiri A, Iqbal M (2006) The results of	Retrospective case series	Mean length increase 40 mm	Study included in systematic

limb lengthening by callus distraction using an extending intramedullary nail (Fitbone) in non-traumatic disorders. J Bone Jt Surg, Br 88 (7): 938–942	N=22 motorised IMN (Fitbone) Femoral and tibial lengthenings were performed with no angulation corrections. Follow up was 36 months (range 12–48).	(range 27-60). Median LI 28 days/cm (range 18.8 -70.9). infection rates 0%	review added to the summary of key evidence.
Szymczuk VL, Hammouda AI, Gesheff MG et al. (2019) Lengthening with monoliteral external fixation versus magnetically motorized intramedullary nail in congenital femoral deficiency. J Pediatr Orthop; 39: 458–465.	Retrospective non-randomised comparative study N=62 (30 in PRECICE group and 32 in LRS external fixation group) Mean follow up was 4.47± 2.7 and 1.86± 0.7 years.	Mean lengthening achieved was 5.6± 1.7 and 4.8 ± 1.4 cm for group A and group B, respectively (p=0.052). Mean distraction index was 0.7± 0.2 mm/d for group A and 0.7 ± 0.2 mm/d for the group B (p=0.99). Mean consolidation index for group A was 29.3± 12.7 and 34.8± 11.2 d/cm for group B (p=0.08). Mean arc of motion before surgery and at final follow up were similar between groups (p=0.35). Group A had significantly less range of motion at the end of distraction (p=0.0007) and at consolidation (P < 0.0001). Both groups had similar rates of obstacles and complications. A significant difference between groups was found in the total problems (P < 0.001) specifically with pin site/superficial	Study included in CADTH review added to the summary of key evidence.

		infection (P < 0.0001).	
Tiefenboeck TM, Zak L, Bukaty A et al. (2016) Pitfalls in automatic limb lengthening: first results with an intramedullary lengthening device. Orthop Traumatol Surg Res; 102 (7): 851-5.	Retrospective case series N=10 patients with LLD of lower extremity, treated with an Ellipse PRECICE® nail (6 tibia, 4 femur). Mean follow up was 18 months	In all patients, limb lengthening goals were reached within a range of ± 0.5 cm after a mean time of 53 days. In 2 patients, mechanical failures with unintended shortening were seen. In a further patient, nail breakage occurred. Overall, 7 patients presented with complications.	Study included in systematic review added to the summary of key evidence.
Thaller PH, Furmetz J, Wolf F et al. (2014) Limb lengthening with fully implantable magnetically actuated mechanical nails (PHENIX1)— Preliminary results. Injury, 45S, S60–S65.	N=10 patients had 6 femoral and 4 tibial procedures with Phenix M21 bone lengthening nail.	The intended distraction goal was achieved in 8/10 patients. In simultaneously malalignment was corrected. Average lengthening was 4.6 cm, average distraction index was 0.85 mm/day Average weight bearing index was 27 days/cm. 3 patients had revisions due to early distraction arrest.	Larger studies included in the summary of key evidence.
Tiefenboeck TM, Wozasek GE. (2015) Unusual complication with an intramedullary lengthening device 15 months after implantation. Injury, 46, 2069–2072	Case report N=1 An IM lengthening device (PRECICE1 P1 nail) was implanted in a 74 year old male patient with a congenital leg	After bone lengthening of 6 cm and obvious radiological callus formation a nail breakage with severe deformity occurred 15 months after implantation.	Adverse event reported in papers included in the summary of key evidence.

	length discrepancy.		
Tomaszewski R, Wikor L, Kler J et al. (2020) Results of femoral elongation treatment using electromagnetic intramedullary nail. Preliminary report. Ortopedia Traumatologia Rehabilitacja, 3 (6), 22, 173-179.	Case series N=5 adolescent patients treated for lower limb discrepancy by femoral lengthening using Precice IM nail.	Femoral lengthening was successful in all patients. Femur was lengthened by a mean 49mm , a knee flexion contracture of 10 degrees occurred in 1 patient.	Larger studies included in the summary of key evidence.
Vogt B, Roedl R, Gosheger G et al. (2020) Tibial lengthening using a retrograde magnetically driven intramedullary lengthening device in 10 patients with preexisting ankle and hindfoot fusion. Acta Orthopaedica; 91 (6): 761–769	Retrospective case series N=10 patients with LLD and pre-existing ankle and hindfoot fusion had tibial lengthening with a retrograde ILN (PRECICE). LLD indications were congenital in 9 and post trauma resection in 1. Mean follow up was 18 months	All patients achieved the goal of lengthening. Toe contractures in 2 patients were resolved with physiotherapy or tenotomy. At last follow up (mean 18 months [12–30]) no true complications were encountered, knee motion remained unaffected, and full osseous consolidation occurred in all patients.	Larger and more comprehensive studies were included in the summary of key evidence.
Wang K, Edwards E. (2012) Intramedullary skeletal kinetic distractor in the treatment of leg length discrepancy-a review of 16 cases and analysis of complications. J Orthop Trauma; 26: e138e44.	Case series (retrospective) N=16 patients treated with ISKD (11 femora and 5 tibiae).	Mean lengthening 35mm. The ISKD is an effective method for correcting leg length discrepancies. Complications are frequent but are manageable with standard techniques.	Study included in systematic review added to the summary of key evidence.
Wiebking U, Liodakis E, Kenawey M et al. (2016) Limb lengthening using the PRECICETM nail system: complications and	Retrospective case series N=9 patients with a PRECICE nail for a leg length discrepancy	The mean distraction rate was 0.5 ± 0.1 mm/day. Average lengthening was 34.7 ± 10.7 mm. All patients reached normal alignment	Study included in systematic review added to the summary of key evidence.

results. Arch Trauma Res; 5(4): e36273.	(posttraumatic 5 and congenital 4). 5 femoral, 4 tibial implants Follow up was 2 months.	and normal joint orientation. An unintentional loss of the achieved length during the consolidation phase was noticed in 2 patients. 1 nail broke and was replaced.	
Wagner P, Burghardt RD, Green SA et al. (2017) PRECICE magnetically-driven, telescopic, intramedullary lengthening nail: pre-clinical testing and first 30 patients. SICOT J, 3, 19	Retrospective case series N=30 patients with LLD treated with a Precice IM nail (24 femoral, 8 tibial implants) Follow up was 19 months	Mean postoperative length achieved was 4.3 cm. Average consolidation index was 36.4 days/cm. Mean nail accuracy was 97.3% with a precision of 92.4%.The preoperative and 12-month postoperative SF-12 physical and mental component scores were not statistically different. 9 complications (2 partial femoral unions, 3 DVT, 1 delayed tibial union, 1 fibular non-union, 1 peroneal nerve irritation, 1 knee joint subluxation) resolved. 91% (/29/32) limb segments achieved successful bone healing without revision surgery.	Larger and more comprehensive studies included in the summary of key evidence.
Wright SE, Goodier WD, Calder P. (2020) Regenerate deformity with the Precice tibial nail. Strategies in Trauma and Limb Reconstruction; 10.5005/jp-journals-10080-1457	Case series N= 17 Precice tibial lengthenings (slightly modified surgical technique) Median follow up was 17 months	All the nails lengthened at the desired rate. There were no complications of infection or poor regenerate formation. Progressive valgus and procurvatum	Larger studies included in the summary of key evidence.

		was prevented in later cases by the positioning of Poller blocking screws at the time of nail insertion. The recommended technique was insufficient to control the deforming forces from the lower limb muscle compartments during lengthening. We therefore recommend the addition of multiple blocking screws in an amended technique.	
Young C, Farrah K, Frey N (2017). Intramedullary distraction devices for lower-limb lengthening: clinical effectiveness and guidelines. Ottawa: CADTH; 2017 Apr. (CADTH rapid response report: reference list).	Systematic review and critical appraisal.	One RCT and 22 NRS were identified about the clinical benefit and safety of IM distraction devices for lower-limb lengthening in adults.	Similar reviews added to the summary of key evidence.