REVIEW ARTICLE

Minimally invasive surgery for hallux valgus: a systematic review of current surgical techniques.

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Abstract

Purpose The aim of this study was to systematically evaluate the available literature on minimally invasive surgical (MIS) treatment for hallux valgus and to provide an overview of the different surgical techniques.

Methods A systematic review of the literature available in MEDLINE, EMBASE, and the Cochrane database was performed including studies from January 2001 to 1 January 2018. The radiological outcomes (hallux valgus angle (HVA), intermetatarsal angle (IMA)), complication rates, and clinical outcome scores were evaluated. The MINORS scale was used to assess the methodological quality of included articles.

Results Of 278 reviewed articles, 23 met the inclusion criteria. The included studies reported on the results of 2279 procedures in 1762 patients. The surgical techniques were divided into five categories: the Bosch technique, MIS Chevron-Akin, Reverdin-Isham procedure, Endolog system, and techniques involving distal soft tissue release and fixation. Results regarding radiological correction, clinical outcomes, and complication rate varied widely.

Conclusions The studies included were of too little level of evidence to allow for data pooling or meta-analysis. There were too few studies on each surgical technique category to assess whether one is more effective than the rest. However, there is some evidence that the Chevron and Akin showed the most potential for improvement of the HVA and the Endolog for the IMA. An overall complication rate of 13% was obtained among all included studies. Appropriately powered randomized controlled trials, utilizing validated outcome measures, blinded assessors, and long-term follow up are needed to assess the efficacy of MIS techniques.

Keywords Hallux valgus · Percutaneous · Minimally invasive surgical procedures · Minimum incision · Arthroscopy · Osteotomy · Metatarsal

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Introduction

Hallux valgus is a foot deformity of the first ray that often requires surgical correction. Over a hundred of open surgical techniques have been described without a clear consensus on which is the most effective [1–3]. Percutaneous or minimally invasive surgery (MIS) has become increasingly popular making the results achieved in forefoot surgery comparable to the more traditional open approaches [4, 5]. Some of the advantages of percutaneous surgery include a reduction in morbidity, as well as in surgical and recovery times [6]. This has resulted in more surgeons adopting percutaneous techniques although not without controversy. The rise in popularity of these techniques has attracted the interest of international societies, and in the recent years, platforms like the Groupe de Recherche et d'Etude en Chirurgie Mini-Invasive du Pied (GRECMIP) were founded to evaluate and develop percutaneous techniques in foot surgery [7].

Initially, percutaneous hallux valgus was carried out using Bosch or Reverdin-Isham procedures and variants of these. Their dominant popularity during the 1990s helped expand the use of MIS and paved the way for the development of newer techniques during the 2000s. These include techniques assisted with the use of arthroscopy, the Endolog system, or percutaneous Chevron and Akin osteotomies [8–11].

Previous systematic reviews have been published to assess the results of MIS techniques to treat hallux valgus [5, 6, 12–16]. Those reviews identified limitations of the available evidence to determine clear recommendations for MIS in HV correction. The latest published reviews had either very restrictive inclusion methods and assessed only four studies [15] or omitted some valid studies [16]. With the emergence of papers reporting on the newer techniques [17], it seems appropriate to include those in an inclusive systematic review in an effort to critically assess the most recent literature.

This systematic review aims to evaluate the efficacy and safety of MIS for HV correction according to the latest evidence. Furthermore, the most commonly used procedures are compared in order to ascertain any potential differences in outcomes.

Materials and methods

This systematic review has been registered with PROSPERO (http://www.crd.york.ac.uk/PROSPERO) on 6 January 2018 (registration number CRD42018085390), in accordance with the National Institute for Health Research (NIHR).

Search strategy

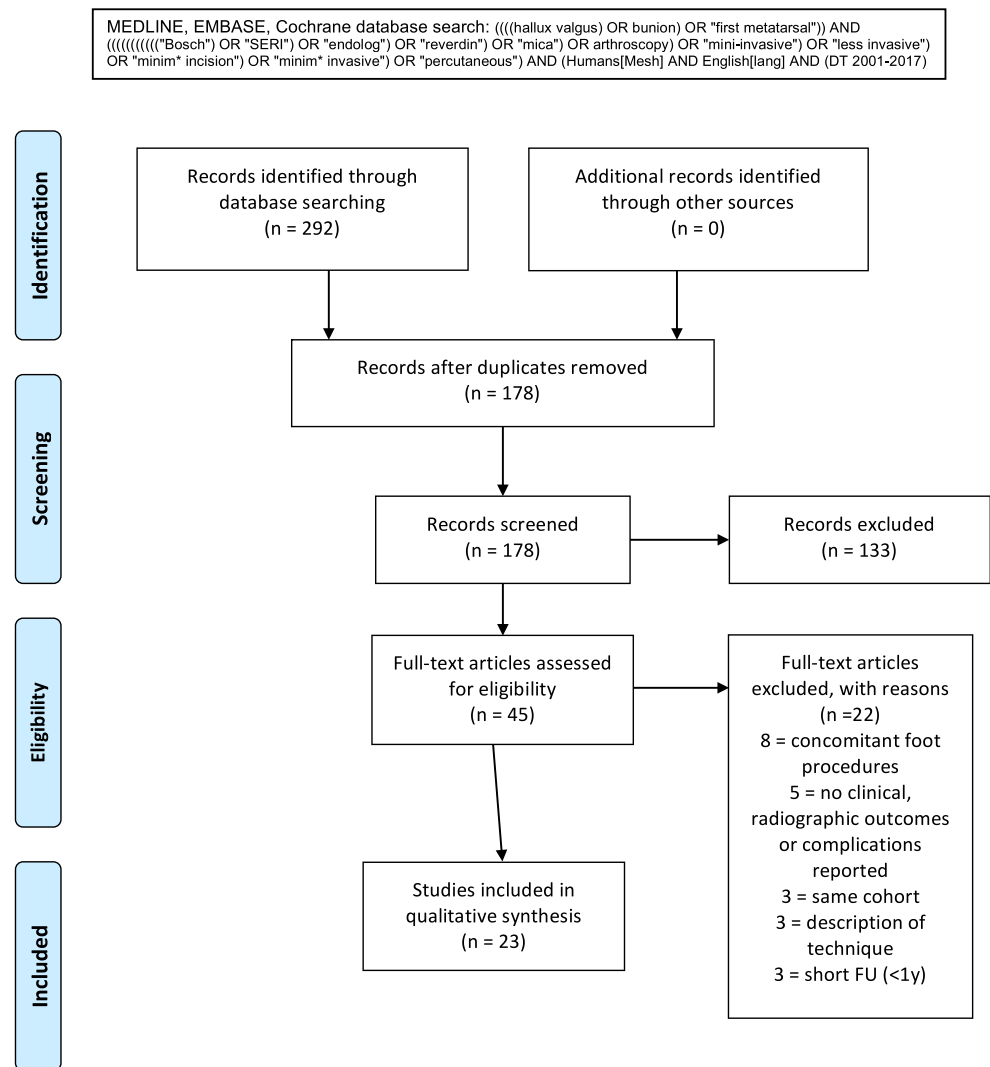The literature search included the following bibliographic electronic databases: Medline, EMBASE, and the Cochrane database of controlled trials. The search terms used and combined are detailed in Fig. 1. All articles relevant to the subject were retrieved, and their bibliographies hand-searched for further references in this context. Only articles published in peer-reviewed journals were included in this systematic review. Additional searches were undertaken via "clinicaltrials.gov" and we enquired the GRECMIP (www.grecmip.org) searching for unpublished trials. Neither of these sources provided any further papers to include in the review. Two hundred ninety-two potential titles and abstracts were identified from the electronic databases.

Study selection

A time frame for the literature search was set from January 2001 to 1 January 2018. This time frame was chosen since research in the area of foot MIS changed as newer techniques were being developed. We decided not to include studies published before 2001 because these reported only on the Bosch technique and during a time when MIS was not as widespread in its use and the majority of surgeons were at the beginning of the learning curve. Included studies fulfilled the following criteria: Investigating humans treated with minimally invasive hallux valgus surgery, published in English, including at least ten patients followed-up for a minimum of one year, and reporting at least one outcome measure relating to pain or function plus radiographic evaluation and complication rates (including recurrence). Exclusion criteria comprised any paper that did not meet the inclusion criteria, as well as those that included patients with concomitant lesser toes or other surgery of the foot, and techniques that involved joint arthrodesis (i.e., Lapidus, 1st MTPJ arthrodesis).

Data extraction

Two reviewers independently extracted data from each included study using a data extraction form developed for this review. Data included demographic information, methodology, details on interventions, and reported outcomes. Data was also collected on the type of scoring system used, its results, and radiological parameters, such as the hallux valgus angle (HVA) and intermetatarsal angle (IMA). A record was made of all reported complications and cases of recurrence. Complications were subclassified as major or minor. Those considered major entail a failure to correct the deformity or complications that place a significant risk to the patient and/or affect the long-term outcome. These included recurrence, nonunion, malunion, transfer metatarsalgia, avascular necrosis (AVN), hallux varus, complex regional pain syndrome (CRPS), deep infection, deep vein thrombosis (DVT), and persistent numbness-paresthesia. Minor complications identified included K-wire decubitus, pin infection,

Fig. 1 Search strategy. PRISMA flow diagram. FU, follow-up

MEDLINE, EMBASE, Cochrane database search: ((((hallux valgus) OR bunion) OR "first metatarsal")) AND ((((((((("Bosch") OR "SERI") OR "endolog") OR "reverdin") OR "mica") OR arthroscopy) OR "mini-invasive") OR "less invasive") OR "minim* incision") OR "minim* invasive") OR "percutaneous") AND (Humans[Mesh] AND English[lang] AND (DT 2001-2017)

Identification

Records identified through database searching
(n = 292)

Additional records identified through other sources
(n = 0)

Screening

Records after duplicates removed
(n = 178)

Records screened
(n = 178)

Records excluded
(n = 133)

Eligibility

Full-text articles assessed for eligibility
(n = 45)

Full-text articles excluded, with reasons
(n =22)
8 = concomitant foot procedures
5 = no clinical, radiographic outcomes or complications reported
3 = same cohort
3 = description of technique
3 = short FU (<1y)

Included

Studies included in qualitative synthesis
(n = 23)

delayed wound healing, metalwork failure, delayed union, superficial infection, stiffness, osteoarthritic changes, and skin burn. The completed forms were compared for accuracy and interpretation; where there was disagreement or any ambiguity, both reviewers met to reach agreement. If disagreement arose and a consensus could not be reached, the plan was that any disagreement would be settled by further discussion with the third or fourth investigator who would adjudicate if necessary.

Study quality assessment

Methodological quality of each study was assessed via the MINORS score, a methodological index for evaluation of non-randomized studies [18]. The exact criteria assessed are found in Table 2. Studies with a MINORS score over or equal to 75% were considered at low risk of bias. Studies with a MINORS score lower than 75% were considered at high risk of bias.

Data analysis

As the available literature for this review included a vast majority of level IV studies, it was determined that pooling the data was not indicated. Furthermore, there was insufficient data to conduct a meta-analysis of the results or to assess the efficacy of the different surgical techniques for HV correction since there were considerable methodological differences between studies particularly with regard to indications for surgery, heterogeneity in participants, and outcome measures. Therefore, narrative synthesis of all included studies was undertaken. Outcome data were presented per study. Ranges of outcome were reported per type of surgical procedure.

The reporting of this systematic review was done in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [19]. Data were extracted from the papers by systematic analysis of each article and summarization in Microsoft Excel version 2010 (Microsoft, Redmond, WA, USA).

Results

The results of the search strategy and study selection criteria are shown in Fig. 1. A total of 23 studies were included in this systematic review [8–11, 20–38].

Population characteristics

The studies reported on a total of 1762 patients with 2279 affected feet. Demographic details are shown in Table 1. Two studies did not report on gender distribution [31, 32]. A few studies reported only the median patient age, which ranged from 51 to 57 [24, 34, 35] but not the mean. All studies followed patients for a minimum of one year, and in 17 (74%), the mean patient follow-up exceeded two years post-operation Table 1.

Study quality

The assessment of the methodological quality using the MINORS scale resulted in a mean score of 10 (maximum score of 16) for non-comparative studies, and of 16.5 (maximum score of 24) for comparative studies Table 2. Three studies were of level II of evidence [28, 30, 36], three level III [11, 22, 38], and the remaining 17 were level IV studies.

Surgical techniques

In this review, the techniques were roughly grouped into five types of procedures. Eleven studies reported on Bosch and modifications of this technique to treat hallux valgus [20–23, 25, 26, 28–32]. Four studies reported on MIS Chevron and Akin osteotomies [10, 11, 37, 38]. Four evaluated the Reverdin-Isham procedure (with Akin osteotomy) [24, 33, 35, 36]. Three studies evaluated the Endolog technique [9, 34, 36], and two reported on distal soft tissue release (DSTR) and fixation [8, 27]. In the same study, two groups were compared using the Reverdin-Isham and Endolog procedures [36], and the results of each group were separately included to the pertinent technique category Tables 1, 3, and 4.

Bosch and modifications

Eleven studies were included in this group. In all cases, the procedure consisted of subcapital osteotomy of the metatarsal and temporary fixation with percutaneous K-wire/s (for 5–6 weeks) (Fig. 2).

Reverdin-Isham

Four studies evaluated the Reverdin-Isham technique which consists of an intra-articular medial wedge closing osteotomy of the metatarsal. It is usually performed with exostectomy of the medial eminence of the metatarsal head, Akin osteotomy of the proximal phalanx, and distal soft tissue release without any form of internal fixation (Fig. 3).

Minimally invasive Chevron and Akin

Five studies included the minimally invasive or percutaneous variation of the Chevron and Akin techniques. There were studies reporting on the so-called percutaneous extra-articular reverse-L Chevron (PERC) osteotomy which also included an Akin osteotomy, and others on the minimally invasive Chevron Akin (MICA), also called percutaneous Chevron Akin (PECA). The two techniques differ in the use of one (PERC) or two (MICA/PECA) screws for fixation of the metatarsal osteotomy, postulating that with the MICA/PECA procedure, higher degrees of correction can be achieved. In the PERC procedure, the screw is inserted from dorsal to plantar and in the MICA/PECA from medial to lateral (Fig. 4).

Endolog

Three studies reported on the use of the Endolog device, a curved titanium endomedullary nail, which serves to push the lateral translation of the metatarsal head and does not require routine removal of the device (Fig. 5).

DSTR and fixation (Akin or arthroscopically assisted DSTR and M1–M2 screw fixation)

Two studies reported on a distal soft tissue release assisted by either arthroscopy or fluoroscopy. In the first study, a screw between the 1st and 2nd metatarsals was used [6], and in the second, an Akin osteotomy was performed under fluoroscopy [27] (Figs. 6 and 7).

Overall

Including all MIS procedures in a total of 2279 ft, the mean HVA improved from pre-operative to post-operative at a range of Δ8.6 to Δ21.1 and the mean IMA from Δ0.9 to Δ9.9. Mean AOFAS scores showed an improvement from pre-operation to post-operation at a range of Δ18.1 to Δ66.1. Complication rates overall ranged from 0 to 73%, with a weighted average of 11%, being 7% classified as major and 4% as minor Tables 1, 3, and 4.

Discussion

This is the first study to separately evaluate the different surgical techniques available for percutaneous or MIS treatment of hallux valgus. Additionally, it demonstrates that MIS and

Table 1 Overview of included studies

Technique	Author	Year	LOE	Type	n	Feet	Male (%)	Age	FU
Bosch	Magnan	2005	IV	Case series	82	118	5 (6)	56.3 ± 13 (17–79)	35.9 ± 10.9 (24–78)
	Lin	2009	IV	Case series	31	47	4 (13)	40.8 (13–63)	23.7 (16–68)
	Maffulli	2009	III	Retrospective comparative	36	36	0	51.5 ± 13.1 (21–70)	25 ± 3.2
	Siclari	2009	IV	Case series	49	59	5 (10)	54.6 (24–70)	31.48 (12–48)
	Enan	2010	IV	Case series	24	36	4 (16)	37.8 ± 12.7 (17–52)	21(12–36)
	Tong	2011	IV	Case series	20	23	2 (10)	55.1 (29–75)	22 (12–60)
	Radwan	2012	II	Prospective comparative	29	31	4 (14)	32.7 ± 7.4	21.7 (12–36)
	Scala	2013	IV	Case series	126	146	11 (9)	52.6 (16–87)	29.1 (12–54)
	Giannini	2013	II	Prospective comparative	20	20	0	53 ± 11	7 years
	Gadek	2013	IV	Case series	54	54	?	45.7	18
	Giannini	2013	IV	Case series	577	896	61 (10)	49 (20–65)	7 years (5–10)
Total					1048	1466	10% (n = 96)	32.7–56.3	18–84
Reverdin	Bauer	2009	IV	Case series	168	189	4 (2)	57 median (23–87)	13 (12–24)
	Gicquel	2013	IV	case series	18	33	0	12.5 (8.1–15.7)	31.4 (14.1–58.2)
	Biz	2016	IV	Case series	80	80	5 (7)	Median 51 ± 15.5 (26–78)	48
	DiGiorgio*	2016	II	Prospective comparative	19	19	1 (3)		23.3 ± 7.7
Total					285	321	4% (n = 10)	12.5–median 57	13–48
Endolog	DiGiorgio	2013	IV	Case series	25	33	2 (8)	52 (35–80)	18.2 (12–36)
	Biz	2015	IV	Case series	30	30	2 (7)	Median 56.5 (range 38–73)	48
	DiGiorgio*	2016	II	Prospective comparative	18	18	–		23.3 ± 7.7
Total					73	81	7% (n = 4)	52–median 56.5	18.2–48
DSTR	Lui	2008	IV	Case series	83	94	8 (10)	45.6 (14–89)	30.45 (24–74)
	Martinez-Nova	2011	IV	Case series	79	79	0	54.7 ± 12.5	28.1 (24–33)
Total					162	173	5% (n = 8)	45.6–54.7	28.1–30.45
Chevron	Lucas y Hernandez	2016	IV	Case series	38	54	3 (8)	48 (17–69)	59.1 (45.9–75.2)
	Brogan	2016	III	Retrospective cohort study	?49	49	3 (6)	53 ± 10.8	31 ± 3.5 (26–39)
	Jowett group A	2017	IV	Case series	36	53	1 (3)	56 ± 13.1 (28–81)	26 ± 12.0 (18–38)
	Jowett group B	2017	IV	Case series	42	53	1 (2)	54 ± 13.5 (25–77	24 ± 5.0 (18–28)
	Lai	2017	III	Retrospective comparative	29	29	4 (14)	54.3 ± 12.8	24
Total					194	238	6% (n = 12)	47–56	24–59.1
Total overall					1762	2279	7.4% (n = 130)		

FU follow-up (in months, unless when stated in years); *LOE* Level of Evidence

*Same study by DiGiorgio et al. [33] comparing two groups of Endolog vs Reverdin procedures

percutaneous procedures in general have acceptable complication rates and satisfactory outcomes. Due to low methodological quality of included studies in combination with large heterogeneity in population, used techniques, and reported outcome measures, we refrained from data pooling. Furthermore, we identified a number of studies that bring value to the current breadth of literature but were not included as they did not fulfill the inclusion criteria [39–42]. There were three randomized controlled trials [28, 30, 36], although two of them have small numbers of patients and only one [28] performed a power calculation to determine the sample size needed to detect statistically significant differences. The sample size was selected to find a difference of 10% on the AOFAS score but not to detect differences in radiographic correction or rate of complications. Radwan and Mansour [28] compared two groups of 31 and 33 patients undergoing a modification of the Bosch technique and an open Chevron, respectively. They found comparable results in all measured

Table 2 MINORS score for each study to assess methodological quality

Procedure	Author	Score	Risk of bias	1	2	3	4	5	6	7	8	9	10	11	12
Bosch	Lin	7/16	High	1	2	0	1	0	2	1	0				
	Maffulli	15/24	High	2	0	0	1	2	2	1	0	2	2	1	2
	Magnan	12/16	Low	2	2	2	2	0	2	2	0				
	Siclari	9/16	High	1	2	0	2	0	2	2	0				
	Enan	10/16	High	1	2	2	2	0	2	1	0				
	Radwan	11/16	High	2	2	2	2	0	2	1	0				
	Scala	8/16	High	1	2	0	2	0	2	1	0				
	Giannini	16/24	High	2	2	2	2	0	2	2	0	2	2	0	0
	Gadek	8/16	High	1	2	0	2	0	2	1	0				
	Giannini	10/16	High	1	2	2	2	0	2	1	0				
	Tong	8/16	High	0	2	0	2	0	2	2	0				
Reverdin	Bauer	12/16	Low	2	2	2	2	0	2	2	0				
	Biz	12/16	Low	2	2	2	2	0	2	2	0				
	Gicquel	8/16	High	2	2	0	2	0	2	0	0				
	DiGiorgio*	15/24	High	1	2	2	2	0	2	0	0	2	2	2	0
Endolog	DiGiorgio	8/16	High	1	1	0	2	0	2	2	0				
	Biz	14/16	Low	2	2	2	2	2	2	2	0				
	DiGiorgio*	15/24	High	1	2	2	2	0	2	0	0	2	2	2	0
DSTR	Lui	9/16	High	2	2	0	2	0	2	1	0				
	Martinez-Nova	14/24	High	2	0	0	1	0	2	1	0	2	2	2	2
Chevron	Lucas y Hernandez	13/16	Low	1	2	2	2	2	2	2	0				
	Brogan	18/24	Low	2	2	2	2	0	2	0	2	2	2	2	0
	Jowett	11/16	High	2	2	2	2	0	1	2	0				
	Lai	21/24	Low	2	0	2	2	1	2	2	2	2	2	2	2

The final score comprises the results of 8 items or 12 items in cases of comparative studies: 1 A clearly stated aim; 2 Inclusion of consecutive patients; 3 Prospective collection of data; 4 Endpoints appropriate to the aim of the study; 5 Unbiased evaluation of the study endpoint; 6 Follow-up period appropriate to the aim of the study; 7 Loss to follow-up less than 5%; 8 Prospective calculation of the study size; 9 An adequate control group; 10 Contemporary groups; 11 Baseline equivalence of groups; 12 Adequate statistical analysis

DSTR distal soft tissue release

*Same study by DiGiorgio et al. [33] comparing two groups of Endolog vs Reverdin procedures

parameters except for a statistically significant shorter operating time and better satisfaction regarding cosmetic results of patients in the MIS group. Giannini and colleagues [30] performed bilateral surgeries on a group of 20 patients, using open Scarf on one side and SERI on the other, with similar outcomes. Di Giorgio and colleagues [36] compared two MIS techniques in 20 patients each, Reverdin-Isham and Endolog detecting no significant differences with respect to the AOFAS score, HVA, and IMA with excellent results obtained in both groups. The rest of the studies included three level III studies comparing mini-incision Chevron versus Bosch technique [22] and MIS versus open Chevron techniques [11, 38], and the remaining 17 level IV studies. It is worth mentioning that the three level II studies were published during the past five years and they add to the literature on the topic since the first systematic review was published in 2009 that included no level II studies. This indicates an increasing improvement on

the level of evidence of the studies on MIS for hallux correction.

Other systematic reviews performed in the past found that due to the limitations of the studies, especially the extensive clinical heterogeneity, it was not possible to determine clear recommendations regarding MIS for hallux valgus correction, even though preliminary results were encouraging [6]. We intended to minimize heterogeneity by including studies performed in the last 15 years while excluding historical cohorts or those series of cases published at the time when percutaneous techniques were being adopted by surgeons, possibly at the early days of the learning curve. Despite our efforts, the heterogeneity of the studies still precludes the pooling of the data and meta-analysis. The latest systematic reviews included similar number of procedures (2197, 1952) to ours (2279), and they concluded that complications reported were comparable with the conventional open techniques, being significantly

Table 3 Radiographic and clinical outcomes

Procedure	Author	HVA Pre	HVA Post	HVA Diff	IMA Pre	IMA Post	IMA Diff	AOFAS Pre	AOFAS Post	AOFAS Diff
Bosch	Lin	26 ± 4.9 (18–37)	14.2 ± 6.7 (0–26)	11.8	11.6 ± 1.6 (8–15)	5.3 ± 2.3 (0–10)	6.3	–	92.7 ± 6.2 (78–100)	–
	Maffulli	27 ± 6	17 ± 4	10	15 ± 6	8 ± 3	7	–	–	–
	Magnan	31.5 ± 10.2 (18–42)	13.7 ± 6.7 (7–25)	17.8	12.3 ± 3 (10–20)	7.3 ± 2.7 (4–16)	5	–	88.2 ± 12.9	45.6
	Siclari	27.9 (12–45)	12.3 (2–21)	15.6	16.5 (8–25)	9.3 (3–15)	7.2	45 (30–65)	90.6 (75–100)	45.6
	Enan	27.7 ± 3.8 (18–36.8)	14.6 ± 5.8 (8–25.4)	13.1	11.2 ± 1.8 (9.8–18)	5.8 ± 2.4 (4–11.6)	5.4	–	91.1 ± 6.8	–
	Radwan	27.6 ± 4.4	13.1 ± 2.8	14.5	12.6 ± 2.0	7.8 ± 1.3	4.8	44.6	90.2 ± 6.8	45.6
	Scala	32.3 ± 7.6 (12–52)	4.5 ± 5 (20 to −4)	27.8	14.4 ± 3.5 (9–22)	4.8 ± 3.4 (0–16)	9.6	54.6 ± 9.6 (12–77)	85.3 ± 18.4 (23–100)	30.7
	Giannini	35.8 ± 3.5	21.8 ± 4.1	14	16.1 ± 3.9	6.8 ± 4.3	9.3	51 ± 10	81.2 ± 15.1	30.2
	Gadek	33.9	14.2	19.7	14.8	9.7	5.1	37	90.7	53.7
	Giannini	32 ± 8.3 (25–50)	13.3 ± 6.4 (4–28)	18.7	14.3 ± 3.3 (10–18)	6.9 ± 3.6 (2–14)	7.4	46.8 ± 16.7 (15–78)	89 ± 10.3 (50–100)	42.2
	Tong	31.3 ± 5.3 (20–38)	15.7 ± 5.4 (2–24)	15.6	16.7 ± 2.8 (10–20)	7.7 ± 3.8 (4–14)	9	53	91.8 ± 7.9 (68–100)	38.8
Totals	Δ Range			10–19.7			4.8–9.6		81.2–92.7	30.2–53.7
Reverdin	Bauer	30 (25–32)	15 (11–18)	14	14 (12–15)	11 (9–13)	3	52 (44–60)	93 (82.5–100)	41
	Biz	26.40 ± 0.64 (10–47.5)	13.90 ± 6.25 (0–34)	12.5	12.9 ± 2.83 (7.5–20)	9.00 ± 2.04 (5–14)	3.9	54.1 ± 8.3	87.1 ± 12.8	33.1
	Gicquel	28.1 ± 6.30 (18–42)	19.5 ± 8.5 (6–38)	8.6	13.6 ± 2.6 (10–18)	12.7 ± 2.7 (8–18)	0.9	–	80.7	–
	DiGiorgio	30.2 ± 6.6	13.1 ± 4.9	17.1	14.1 ± 2.2	8.9 ± 2.4	5.2	40.5	90.3	49.8
Totals	Δ Range			8.6–17.1			0.9–5.2		80.7–93	33.1–49.8
Endolog	DiGiorgio	36.6 ± 8.1 (20–53)	22.7 ± 6.7 (8–32)	13.9	16.0 ± 1.9 (14–19.9)	6.1 ± 2.9 (3–11)	9.9	22.1 ± 11.1 (0.34)	88.2 ± 6.1 (85–100)	66.1
	Biz	33.38 ± 10.72 (17.84–66.62)	16.57 ± 5.40 (7.18–25.18)	16.8	12.31 ± 3.05 (7.09–18.55)	6.36 ± 1.38 (7.74–4.98)	5.9	28.7 (19–42)	93.98	65.3
	DiGiorgio	27.5 ± 7.2	13.4 ± 4.4	14.1	15.9 ± 3	8.2 ± 1.9d	7.7	32.4	89.2	56.8
Totals	Δ Range			13.9–16.8			5.9–9.9		88.2–94	56.8–66.1
DSTR	Lui	33 ± 7 (20–58)	14 ± 5 (4–30)	19	14 ± 3 (10–26)	9 ± 2 (5–18)	5	–	93 ± 8	–
	Martinez-Nova	24.1 ± 3.7	11 ± 1.7	13.1	11.8 ± 0.5	9.5 ± 0.5	2.3	68.5 ± 10.6	86.6 ± 8.5	18.1
Totals	Δ Range			13.1–19			2.3–5.0		86.6–93	18.1
Chevron	Lucas y Hernandez	26.2 ± 4.9 (16–40)	9.6 ± 3.1 (4–18)	16.6	11.8 ± 2.7 (6–18)	7.9 ± 2.1 (3–11)	3.9	62.5 ± 8.0 (30–80)	97.1 ± 5.4 (75–100)	34.6
	Brogan	26.6 ± 10.6	10.4 ± 5.7	16.2	11.7 ± 4.4	6.8 ± 3.6	4.9	–	–	–
	Jowett group A	28.7 ± 8.1 (12–46)	10.6 ± 5.4 (4–25)	18.1	13.6 ± 3.3 (8–20)	8.1 ± 3.6 (3–15)	5.5	55 ± 11.3 (23–76)	85 ± 9.3 (75–98)	30
	Jowett group B	30.7 ± 5.7 (20–44)	9.9 ± 4.01 (0–18)	20.8	14.4 ± 1.8 (10–18)	7.1 ± 1.8 (4–12)	7.3	57 ± 8.6 (42–76)	89 ± 10.9 (50–100)	32
	Lai	29.9 ± 8.5	8.8 ± 5.9	21.1	14.6 ± 3.9	10.3 ± 3.1	4.3	58.6 ± 16.6	87.4 ± 17.8	28.8
Totals	Δ Range			16.2–21.1			3.9–7.3		85–97.1	28.8–34.6
Totals overall	Δ Range			8.6–21.1			0.9–9.9		80.7–97.1	18.1–66.1

*Same study by DiGiorgio et al. [33] comparing two groups of Endolog vs Reverdin procedures

DSTR distal soft tissue release, *HVA* hallux valgus angle, *IMA* intermetatarsal angle, *AOFAS* American Orthopaedic Foot and Ankle Score, *Pre* preoperative value, *Post* postoperative value, *Diff* difference in value between pre- and post-operative, Δ difference in

Table 4 Complications

Author	Feet	Major		Minor		Totals	
		n	%	n	%	n	%
Bosch							
Lin	47	1	2	8	17	9	19
Maffulli	36	0	0	1	3	1	3
Magnan	118	2	2	9	8	11	9
Siclari	59	4	7	1	2	5	8
Enan	36	4	11	3	8	7	19
Radwan	31	0	0	4	13	4	13
Scala	146	7	5	6	4	13	9
Giannini	20	0	0	0	0	0	0
Gadek	54	0	0	1	2	1	2
Giannini	896	67	7	21	2	88	10
Thong	23	0	0	5	22	5	22
Totals	1466	85	6	59	4	144	10
Reverdin							
Bauer	189	8	4	2	1	10	5
Biz	80	5	6	1	1	6	8
Gicquel	33	24	73	0	0	24	73
DiGiorgio[#]	19	0	0	0	0	0	0
Totals	321	37	11	3	1	40	12*
Chevron							
Lucas y Hernandez	54	0	0	5	9	5	9
Brogan	49	5	10	4	8	9	18
Jowett group A	53	9	17	12	23	21	40
Jowett group B	53	7	13	7	13	14	26
Lai	29	0	0	0	0	0	0
Totals	238	24	10	29	12	53	22**
Endolog							
DiGiorgio	33	0	0	0	0	0	0
Biz	30	2	7	1	3	3	10
DiGiorgio[#]	18	0	0	0	0	0	0
Totals	81	2	3	1	2	3	4
DSTR + fixation							
Lui	94	3	3	1	1	4	4
Martinez-Nova	79	0	0	0	0	0	0
Totals	173	3	2	1	1	4	2
Totals	2279	151	7	93	4	244	11

DSTR distal soft tissue release

[#] Same study by DiGiorgio et al. [33] comparing two groups of Endolog vs Reverdin procedures

*The study by Gicquel is the only one to include children younger than 16. **The study by Jowett is the only one to include a subgroup of patients during the early stages of the learning curve of the surgeon. If this subgroup were to be excluded from the analysis, the overall complication rate for the Chevron Akin group would be 13% instead of 22%

use of MIS techniques could be provided while encouraging the need for methodologically sound prospective and randomized controlled studies. In that early study, only the historical percutaneous techniques were assessed (Reverdin-Isham) which has been criticized in the more modern literature and has justified the evolution of the percutaneous techniques. Subsequently, published systematic reviews had some limitations that might affect the quality of the review. They included series of less than five patients, studies that evaluated concomitant techniques to lesser toes, or series by the same authors including the same patients which would be assessed in duplicate. They also omitted some studies despite fulfilling their inclusion criteria, or used strict criteria that would exclude the new generation of percutaneous techniques [6, 13, 15, 16]. Another critical review of the evidence by Trnka [12] was published, although no assessment of study quality was undertaken. In the current study, we have taken these considerations into account to bring the highest possible methodological quality in the review.

No MIS techniques have shown superiority over others due to lack of well-designed randomized control trials (RCT) and insufficient comparative case control studies. The only RCT that compared two MIS/percutaneous techniques showed similar outcomes for the Reverdin-Isham and the Endolog techniques [36]. Some of the results encountered in this systematic review may evoke some trends in the outcomes of the different techniques. The Reverdin-Isham technique showed the least potential for improvement of the HVA (range Δ8.6–Δ17.1°) and the Chevron Akin the most (range Δ16.2–Δ21.1°). Similarly, the IMA is least improved in the Reverdin-Isham series (range Δ0.9–Δ5.2°), and most improved in the Endolog series (range Δ5.9–Δ9.9°). The nature of these techniques would explain the findings, as in the Reverdin-Isham procedure, a closing wedge medial osteotomy has less capability of reducing the IMA than a complete translation of the metatarsal head, as in the Endolog, Chevron, or Bosch procedures.

With regard to complications, the reported rates varied widely even within the same technique groups. The Bosch technique was reported to have 0% complication rates by some authors [30] or 22% by others [26]. The Reverdin-Isham technique varied from a 5% [24] to a 73% [33] rate of complications. Such a high complication rate of 73% was not seen in any other technique group, and it is worth mentioning that this particular study was the only one that evaluated exclusively children younger than 16 years of age, finding high rates of recurrence. In the Chevron Akin group, complications were reported at a rate of 0 to 40%. It is also worth stressing that the 40% rate was found in a subgroup of patients that assessed the early stages of the learning curve, with the first 60 procedures performed by the author and the same study obtained a 26% rate when assessing procedures number 61 to 120 performed by the same author [37]. They concluded that

lower in centers specializing with MIS. The first published systematic review in 2009 by Roukis [5] had strict exclusion and inclusion criteria that made it methodologically robust, but as a consequence, only three studies were evaluated and the conclusion was that no strong evidence for or against the

Fig. 2 Bosch. Schematic
representation of Bosch technique
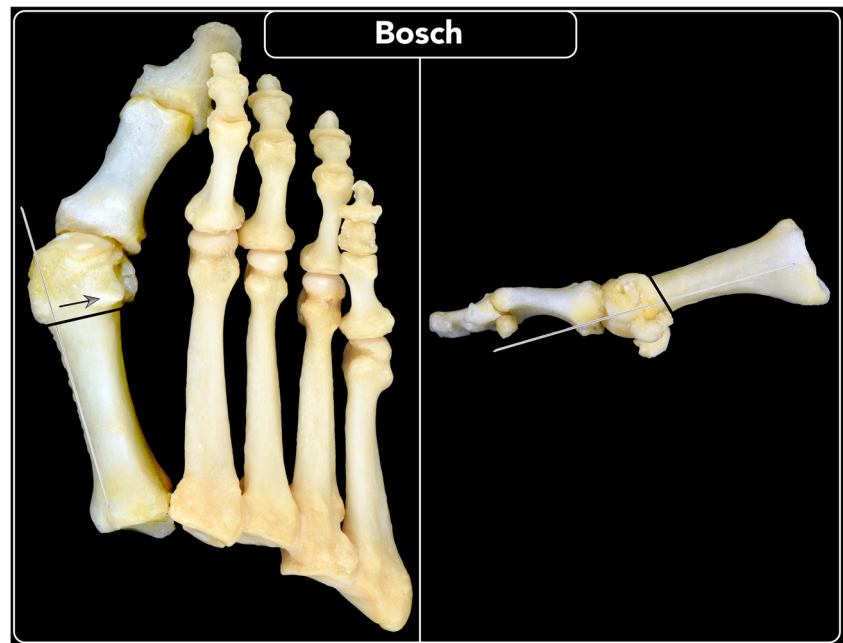
the learning curve for the MICA technique is steep and comparable to that for open hallux valgus surgery. If we excluded the early stages subgroup from the analysis, the Chevron Akin group would have had an overall complication rate of 13% which is more in keeping with the rest of the procedures. In the Endolog group, complications ranged from 0 to 10% of cases and in the DSTR group from 0 to 4% of cases. It is possible that some of these studies with such a low complication rate might not have considered complications such as stiffness or prominent metalwork which have been included and counted in other papers.

In the Bosch group, we included variations of the original technique like the SERI (simple, effective, rapid, inexpensive) which was evaluated in the largest series of all studies included. After prospectively studying 1000 ft with some lost to follow-up, a total of 896 cases by a single surgeon were evaluated at a mean of seven years of follow-up [32]. A well-known complication of the Bosch technique is reduced range of motion or stiffness of the 1st MTPJ due to the fact that with a KW in the toe for six weeks, there is no movement of the joint or potential for physiotherapy [13]. Unfortunately, most studies do not report the postoperative loss in range of motion. Another

Fig. 3 Reverdin-Isham. Schematic representation of Reverdin-Isham technique
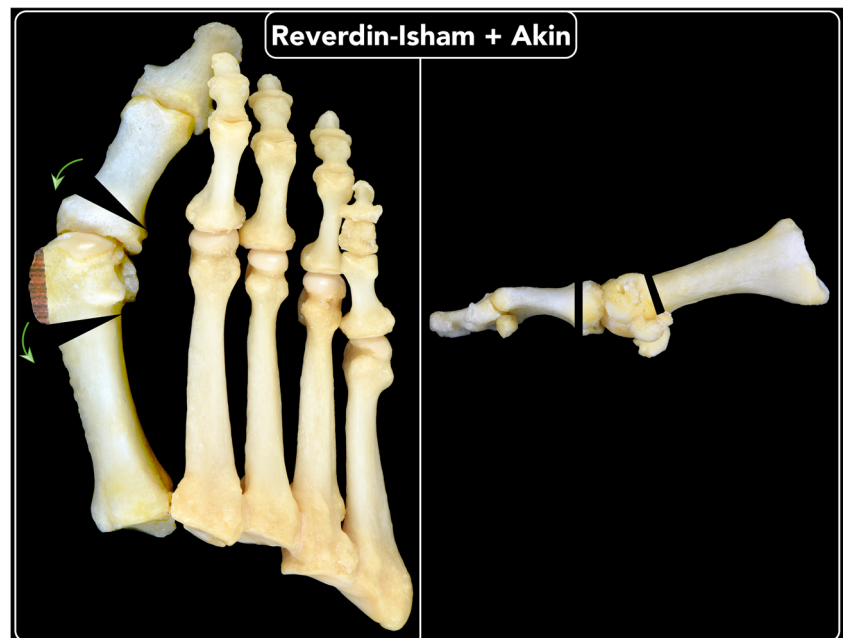
Fig. 4 Chevron. Schematic representation of techniques using Chevron osteotomy, MICA (minimally invasive Chevron Akin) and PERC (percutaneous extra-articular reverse-L Chevron)
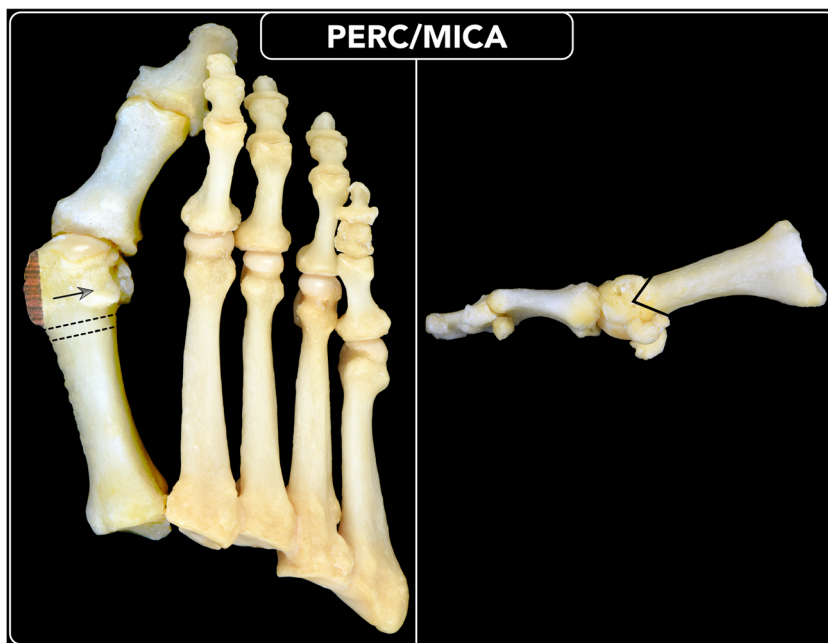
complication seen with this technique is the dorsal or plantar malalignment of the metatarsal head. Again, not all studies report metatarsal head position at follow-up but the position of the head was mentioned in some. Enan and colleagues reported 55.6% cases of malalignment, although none of them was classed as malunion in their analysis of the complications [25]. Similarly, Magnan reported malalignment of the metatarsal head in 61% of the cases but no mention of malunion in the assessment of complications [20].

The Reverdin-Isham procedure was performed with an Akin osteotomy of the proximal phalanx in the evaluated studies. Some authors added an additional lateral wedge osteotomy of the base of the first metatarsal in cases of IMA greater than 18° [33]. In the study by Biz and colleagues [35], a note was made on the less encouraging results in patients with severe deformities and the long learning curve required because of its inherent technical difficulty. Another well-known complication of the Reverdin-Isham technique is the lack of congruency of the joint, predisposing to recurrence and stiffness. Recurrence in particular was found in 6% [35] and 60% (in patients under 16 years of age) [33] in two separate studies.

Fig. 5 Endolog. Schematic representation of Endolog technique
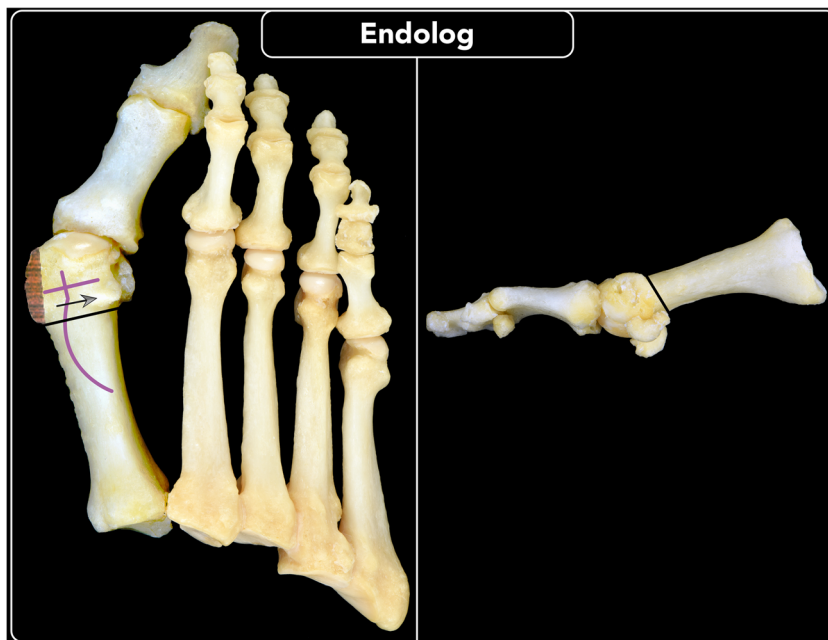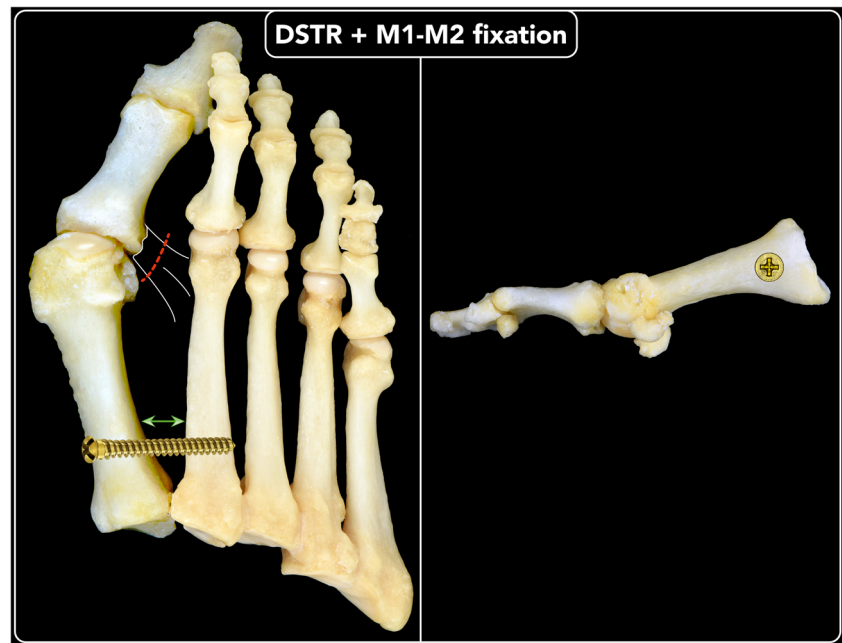
Fig. 6 Distal soft tissue release + M1–M2 fixation. Schematic representation of distal soft tissue release (DSTR) and M1–M2 fixation with screw


The MIS Chevron and Akin has evolved from the original open technique with the same name. The study by Brogan et al. [11] found no statistically significant differences when these two procedures were compared in terms of clinical and radiological scores or complication rates. Some of the cited potential shortcomings attributed to MIS were overcome by this technique. To mention some, the degree of correction achieved was sufficient without the need for capsular plication. The shortening of the metatarsal secondary to the use of the burr was counteracted by performing the transverse portion of the osteotomy at an oblique angle, and the time for healing of

the osteotomy was within the same period as with open surgery, with no reported changes in sensory status (i.e., nerve damage by the burr) [37]. Lucas y Hernandez and colleagues [10] in their series of 53 cases of moderate hallux valgus correction using the PERC technique highlighted a main advantage of good first MTPJ range of motion following surgery with this technique. They also recommended that for more severe deformities, the MICA technique allows for a greater translation and limited secondary displacement.

The Endolog system has shown excellent results and very low complication rates in all the studies assessed. It is worth

Fig. 7 Distal soft tissue release + Akin. Schematic representation of distal soft tissue release (DSTR) and Akin
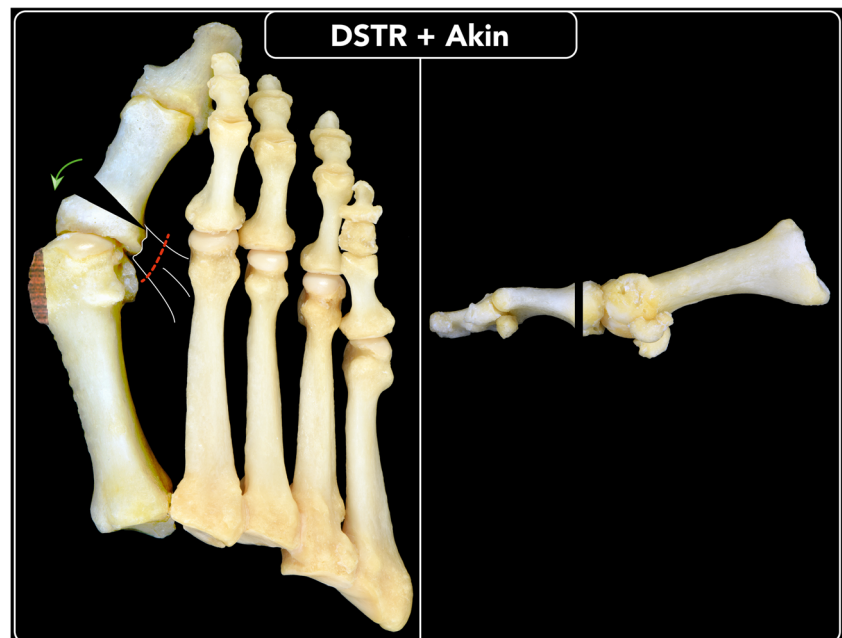
mentioning that this procedure differs from all the others assessed in this systematic review in the sense that it is a mini incision procedure as opposed to a purely percutaneous. The concepts of this technique are closer to those of open surgery (direct view of the metatarsal) than those of percutaneous (relies on fluoroscopic control). So far, the available literature is limited to a handful of studies with reduced number of patients.

Distal soft tissue release (DSTR) procedures complemented with some sort of fixation were reported in two studies. In one [8], the procedure was assisted with arthroscopic view and screw fixation between the first and second metatarsals to correct the IMA. It requires a high degree of expertise in arthroscopic and endoscopic surgery with the benefit of non-existent radiation. Even in expert hands, the operative time can be significantly higher than the rest of the techniques. No mention of operative time was reported in this study. Direct visualization of the MTPJ permits further intra-articular pathology to be addressed. In another study [27], the DSTR was complemented with an Akin osteotomy to evaluate cases of only mild hallux valgus. One of their findings was the restoration of physiological patterns in pressure under the hallux on biomechanical analysis.

This systematic review study has some limitations. First, except for the three prospective comparative studies [28, 30, 36], most of the included studies are case series with a low level of evidence (level IV). Furthermore, the majority of the studies that have been included have a poor MINORS score and have been considered at high risk of bias. In addition, the inconsistency of the clinical outcome measures used in the different studies made it difficult for comparison, and the AOFAS score reported by the vast majority, although widely used, is not a validated measure. Therefore, caution should be taken when interpreting the results presented in this review.

We strongly encourage future studies to be conducted using validated instruments to assess pain and functional outcome. As often advocated, larger populations, prospective studies, and long-term follow-up studies are needed to draw conclusions on the best surgical treatment option for percutaneous hallux valgus correction.

Conclusion

The study provides a comprehensive overview of the current literature and clearly demonstrates the variation in outcome and complication rates amongst studies. There were no wide differences of these parameters between the different techniques evaluated as a group. However, the Reverdin-Isham technique showed the least potential for improvement of the HVA and the Chevron and Akin the most. Similarly, the IMA is least improved in the Reverdin-Isham series, and most improved in the Endolog series. The Reverdin-Isham and Chevron-Akin procedures resulted in the higher complication rates, although in their groups, there were studies that assessed only children and the initial learning curve period, respectively. Minimally invasive and percutaneous procedures may therefore continue to represent an effective treatment option for hallux valgus surgery and evolve to further improve their outcomes.

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