



# Is arthrodesis still the best treatment option for first metatarsophalangeal joint arthritis? – a systematic review of arthrodesis and arthroplasty outcomes

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**Background:** To analyse if there is scientific support to consider arthrodesis as the gold standard treatment for advanced hallux rigidus, as compared to hemi or total arthroplasty. The hypothesis was that arthroplasty would provide at least comparable results to arthrodesis in patients with advanced hallux rigidus.

**Methods:** PubMed and EMBASE databases were searched for clinical studies up to July 2019. We included cohort studies and case series that report the clinical outcomes of arthrodesis or arthroplasty (either hemi or total) in adult patients with primary or secondary osteoarthritis of the first metatarsophalangeal joint that used a still commercialized implant type and with a minimum of 12 months follow-up. Meta-analysis was not feasible and we present the results as a narrative synthesis for each surgical approach and implant type. The methodological index for non-randomized studies (MINORS) was used to assess study quality.

**Results:** Forty-six studies comprising of 1,868 patients (arthrodesis, n=570; total arthroplasty, n=690; hemiarthroplasty, n=608). Arthrodesis showed high satisfaction rates (>90%) and American Orthopaedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal score (around 80 points). ToeFit-Plus<sup>®</sup> was the most common implant (n=300) for total arthroplasty. Postoperative American Orthopaedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal score was generally high (range, 80–100). Survivorship was high (100%) at 2 years, but decreased at 3 years (76%). Considering hemiarthroplasties, HemiCap<sup>®</sup> had high postoperative AOFAS-HMI (83–94.1 points) and satisfaction rates (95–100%).

**Conclusions:** Metatarsal head hemiarthroplasties, may be considered as an optimal choice for first-line of treatment of advanced hallux rigidus showing comparable outcomes to arthrodesis while preserving motion.

**Keywords:** First metatarsophalangeal joint; hallux rigidus; arthritis; arthrodesis; hemiarthroplasty; arthroplasty

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## Introduction

First metatarsophalangeal joint osteoarthritis, also designated as hallux rigidus, is the most common arthritic condition of the foot, affecting 2.5% of the patients aged over 50 years (1).

Conservative management of hallux rigidus is the first-line treatment and includes anti-inflammatory medication, physical therapy, modified shoes, icing, and intra-articular injections (2,3). For advanced stages, in which conservative treatment has failed, operative management is indicated and consists mainly of arthrodesis, which is still considered the gold standard surgical procedure, or arthroplasty (4).

Arthrodesis of the first metatarsophalangeal joint provides consistent and reliable results with good fusion rates, functional scores and patient satisfaction (1,5). Arthrodesis is associated to a few disadvantages including loss of joint motion, diminished gait efficiency, limitations in running and jumping sports and footwear choice (6,7).

Arthroplasty is expected to preserve the length and motion of the joint, provide good functional outcomes, with lasting pain relief, a better cosmetic appearance and use of normal footwear. Unfortunately, many designs have been used over the years and no implant has succeeded in granting patient satisfaction and implant survival to the levels established for hip and knee replacements (8). Implants have been evolving since the first silastic prosthesis to overcome the high failure rate, osteolysis and immune reactions (9). Most recent advances include tapered stems, new materials such as cartilage substitutes and the popularization of hemi-arthroplasties.

Given the advances of implant designs in last years, this systematic review intends to analyse the literature to determine if there is still scientific support to consider arthrodesis as the gold standard treatment modality for advanced hallux rigidus. Our objective is to assess the treatment outcomes (clinical, functional and implant survival) of arthrodesis compared to arthroplasty of the first metatarsophalangeal joint in patients with advanced hallux rigidus. Since arthrodesis is traditionally used for advanced hallux rigidus, our hypothesis was that arthroplasty would provide at least comparable results to arthrodesis in patients with advanced hallux rigidus. We present the following article in accordance with the PRISMA reporting checklist (available at <http://dx.doi.org/10.21037/aoj-20-88>).

## Methods

The systematic review of the literature was conducted

according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (10). We did not register an à priori protocol.

### *Search strategy*

A systematic literature search was performed on PubMed and EMBASE database until 31<sup>st</sup> July 2019. The search strategy was conducted using the Boolean operators (AND, OR) to combine the following keywords: “first metatarsophalangeal joint”, hallux, osteoarthritis, arthritis, rigidus, valgus, arthrodesis, hemiarthroplasty, arthroplasty and fusion. The complete search strategy is reported in [Table S1](#). The reference list of the most relevant original studies was scanned for additional studies.

### *Study selection*

One author (G. F.) screened all the title and abstracts of all database records and retrieved the full-text of relevant studies for further analysis according to the inclusion and exclusion criteria. Any doubts were discussed with another author (J. N.). Both authors (G. F. and J. N.) screened the full-text for inclusion in this systematic review. The inclusion criteria comprised: (I) cohort studies and case series that report adult (>18 years old) human patients with primary or secondary osteoarthritis of the first metatarsophalangeal joint; (II) reported the clinical outcomes from primary procedures of arthrodesis or arthroplasty of the first metatarsophalangeal joint with a minimum of 12 months follow-up; (III) using an implant type that is still commercialized; and (IV) written in the English language. As exclusion criteria were defined as: (I) other reviews or meta-analyses; (II) small case series (n<15) or case reports; (III) cadaveric studies; (IV) interposition or resection arthroplasties; (V) revision surgeries; (VI) multiple procedures in other toes; and (VII) neurologic conditions or tumours.

### *Data extraction*

Data were extracted by one author (G.F.) using a predefined form. The follow-up outcomes for arthrodesis studies included functional scores, fusion rate, revision rate, satisfaction and complications. For arthroplasty studies, the fusion rate was replaced by pre and postoperative range of motion (ROM) and revision rate replaced by implant survivorship. Implant survivorship was determined as the

time between primary arthroplasty and revision of any component of the implant, extraction or conversion to fusion.

### *Synthesis of results*

Meta-analysis comparing arthrodesis and arthroplasty was not possible due to the low number of comparative studies. We thus employed a narrative synthesis of results for each surgical approach (arthrodesis, hemiarthroplasty and total arthroplasty) and grouped by type of implant (for total and hemiarthroplasties). Summary of results is presented as range (minimum and maximum) to prevent heterogeneity when pooling the results from different surgical approaches and types of implants.

### *Methodological quality*

All articles were reviewed for methodological quality using the methodological index for non-randomized studies (MINORs) scale (11). The MINORs scale is a validated instrument consisting of 12 items that assess the methodological quality of non-randomized cohort studies. There are four items that are specific to comparative methods and thus only applied to comparative studies. Each item was scored as 0 (if not reported), 1 (when reported but inadequate or incomplete), and 2 (when reported and adequate/complete). The maximum score is 16 for non-comparative studies and 24 for comparative studies.

## **Results**

### *Study selection*

The database search resulted in 2,058 potential titles. After duplicates exclusion 1,271 records remained. Titles and abstracts were screened and 109 full-texts were retrieved for eligibility assessment. A total of 46 studies were eligible (12-32) and included for qualitative evaluation (*Figure 1*) (33-53).

### *Methodological quality*

The methodological quality of the 46 included studies is displayed in [Table S2](#). Non-comparative studies had an average score of  $10.3 \pm 1.4$  out of 16 possible points ( $9.3 \pm 2.2$  for arthrodesis,  $10.5 \pm 2.2$  for total arthroplasty and  $10.6 \pm 0.8$  for hemiarthroplasty). Comparative studies scored a mean of  $15.5 \pm 1.2$  out of 24 possible points. The unbiased assessment

of the study aim and the prospective calculation of study size were the areas with major methodological concerns as only one study blinded their evaluators and none of the studies reported an *à priori* power sample size calculation. More than half of the included studies made a retrospective collection of data (29 studies) or did not make an adequate assessment of data at predetermined endpoints (26 studies). Half of the comparative studies did not have a homogenous sample at baseline.

### *Population demographic characteristics*

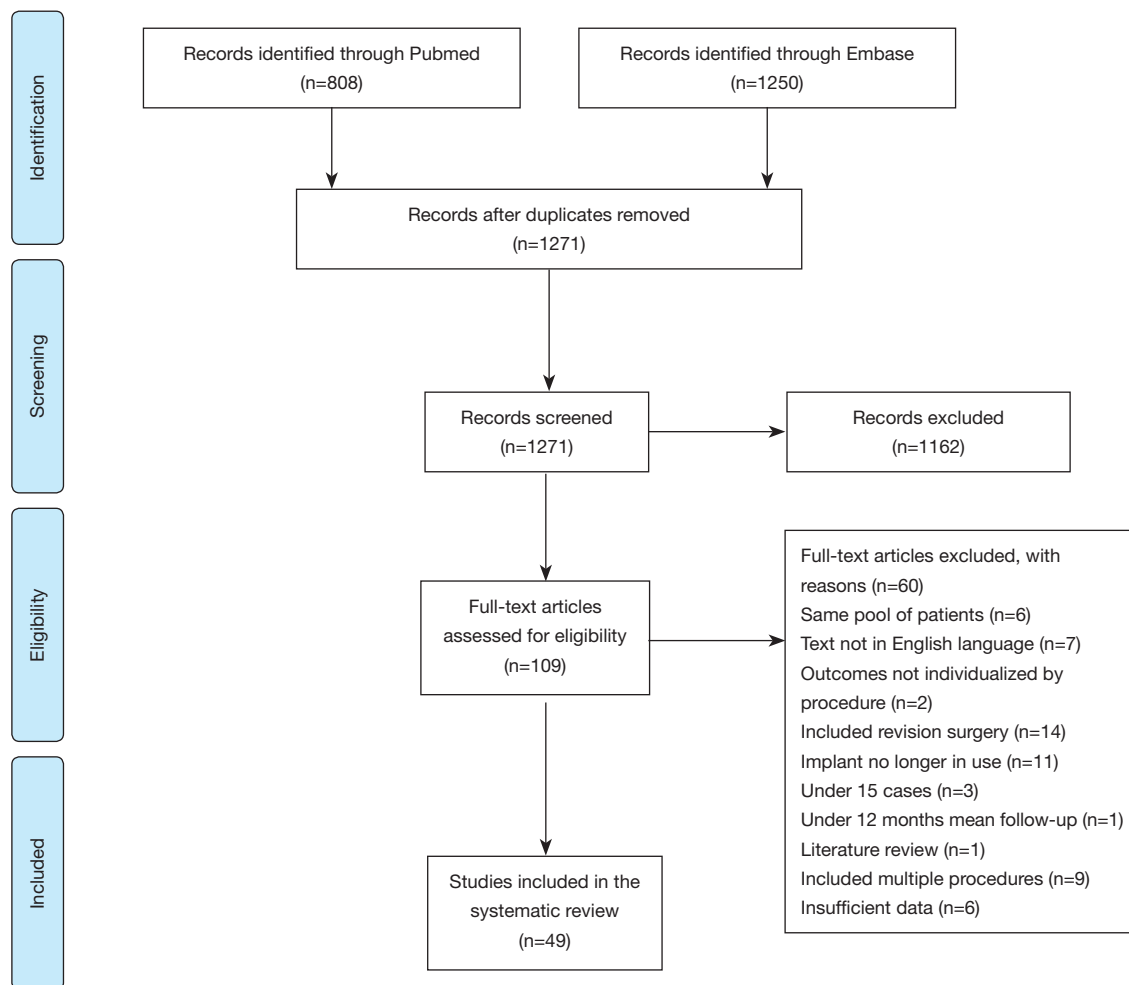
A total of 1,868 patients (2,056 first metatarsophalangeal joints) with a weighted mean age of 59.4 years were included in this systematic review. Most of patients were female (72%). Subgrouping by procedure, there was no relevant difference on the total number of patients, mean age or gender: the arthrodesis sample included 570 patients (mean 60.3 years old and 24% males) and 625 joints; the total arthroplasty 690 patients (mean 59.6 years old and 28% males) and 761 joints; and the hemiarthroplasty 608 patients (mean 58.3 years old and 31% males) and 670 joints.

### *Arthrodesis*

The American Orthopaedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal (AOFAS-HMI) score, was used to measure the clinical outcome in 9 of 12 studies. The AOFAS-HMI for arthrodesis studies ranged from 53 to 90 points at a follow-up of 15 months to 8 years. Ettl *et al.* (13) reported the lowest score (53 points), but the fusion rate was 100% and revision rate 0%. Kim *et al.* (16) on the other extreme reported a 90 points average score, but with a 9.8% prevalence of metatarsalgia and 7.8% of non-union. Regardless of the follow-up length, most articles reported an AOFAS-HMI score around 80 (*Table 1*). Most studies reported high rates (>90%) of good and excellent or satisfied and very satisfied (15,17,19). Simons *et al.* (18) reporting the largest series (n=132) showed the lowest satisfaction rate with only 64% of patients satisfied.

Fusion rates were high, ranging from 85.7% to 100%, with three studies reporting fusion in all treated cases (13,19,21). In the studies reporting larger series of patients (n>100), fusion rates were lower but still close to 100%, ranging from 90 to 96.3% (17,18).

The revision rate varied substantially, from 0% to 20.5%. Although half of the studies reported low revision rates



**Figure 1** PRISMA flow chart of database searches and included studies.

(0.0 to 5.9%), the other half reported considerably high revision rates, ranging from 9% up to 20.5%. These higher revision rates were associated with also higher rates of complications. Aas *et al.* (12) reports the highest rate (20.5%) which is consistent with the 10.3% non-union rate and 12.8% hardware discomfort. Hardware discomfort (2.5% to 12.8%), metatarsalgia (8.6% to 9.8%), wound infection (2.0% to 18.4%) and non-union (2.0% to 14.3%) were the most common complications (*Table 1*).

### Total arthroplasty

Eight different implants were described in the included studies (mostly comprising metallic components), with the ToeFit-Plus<sup>®</sup> and Moje<sup>®</sup> being the most commonly reported, in 37% and 21% of the studies, respectively

(*Table 2*).

ToeFit-Plus<sup>®</sup> was the most commonly reported implant (n=300). The postoperative AOFAS-HMI score was generally high, ranging from 80 to 100 points. Four studies (23,24,26,27) evaluated ROM and the postoperative ROM was usually around 55 degrees (52.7 to 59 degrees), except for Mermerkaya & Adli (27) who achieved 83 degrees at 2 years follow-up. Satisfaction was generally acceptable, ranging from 66% to 87.5%. Akkurt *et al.* (23) found in their series the lowest satisfaction rate (66%). The most frequent described complications were lucency (0% to 40%), loosening (2.9% to 8%), implant malalignment (2.1% to 2.9%), persistent pain (3.3% to 8.7%) and infection (1.5% to 3.3%). Lucency was the most frequent complication (5 out of 7 studies) and rates were generally high, reaching up to 40%. Titchener *et al.* (28) in a series of 86 patients

**Table 1** Clinical and functional outcomes after arthrodesis of the first metatarsophalangeal joint

Study	MINORS	No of MTPs	Mean age	Males	AOFAS-HMI pre-op	AOFAS-HMI post-op	Fusion rate	Revision rate	Satisfaction	Complications	Follow up (years)
Aas <i>et al.</i> [2008] (12)	9/16	35	52 [34–69]	40%	–	74	89.7%	20.5%	Excellent 84%	Non-unions 10.3%; hardware discomfort 12.8%	8 years
Ettl <i>et al.</i> [2003] (13)	5/16	34	52 [24–71]	21%	–	53	100%	0%	–	Wound infection 15.8%	5 years
Voskuil <i>et al.</i> [2015] (14)	17/24	50	63±7.1	16%	–	77.8	88%	13.8%	–	Non-union 12%; metatarsalgia 8.6%	4 years
Chraim <i>et al.</i> [2016] (15)	9/16	60	68.5 [55–81]	10%	40.9	79.3	93.3%	3.28%	Very satisfied 71.7%; satisfied 18.3%; acceptable 10%	Non-unions 6.7%; hardware discomfort 3.28%; wound infection 3.28%	4 years
Kim <i>et al.</i> [2012] (16)	15/24	51	60.5±9.7 [36–84]	39%	–	90	92.2%	5.9%	–	Metatarsalgia 9.8%; malalignment 7.8%; non-union 7.8%	4 years
Migues <i>et al.</i> [2013] (17)	10	76	68	16%	38	85	90%	9%	Excellent 61%; good 31%; fair 6%; poor 1%	Non-union 10% (symptomatic 5%); hardware discomfort 4%; wound infection 2%	3 years
Simons <i>et al.</i> [2015] (18)	16	132	59.6±9.5	26%	–	FAOS 80.2	96.3%	14.8%	Satisfied 64%; dissatisfied but would repeat 13%	Hardware discomfort or infection 11.1%; Non-union 3.7%	3 years
Raikin <i>et al.</i> [2007] (19)	15	26	54.1 [32–73]	38%	36.1	83.8	100%	11.1%	85% would repeat; excellent 78%; good 15%; fair 15%; poor 4%	Hardware discomfort 7.4%; dorsal osteophytes 3.7%	2.5 years
Lombardi <i>et al.</i> [2001] (20)	9	17	53.2 [36–77]	26%	39.1	76.5	85.7%	14.3%	Very satisfied 47%; satisfied 47%; somewhat dissatisfied 6%	Hardware discomfort 9.5%; non-union 14.3%	2 years
Latif <i>et al.</i> [2017] (21)	12	38	56 [20–74]	–	MOXFQ: walking 60, pain 58, social 42	MOXFQ: walking 8, pain 4, social 30	100%	2.5%	–	Hardware discomfort 2.5%	15 months
Marudanayagam & Appan [2014] (22)	11	51	58 [28–74]	23%	31	86	98%	2%	–	Non-union 2%; wound infection 4%	15 months

MINORS, methodological index for non-randomized studies; MOXFQ, Manchester Oxford Foot Questionnaire (100–0); FAOS, Foot and Ankle Outcome Score (0–100); AOFAS-HMI, American Orthopedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal (0–100).

Table 2 Clinical and functional outcomes after metatarsophalangeal total arthroplasty

Study	MINORS	Implant	N	No of MTPs	Mean age	Males	AOFAS-HIMI pre-op	AOFAS-HIMI post-op	ROM pre-op	ROM post-op	Satisfaction	Complications	Follow up (years)
Akkurt <i>et al.</i> [2016] (23)	9	Toefit-plus (metal)	30	30	66.2±5.3 [55-70]	20%	44	80	17	59	Excellent 66%; unsatisfactory 13%	Lucency 40%; persistent pain 3.3%; infection 3.3%; osteophyte formation 10%	2 years
Daniilidis <i>et al.</i> [2010] (24)	12	Toefit-plus (metal)	23	23	57.0±3.7	30%	44.6	82.5	28.1	52.7	Very satisfied 52.2%; satisfied 30.4%; dissatisfied 17.4%	Lucency 13%; persistent pain 8.7%	1 year
Duncan <i>et al.</i> [2014] (25)	11	Toefit-plus (metal)	57	69	61 [45-83]	21%	37	100	-	-	-	Lucency 33%; malalignment 2.9%; infection 1.5%; loosening 2.9%	2 years
Erkocak <i>et al.</i> [2013] (26)	11	Toefit-plus (metal)	24	26	55 [38-78]	-	42.7	88.5	25.9	53.8	Very satisfied 37.5%; satisfied 50%; dissatisfied 12.5%	Lucency 7.7%; wound healing delay 3.8%; metatarsal fracture 3.8%	2 years
Mermerkaya & Adli [2016] (27)	17	Toefit-plus (metal)	19	19	57.1±5.8 [45-66]	42%	25	75	31	83	-	No reported complications; Lucency 0%	2 years
Titchener <i>et al.</i> [2015] (28)	11	Toefit-plus (metal)	73	86	60.3 [38-83]	22%	41	91	-	-	-	Intra-operative fracture 9%; revision rate 24%; lucency 29%; loosening 8%	3 years
Dulgeroglu <i>et al.</i> [2017] (29)	10	Integra Movement (metal)	15	15	61.6±9.1 [44-74]	20%	26.9	78.7	22.3	77	Would repeat surgery 100%	No reported complications	2 years
Horisberger <i>et al.</i> [2016] (30)	11	Metis (metal)	25	29	63.1±10.2 [48-87]	40%	54.8	83.5	37.7	42	Fully satisfied 73.7%; satisfied 15.8%; partially satisfied 10.5%	Painful arthrofibrosis 17.2%; instability 3.4%; malalignment 3.4%; subluxation 3.4%	4 years
Wassink <i>et al.</i> [2017] (31)	12	Metis (metal)	53	58	58 [36-83]	-	49.6	82.0	26.9	34.4	Moderately to well satisfied 87.3%; moderately lucency 10.9%; completely dissatisfied 1.8%	Arthrofibrosis 10%; progressive deformity 2%; lucency 31%; loosening 2%	2 years
Tunstall <i>et al.</i> [2017] (32)	10	Roto-glide (metal)	30	33	58.6 [45-77]	30%	41.4	76	31	61	-	1 <sup>st</sup> metatarsal stress fracture 3%; 0% lucency	1 year

Table 2 (continued)

Table 2 (continued)

Study	MINORS	Implant	N	No of MTPs	Mean age	Males	AOFAS-HMI pre-op	AOFAS-HMI post-op	ROM pre-op	ROM post-op	Satisfaction	Complications	Follow up (years)
Karpe et al. [2018] (33)	12	Roto-glide (metal)	29	34	60.5 [45–77]	48%	41.2	89.1	29.6	68.2	Very satisfied 46.4%; satisfied 46.4%; dissatisfied 7.2%	Lucency 5.9%; wound infection 2.9%; severe pain and stiffness 5.9%	2 years
Kofoed et al. [2017] (34)	11	Roto-glide (metal)	80	90	58 [41–76]	34%	40	95	–	38 peak dorsiflexion	84% would repeat	2% implant infection; 4% reoperation for sesamoid; 16% periprosthetic cyst	12 years
Sinha et al. [2010] (35)	10	Bio-action (metal)	14	15	59	29%	–	62	–	–	Satisfied 57.1%; dissatisfied 42.9%	Phalangeal loosening 93.3%; metatarsal loosening 86.6%	5 years
Arbuthnot et al. [2008] (36)	12	Moje (ceramic)	40	42	–	–	36	84.2	9	33.30	82.5% satisfied; 5% dissatisfied	Implant sinking 2.4%; wound complications 7.1%	2 years
Barwick et al. [2008] (37)	10	Moje (ceramic)	22	24	54.5* [43–68]	23%	–	80	–	–	63% very satisfied; 20% somewhat dissatisfied	Persistent pain 62.5%; heterotopic ossification 25%	2 years
Chee e tal. [2011] (38)	10	Moje (ceramic)	37	41	62 [50–77]	16%	–	83.7	–	–	82.9% satisfied; 17.1% dissatisfied	Wound infection 2.4%; loosening 14.6%	3 years
Dawson-Bowling et al. [2012] (39)	10	Moje (ceramic)	30	32	61.9 [37–76]	30%	–	61.3	–	<36: 48%; >36: 52%	–	Loosening 52%; implant fracture 3.21%	8 years
Fieschi et al. [2017] (40)	8	Futura Primus (Silicone)	64	70	59.8±7.2 [45–77]	30%	51.6	88.9	–	–	–	Lucency 18.6%; loosening 36%; metatarsalgia 48.5%; wound infection 1.6%; severe pain 3.2%	7 years
Valentini et al. [2014] (41)	9	Reflexion	25	25	58.1	28%	45	90	–	72	–	Loosening 4%; subluxation 4%	1 year

\* , median. MINORS, Methodological index for non-randomized studies; AOFAS-HMI, American Orthopedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal; ROM, range of motion.

**Table 3** Implant survival after metatarsophalangeal total arthroplasty

Study	Implant	Survivorship 1 year	Survivorship 2 years	Survivorship 3–7 years	Survivorship 8–11 years	Survivorship >11 years
Akkurt <i>et al.</i> [2016] (23)	ToeFit-Plus (metal)	100%	100%	–	–	
Daniilidis <i>et al.</i> [2010] (24)	ToeFit-Plus (metal)	100%	–	–	–	
Duncan <i>et al.</i> [2014] (25)	ToeFit-Plus (metal)	–	92.8%	–	–	
Erkokocak <i>et al.</i> [2013] (26)	ToeFit-Plus (metal)	100%	100%	–	–	
Mermerkaya & Adli [2016] (27)	ToeFit-Plus (metal)	100%	100%			
Titchener <i>et al.</i> [2015] (28)	ToeFit-Plus (metal)	–	–	76%		
Dulgeroglu <i>et al.</i> [2017] (29)	Integra Movement (metal)	100%	100%	–	–	
Horisberger <i>et al.</i> [2016] (30)	Metis (metal)	–	–	86.3%	–	
Wassink <i>et al.</i> [2017] (31)	Metis (metal)	98%	96%	–	–	
Tunstall <i>et al.</i> [2017] (32)	Roto-glide (metal)	100%	–	–	–	
Karpe <i>et al.</i> [2018] (33)	Roto-glide (metal)	94.1%	94.1%	–	–	
Kofoed <i>et al.</i> [2017] (34)	Roto-glide (metal)	–	–	–	–	91.5%
Sinha <i>et al.</i> [2010] (35)	Bio-action (metal)	100%	100%	73.3%		
Arbuthnot <i>et al.</i> [2008] (36)	Moje (ceramic)	–	97.6%	–	–	
Barwick <i>et al.</i> [2008] (37)	Moje (ceramic)	100%	100%	–	–	
Chee <i>et al.</i> [2011] (38)	Moje (ceramic)	95.1%	92.7%	–	–	
Dawson-Bowling <i>et al.</i> [2012] (39)	Moje (ceramic)	–	–	–	74%	
Fieschi <i>et al.</i> [2017] (40)	Futura Primus (Silicone)	100%	100%	100%	–	
Valentini <i>et al.</i> [2014] (41)	Reflexion	96%	–	–	–	

reported 8% loosening and 9% intra-operative fractures with a high revision rate of 24% at 3 years follow-up. The survivorship was very high (100%) in most studies at up to 2 years (Table 3), but decreased significantly at 3 years follow-up (76%) (28).

Moje<sup>®</sup> is the only ceramic implant included and reported in 4 studies (n=138). At short-term (2 to 3 years), the AOFAS-HMI score was consistent, ranging from 80 to 84.2, with a satisfaction rate around 80% in two studies and 63% in another (36–38). At longer follow-up (8 years), the AOFAS-HMI score was considerably lower (61.3 points) (39). Complications were high at short-term with 62.5% persistent pain, 25% heterotopic ossification and 14.6% loosening, but especially at longer follow-up with a 52% loosening. The survival rate drops from 93% to 100% at 3 years to 74% at 8 years (Table 3).

Metis<sup>®</sup> is a three-component press fit metal prosthesis and was reported in 2 studies (n=87) (30,31). The postoperative AOFAS-HMI was around 82 points and the

ROM ranged from 34.4 to 42 degrees. Satisfaction was also consistent, with almost 90% of patients reporting that were well to moderately satisfied (89.5% and 87.3%). Arthrofibrosis was the most common complication (10% to 17.2%), but one study reported a 31% lucency. The implant survival was high (96%) at 2 years, but decreased to 86.3% at 5 years follow-up. The Roto-glide<sup>®</sup> implant was also reported in 3 studies (n=157) at short and long term follow up, achieving good and persistent functional results (76 to 95 in AOFAS-HMI) and high satisfaction rate (92.8% satisfied, 84% would repeat) with a low complication rate (32–34).

Integra Movement<sup>®</sup>, Bio-action<sup>®</sup> and Reflexion<sup>®</sup> implants were only reported in one study each. Integra Movement<sup>®</sup> implant (n=15) averaged an AOFAS-HMI score of 78.7, with 77 degrees of ROM and no reported complications at 2 years follow-up, with all patients stating that would repeat surgery (29). Bio-action<sup>®</sup> (n=15) showed disappointing results at 5 years follow-up, with 42.9%



of patients dissatisfied, 93.3% phalangeal and 86.6% metatarsal loosening (35). In turn, the Reflexion<sup>®</sup> implant (n=25) showed a very satisfying 90 points in AOFAS-HMI score and low complication rate but within a short period of follow-up (1year) (41).

Futura Primus<sup>®</sup>, the only silicone implant included, was reported in one study (n=64) with 7 years follow-up. The AOFAS-HMI score of 88.9 points and a 100% rate of implant survival at final follow-up were satisfying, but complications were frequent. Metatarsalgia was present in 48.5%, lucency was observed in 18.6% and loose implants were reported in 36% of patients (40).

### Hemiarthroplasty

Hemiarthroplasty implants were divided in two main types, phalanx base implant (7 studies, n=273) or metatarsal head implant (5 studies, n=200; *Table 4*).

Trihedron<sup>®</sup> and BioPro<sup>®</sup> were the two phalanx metallic implants included in this review. Trihedron<sup>®</sup> was only reported in a series of 23 cases that were followed for 5 years and achieved very satisfactory results, with an average AOFAS-HMI score of 88.2. Also, 91% of patients were satisfied or very satisfied and 0% of loosening or revision surgery were reported (53). The BioPro<sup>®</sup> implant was reported in 6 studies with a follow up ranging from 2 to 8 years. Functional evaluation scores used were heterogeneous, but all report good improvement from the pre-operative scores. The ROM was reported in three studies but varied considerably from 10 to 67.6 degrees (19,45,46). Most patients were satisfied with their implant, with up to 96.6% satisfaction rate (43). Only one study reported a high rate of complications, including 100% lucency, 24% loosening, 24% persisting pain and 44% plantar cut-out (19). Other studies reported a lower rate of complications (4.1% to 18%). Implant survival was moderate, ranging from 90.3%, 76% and 90.3% at 5, 6.5 and 8 years, respectively (*Table 5*).

HemiCap<sup>®</sup> is a two-part tapered metatarsal head metallic implant. It was reported in 7 studies with an average follow-up ranging from 1 to 10 years. Very satisfactory postoperative AOFAS-HMI score was reported in all articles (83 to 94.1 points) associated with an impressive improvement from pre to postoperatively (42.6 to 58.5 points). Postoperative ROM substantially increased ranging from 47.9 to 75 degrees (27,48,49,51). Satisfaction rates were impressive, ranging from 95% to 100%. Complication rates were very low and lucency and loosening were

consistently reported as not existent. Implant survival was mostly 100% at 1 and 2 years, 87–89% at 5 years and 89.2–97.8% at 7–10 years follow-up.

Cartiva<sup>®</sup> is a synthetic polyvinyl alcohol (PVA) hydrogel metatarsal head resurfacing implant and was reported in 1 study (n=119) at 5 years follow-up (42). Functional outcomes were measured by the Foot and Ankle Ability Measure Activities of Daily Living (FAAM-ADL) score and improved from 59.4 points pre-operatively to 91 at 5 years. Peak dorsiflexion slightly improved from 22.7 to 26 degrees. Overall, 87.6% of patients were satisfied and complications were low. The most frequent complication was persistent pain present in 7.1% of patients and osteolysis in 2.1%. Implant survival was 84.9% at 5 years follow-up.

### Discussion

Arthrodesis has been considered the gold standard treatment for advanced hallux rigidus, providing consistent and reliable results with a low complication rate, but at the cost of loss of joint ROM, diminished gait efficiency, and limitations in running and jumping sports, as well as footwear choice (6,7). In turn, arthroplasty allows restoration of motion, which improves propulsive power, weight bearing function of the foot, and stability during gait (24,54). The findings of this systematic review show comparable results for both arthrodesis and arthroplasty supporting the use of either approach, but for patients who wish to wear fashionable high heel shoes or desire to maintain recreational or competitive sports activities, in which maintaining metatarsophalangeal motion is paramount, the arthroplasty procedure is the most suitable surgical approach. The results from the studies included in this systematic review show that both arthrodesis and arthroplasty provide satisfactory outcomes and that both surgical approaches show comparable outcomes.

Arthrodesis for advanced hallux rigidus can achieve favourable postoperative functional outcomes and high patient satisfaction rates. The fusion rate was high as expected but the revision rate is inconsistent (0% to 20.5%) and usually associated with postoperative complications, including hardware discomfort, metatarsalgia, wound infection and non-union.

Total metatarsal arthroplasties have regained popularity in recent years. Total metallic joint replacement implants showed comparable results to arthrodesis at short-term follow-up but slightly worst outcomes at medium to long-term follow-up, displaying higher complication rates and

**Table 4** Clinical and functional outcomes after metatarsophalangeal hemiarthroplasty

Study	MINORS	Implant	N	No of MTPs	Mean age	Males	AOFAS pre-op	FAAM-ADL 91	AOFAS post-op	PDF pre-op	ROM pre-op	PDF post-op	ROM post-op	Satisfaction	Complications	Follow up (years)
Glazebrook et al. [2018] (42)	11	Cartiva (PVA)	112	119	58.2±8.8 [31-79]	33%	FAAM-ADL 59.4	89.7	89.7	22.7	-	26	26	Satisfied 87.6%	Persistent pain 7.1%; infection 0.9%; osteolysis 2.1%	5 years
Beekhuizen et al. [2018] (43)	15	BioPro (metallic phalanx)	27	31	58.3±6.9 [36-67]	37%	-	-	-	<20	Range 30 to 75	-	-	Very satisfied 80.6%; satisfied 16%	Loosening 3.2 %; limited ROM 6.5%	8 years
Raikin et al. [2007] (19)	15	BioPro (metallic phalanx)	20	21	59.7 [39-70]	30%	35.6	71.8	71.8	-	10	-	-	60% would repeat; excellent 24%; good 33%; fair 10%; poor 33%	Loosening 24%; pain 24%; plantar cutout 44%; osteolysis 100%	6.5 years
Clement et al. [2016] (44)	11	BioPro (metallic phalanx)	80	97	55 [22-74]	24%	MOFQ 53.2	MOFQ 33.2	MOFQ	-	-	-	-	ROM satisfaction 90%; general satisfaction 75%	Deep infection 1%; osteolysis 2%; persistent pain 12%	5 years
Voskuil et al. [2015] (14)	17	BioPro (metallic phalanx)	33	36	60±6.6 [47-78]	24%	-	77.8	77.8	-	-	-	-	Metatarsalgia 8.3%	-	3 years
Simons et al. [2015] (18)	16	BioPro (metallic phalanx)	46	50	61.9±8.4	2%	-	79.2	79.2	-	-	-	-	Satisfied 81.6%; not satisfied 19.4%	Pain 4.1%	3 years
Giza et al. [2010] (45)	11	BioPro (metallic phalanx)	20	22	61 [46-80]	35%	61	86	86	32.7	48.1	-	-	Wound infection 4%; stiffness 14%	-	2 years
Kissel et al. [2008] (46)	10	BioPro (metallic phalanx)	23	23	56.9±9.2 [42-80]	30%	ACFAS 41.2	ACFAS 80.4	ACFAS	20.5	67.6	-	-	-	-	1 year
Carpenter et al. [2010] (47)	10	HemiCap (metallic head)	32	32	62.8±9.7 [39-86]	28%	30.84	89.31	89.31	-	-	-	-	Satisfied 100%; would repeat surgery 100%	No reported complications	2 years
Mermerkaya & Adli [2016] (27)	17	HemiCap (metallic head)	26	28	56.3±4.5 [47-63]	46%	33	87.7	87.7	27.5	75	-	-	Wound infection 3.6%; lucency/loosening 0%	-	2 years
Aslan et al. [2012] (48)	11	HemiCap (metallic head)	25	27	58 [40-71]	24%	40.94	85.1	85.1	14.36	54.38	-	-	Wound infection 3.7%	-	3 years
Kline & Hasselman [2013] (49)	12	HemiCap (metallic head)	26	30	51 [35-74]	43%	51.5	94.1	94.1	19.7	47.9	-	-	Lucency/loosening 0%; wound infection 3.3%; phalangeal arthrosis 13%	-	5 years

**Table 4** (continued)

Table 4 (continued)

Study	MINORS	Implant	N	No of MTPs	Mean age	Males	AOFAS pre-op	AOFAS post-op	ROM pre-op	ROM post-op	Satisfaction	Complications	Follow up (years)
Akiki <i>et al.</i> [2018] (50)	11	HemiCap (metallic head)	20	21	63 [53–68]	20%	32	88	-	-	95% completely satisfied	5% implant malpositioning; 0% radiolucency	6 years
Mermerkaya <i>et al.</i> [2018] (51)	10	HemiCap (metallic head)	57	65	61.0±6.4 [44–78]	44%	34	83	25	75	-	Persistent pain 12.3%; lucency/loosening 0%	7 years
Hilario <i>et al.</i> [2017] (52)	9	HemiCap (metallic head)	42	45	57.4 [33–86]	36%	36.6	90.6	-	-	Satisfied 97.8%; dissatisfied 2.2%	Persistent pain 2.22%; dorsal osteophytes 2.22%	10 years
Sorbie & Saunders [2008] (53)	11	Triherdron (metallic phalanx)	19	23	52.9 [35–70]	47%	56.8	88.2	-	-	Very pleased 52%; pleased 39%; disappointed 9%	0% loosening	5 years

MINORS, methodological index for non-randomized studies; AOFAS-HMI, American Orthopedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal (0–100); ROM, range of motion; PVA, polyvinyl alcohol hydrogel; PDF, peak dorsiflexion; FAAM-ADL, Foot and Ankle Ability Measure activities of daily living (0–100); MOXFQ, Manchester Oxford Foot Questionnaire (100–0); ACFAS, American College of Foot and Ankle Surgeons (0–100).

heterogeneous patient satisfaction levels (57% to 84%) (34,35,39). Gupta & Masud (55), not included on the review for lack of functional evaluation, retrospectively reviewed 47 patients for a period of 11 years and based on low satisfaction, high complications, high revision rate and complexity of revision surgeries, concluded that arthrodesis was a better option and recommended against ToeFit-Plus implants. Titchener *et al.* (28) published the mid-term outcomes of ToeFit-Plus® and indicated that the revision rate was unacceptably high and subsequently discontinued its use. Other implants with less studies, shorter follow-up periods and smaller series were evaluated, but except for Roto-glide with good functional results, low complication and high patient satisfaction rates at 2 years follow-up, all implants displayed similar outcomes when compared to ToeFit-Plus. Bio-action had a very disappointing performance with 42.9% dissatisfied patients and an astonishing 86.6% loosening rate, and its use is thus not recommended (35). Although the popularity significantly decreased since 1995, some silicone implants persist in the market and are still fairly commonly used. These may be suitable for low demand elderly patients but may cause silastic granulomas, which then make revision difficult (56). Second generation ceramic total metatarsophalangeal arthroplasty show poor to suboptimal functional and patient satisfaction outcomes with high complication rates, especially persistent pain and implant loosening. For these reasons, the routine use of this implant is not recommended (30,31).

Hemiarthroplasty is formed by two major types, depending on which surface is replaced—phalanx base or metatarsal head. BioPro® is a metallic implant and is in use since 1952, which makes it one of the most used and studied phalanx base implant. Most studies report high patient satisfaction rates combined with few complications. However, it must be considered that one study (19) reported an unacceptably high rate of complications, including 100% lucency, 24% of implant loosening, 24% persisting pain and 44% plantar cut-out. When compared to arthrodesis, Raikin *et al.* (19) noted a failure rate of 24% in the arthroplasty group at 6.5 years follow-up and concluded that arthrodesis was more predictable in alleviating symptoms and restoring function. Conversely, Beekhuizen *et al.* (43) showed that functional outcomes were more favourable for hemiarthroplasty and recommended this procedure for patients with metatarsophalangeal osteoarthritis, with preference for younger more active patients. Although phalanx base were the most used implants in the past, this

**Table 5** Implant survival after metatarsophalangeal hemiarthroplasty

Study	Implant	Survivorship 1 year	Survivorship 2 years	Survivorship 5–6 years	Survivorship 7–10 years
Glazebrook <i>et al.</i> [2018] (42)	Cartiva (PVA)	–	90.8%	84.9%	–
Beekhuizen <i>et al.</i> [2018] (43)	BioPro (metallic phalanx)	–	–	–	90.3%
Raikin <i>et al.</i> [2007] (19)	BioPro (metallic phalanx)	100%	76%	76%	–
Clement <i>et al.</i> [2016] (44)	BioPro (metallic phalanx)	94.8%	92.8%	85.6%	–
Voskuijl <i>et al.</i> [2015] (14)	BioPro (metallic phalanx)	–	92.7%	–	–
Simons <i>et al.</i> [2015] (18)	BioPro (metallic phalanx)	98%	95.9%	–	–
Giza <i>et al.</i> [2010] (45)	BioPro (metallic phalanx)	–	91%	–	–
Kissel <i>et al.</i> [2008] (46)	BioPro (metallic phalanx)	100%	–	–	–
Carpenter <i>et al.</i> [2010] (47)	HemiCap (metallic head)	100%	100%	–	–
Mermerkaya & Adli [2016] (27)	HemiCap (metallic head)	100%	100%	–	–
Aslan <i>et al.</i> [2012] (48)	HemiCap (metallic head)	100%	100%	–	–
Kline & Hasselman [2013] (49)	HemiCap (metallic head)	100%	100%	87%	–
Akiki <i>et al.</i> [2018] (50)	HemiCap (metallic head)	100%	100%	100%	–
Mermerkaya <i>et al.</i> [2018] (51)	HemiCap (metallic head)	92.3%	89.2%	89.2%	89.2%
Hilario <i>et al.</i> [2017] (52)	HemiCap (metallic head)	–	–	–	97.8%
Sorbie & Saunders [2008] (53)	Triherdron (metallic phalanx)	100%	100%	100%	–

PVA, polyvinyl alcohol hydrogel.

trend is shifting towards metatarsal head implants in more recent years. Metatarsal head hemiarthroplasties have the advantage of allowing minimal bone resection of the joint and not interfering with the intrinsic muscle insertions at the proximal phalanx, still leaving arthrodesis without bone graft as a viable option (52). Indeed, this systematic review showed excellent outcomes for metatarsal head hemiarthroplasties. AOFAS-HMI scores were very close to 90 in most studies and patient satisfaction rate was nearly 100. Unlike most implants, loosening and lucency did not occur and showed consistent survival rates. Metatarsal head resurfacing can be considered with a prognosis of excellent outcomes, low risk of complications and high survival at long term follow-up. This is an effective option to recover function and motion, but might not be appropriated to patients older than 70 years (51). Synthetic cartilage substitutes are a viable option, to achieve decreased pain and improved function that are comparable to metatarsophalangeal arthrodesis, with the advantage of preserving or improving dorsiflexion (42).

A recent meta-analysis of comparative studies between arthrodesis and arthroplasty also concluded that the

clinical outcomes, patient satisfaction, reoperation rate and complication rate were equivalent between the two surgical approaches, with only pain intensity being greater in arthroplasty (57). Their conclusions are in line with the findings reported in this systematic review. We provide however a broader overview of outcomes from all available studies, including the report of results subgrouped by type of implant. This will provide the orthopaedic surgeon a summary of available results for each type of implant and help them make a more informed decision when choosing surgical technique and type of implant in case of opting to perform an arthroplasty.

There is still not enough high-quality evidence to achieve ascertain superiority of one of the techniques and to provide a definitive recommendation. Metatarsal head hemiarthroplasty (either metallic or cartilage substitute) showed to be comparable to arthrodesis, but with the advantage of preserving function, toe length, gait pattern and allowing normal footwear. Moreover, when metatarsal head hemiarthroplasty fails, given the small bone resection, still allows the conversion to arthrodesis without bone graft and not compromising the results. These features make

metatarsal head hemiarthroplasty a more suitable solution for young and active patients and may be considered as first-line treatment in this population.

Further research is warranted to achieve stronger and more definitive conclusions. Future studies should focus on comparing arthrodesis and total and/or hemiarthroplasty through well-designed and high-powered randomized controlled trials.

This review has some limitations. The level of evidence of the included studies is low which precludes more strong and definitive conclusions. Comparative studies were scarce and included studies using different functional scores, satisfaction and ROM evaluation methods which precluded meta-analysis of results and hampered more direct comparisons.

## Conclusions

Arthrodesis provides good reliable results with low complication rates, more predictable functional scores and a higher patient satisfaction than total joint arthroplasty. Metatarsal head hemiarthroplasties, either metal or synthetic cartilage substitutes showed comparable outcomes to arthrodesis, but with the advantages of preserving metatarsophalangeal motion, allowing normal gait pattern, use of fashionable footwear, facilitating sports activities and still allowing conversion to arthrodesis without bone graft due to the minimal bone resection. These advantages make the metatarsal head hemiarthroplasty a more suitable option for young and active patients. Future research should focus on comparing these approaches in high-power randomized controlled trials to allow stronger and more definitive recommendations.

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**Table S1** Database searches and results

Database	Search strategy
Pubmed; results: 808	(("first metatarsophalangeal joint" [Title/Abstract] OR "hallux" [Title/Abstract]) AND (osteoarthritis OR arthritis OR rigidus OR valgus) AND (arthrodesis [Title/Abstract] OR hemiarthroplasty [Title/Abstract] OR arthroplasty [Title/Abstract] OR fusion [Title/Abstract])
EMBASE; results: 1,250	('first metatarsophalangeal joint':ab,ti OR 'hallux':ab,ti) AND (osteoarthritis OR arthritis OR rigidus OR valgus) AND (arthrodesis OR hemiarthroplasty OR arthroplasty OR fusion)



Table S2 MINORS scoring for the included studies

First author [year]	Clearly stated aim	Inclusion of consecutive patients	Prospective data collection	End points appropriate to study aim	Unbiased assessment of study aim	Follow-up period appropriate to study aim	Loss to follow-up (<5%)	Prospective calculation of study size	Adequate control group	Contemporary Groups	Baseline Equivalence Of Adequate Statistical Analysis	Total
Arthrodesis												
Aas [2008] (12)	2	2	1	1	0	2	1	0	NA	NA	NA	9
Ettl [2003] (13)	1	1	1	0	0	2	0	0	NA	NA	NA	5
Chraim [2016] (15)	2	1	1	1	0	2	2	0	NA	NA	NA	9
Mígues [2013] (17)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Lombardi [2001] (20)	2	1	1	1	0	2	2	0	NA	NA	NA	9
Latif [2017] (21)	2	2	2	2	0	2	2	0	NA	NA	NA	12
Marudanayagam & Appan [2014] (22)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Total arthroplasty												
Akkurt [2016] (23)	2	2	1	1	0	2	1	0	NA	NA	NA	9
Daniilidis [2010] (24)	2	2	2	2	0	2	2	0	NA	NA	NA	12
Duncan [2014] (25)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Erkokak [2013] (26)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Titchener [2015] (28)	2	2	2	2	0	2	1	0	NA	NA	NA	11
Dulgeroglu [2017] (29)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Horisberger [2016] (30)	2	2	2	2	0	2	1	0	NA	NA	NA	11
Wassink [2017] (31)	2	2	2	2	0	2	2	0	NA	NA	NA	12
Tunstall [2017] (32)	2	2	2	1	0	2	1	0	NA	NA	NA	10
Karpe [2018] (33)	2	2	2	2	0	2	2	0	NA	NA	NA	12
Sinha [2010] (35)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Kofoed [2017] (34)	2	2	2	1	1	2	1	0	NA	NA	NA	11
Arbuthnot [2008] (36)	2	2	2	2	0	2	2	0	NA	NA	NA	12
Barwick [2008] (37)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Chee [2011] (38)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Dawson-Bowling [2012] (39)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Fieschi [2017] (40)	2	1	1	1	0	2	1	0	NA	NA	NA	8
Valentini [2014] (41)	2	1	1	1	0	2	2	0	NA	NA	NA	9
Hemiarthroplasty												
Glazebrook [2019] (42)	2	2	2	2	0	2	1	0	NA	NA	NA	11
Clement [2016] (44)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Giza [2010] (45)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Kissel [2008] (46)	2	2	2	1	0	2	1	0	NA	NA	NA	10
Carpenter [2010] (47)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Aslan [2012] (48)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Kline & Hasselman [2013] (49)	2	2	2	2	0	2	2	0	NA	NA	NA	12
Akiki [2018] (50)	2	2	2	1	0	2	2	0	NA	NA	NA	11
Mermerkaya [2018] (51)	2	2	1	1	0	2	2	0	NA	NA	NA	10
Hilario [2017] (52)	2	2	1	1	0	2	1	0	NA	NA	NA	9
Sorbie & Saunders [2008] (53)	2	2	1	2	0	2	2	0	NA	NA	NA	11
Comparative												
Voskuil [2015] (14)	2	2	1	1	0	2	1	0	2	2	2	17
Kim [2012] (16)	2	2	1	1	0	2	0	0	2	2	1	15
Simons [2015] (18)	2	1	1	1	0	2	0	0	2	2	1	14
Raikin [2007] (19)	2	2	1	1	0	2	0	0	2	1	2	15
Mermerkaya & Adli [2016] (27)	2	2	1	1	0	2	1	0	2	2	2	17
Beekhuizen [2018] (43)	2	0	1	1	0	2	2	0	2	2	1	15