NATIONAL INSTITUTE FOR HEALTH AND CARE EXCELLENCE

INTERVENTIONAL PROCEDURES PROGRAMME

Interventional procedure overview of synthetic cartilage implant insertion for first metatarsophalangeal joint osteoarthritis (hallux rigidus)

Osteoarthritis in the big toe joint (the first metatarsophalangeal joint) can result in a condition called hallux rigidus. Cartilage in the joint wears away, causing pain and stiffness. In this procedure, which is done under general or regional anaesthesia, damaged cartilage is replaced with an artificial (synthetic) implant. A small cut is made over the top of the big toe joint, a hole is drilled into the bone and the implant is pressed into the hole. The aim is to reduce pain and improve mobility.

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Abbreviations

Word or phrase	Abbreviation
Activities of daily living	ADL
US Food and Drug Administration	FDA
Foot and Ankle Ability Measure	FAAM
Intent to treat	ITT
Manchester Oxford Foot/Ankle Questionnaire	MOXFQ
Manufacturer and User Facility Device Experience database	MAUDE
Modified intent to treat	mITT
MTP	Metatarsophalangeal
Patient Reported Outcomes Measurement Information System	PROMIS
Randomised controlled trial	RCT
Standard deviation	SD
Visual analogue scale	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 September 2020 and updated in October 2021.

Procedure name

- Synthetic cartilage implant insertion for first metatarsophalangeal joint osteoarthritis (hallux rigidus)

Professional societies

- British Orthopaedic Foot & Ankle Society
- British Orthopaedic Association
- The College of Podiatry.

Description of the procedure

Indications and current treatment

Osteoarthritis is a common condition in which the surface of the joint becomes worn and the adjacent bone thickens and forms osteophytes. It can affect the metatarsophalangeal (MTP) joint at the base of the big toe, which may become painful and stiff (hallux rigidus).

Conservative treatments include exercise, physiotherapy, orthotics, analgesics, non-steroidal anti-inflammatory tablets and cream, and steroid injections into the joint. Severe first MTP joint osteoarthritis that does not respond to conservative measures may need surgery. If an osteophyte on the surface of the joint is the only problem, it can be trimmed (cheilectomy). The main surgical options for treating the whole joint are fusion, osteotomy, joint replacement or rarely excision arthroplasty.

What the procedure involves

Synthetic cartilage implant insertion for first MTP joint osteoarthritis (hallux rigidus) is usually done under general or regional anaesthesia. A moulded cylindrical implant made of polyvinyl alcohol (a soft plastic-like substance) and saline is used with specifically designed single-use instruments. A small incision is made over the top of the big toe joint and a drill is used to remove enough bone to make an appropriately-sized hole for the implant. The implant is then placed into the hole in the bone and left slightly raised, providing a smooth and slippery surface in the area of the cartilage defect. Once the implant is in place, the incision is closed with sutures. Weight bearing can typically resume immediately after the procedure. The aim is to reduce pain and improve the toe's range of motion.

Outcome measures

Foot and Ankle Ability Measure

The Foot and Ankle Ability Measure (FAAM) is a validated outcome measure with 29 items made up of sports and activity of daily living (ADL) subscores. Responses are scored from 4 to 0 ranging from 'No difficulty at all' to 'Unable to do'. Patients may also respond 'Not applicable' if an activity in question is limited by something other than their foot or ankle. The score total ranges from 0 to 84 for the ADL subscale and 0 to 32 for the sports subscale, which is converted to a percentage score. Higher scores represent higher levels of function with 100% representing no dysfunction. The reported minimal clinically important difference is 9 points for the sports score and 8 points for the ADL score.

Manchester Oxford Foot/Ankle Questionnaire

The Manchester Oxford Foot/Ankle Questionnaire (MOXFQ) is a validated measure of health-related quality of life. It has 3 domains: pain, walking or standing, and social interaction, with a maximum score of 100 in each domain. Higher scores signify poorer quality of life.

Efficacy summary

Function

In a randomised controlled trial (RCT) of 219 patients, 79% of patients who had implant insertion and 62% of patients who had arthrodesis had a successful outcome in the intention-to-treat population. This was defined as improvement

from baseline in the VAS of pain of 30% or more at 12 months, maintenance of function from baseline in Foot and Ankle Ability Measure (FAAM) sports subscore at 12 months, and absence of major safety events ($p<0.001$ for non-inferiority). In a modified intention-to-treat population (all patients who had treatment), the proportion of patients with a successful outcome was 80% in both groups ($p<0.0075$ for non-inferiority). The mean FAAM sports score was 66.6 in the implant group (n=120) and 78.6 (n=42) in the arthrodesis group at 6-month follow up ($p=0.01$). At 1 year, the scores were 75.8 (n=120) and 84.1 (n=43; $p=0.043$), and at 2 years they were 79.5 (n=113) and 82.7 (n=41) respectively ($p=0.461$). The mean SF-36 physical functioning scores were 72.3, 78.9 and 83.2 in the implant group at 6 months (n=124), 1 year (n=123) and 2 years (n=116) respectively and 82.8, 83.7 and 85.1 respectively in the arthrodesis group (n=43, n=43 and n=41; $p=0.021$, $p=0.247$ and $p=0.613$) (Baumhauer, 2016). Success rates between the groups were similar when stratified by hallux rigidus grade, gender, age, body-mass index, symptom duration, previous surgery status, preoperative VAS pain, hallux valgus and range of motion (Goldberg, 2017). In a case series of 119 patients who were in the implant group of the RCT, the mean change in FAAM sports was 47.9 points (95% confidence interval [CI] 39.3 to 57.1) at final follow up (mean 5.8 years). Of 105 patients who still had the implant at final follow up, 97 (93%) had a clinically significant improvement in FAAM sports score (Glazebrook, 2019).

In a non-randomised comparative study of 72 patients, the mean postoperative FAAM sports scores were 76% for patients who had implant insertion and 81% for patients who had arthrodesis ($p>0.3$, Brandao, 2020a). In a non-randomised comparative study of 133 patients treated by cheilectomy and Moberg osteotomy with or without a synthetic cartilage implant, there were statistically significant improvements in the Patient-Reported Outcomes Measurement Information System (PROMIS) for physical function, pain interference, pain intensity, and global physical health domains within each group after surgery ($p<0.01$). Patients who did not have an implant inserted had statistically significantly higher postoperative physical function, lower pain intensity and a greater improvement in physical function compared with those patients who did have an implant (Chrea, 2020). In a non-randomised comparative study of 78 patients who had synthetic cartilage implant insertion or cheilectomy, the mean postoperative FAAM sports scores were 74.9% and 82.7%, respectively ($p=0.11$) (Brandao, 2020c).

In a case series of 55 patients, the mean objective FAAM ADL scores improved from 64% at baseline to 87% at follow up (mean 21 months; $p<0.0001$) (Brandao, 2020b).

In a case series of 60 patients (64 implants), the mean PROMIS physical function score was 42 at follow up (mean 15 months), reported as corresponding to mild dysfunction (Cassinelli, 2019). In a case series of 103 patients, the mean PROMIS physical function score improved from 44.7 to 48.2 at follow up (mean 14 months; p=0.009) (Eble, 2020).

In a case series of 16 patients (18 implants) who had MRI after the implant insertion because of persistent pain or dysfunction at the metatarsophalangeal joint, the mean PROMIS physical function score was 41 (range 27 to 56) at follow up (mean 21 months), reported as corresponding to moderate dysfunction (An, 2020).

In a non-randomised comparative study of 181 patients, the mean PROMIS physical function score improved from 47.1 to 51.1 in patients who had synthetic cartilage implant insertion and from 43.9 to 45.9 in patients who had arthrodesis at final follow up (mean 27 months and 38 months respectively). The difference in scores between the groups was statistically significant at both baseline and final follow up ($p<0.01$) (Joo, 2021).

In a case series of 90 patients (96 implants), the range of motion was better after surgery in 69% (66/96) of implants and worse in 24% (23/96) of implants (Lee, 2021).

Dorsiflexion

In the RCT of 219 patients, the mean active peak dorsiflexion angles were statistically significantly higher in the implant group compared with the arthrodesis group after treatment. The results were 25.1, 28.1, 28.8 and 29 at 6 weeks, 6 months, 1 year and 2 years, respectively, in the implant group compared with 13.0, 14.9, 16.0 and 15.1 in the arthrodesis group; $p<0.0001$ for all time periods (Baumhauer, 2016).

Pain

In the RCT of 219 patients, the VAS pain scores were statistically significantly higher in the implant group compared with the arthrodesis group after treatment. The scores were 33.2, 28.9, 17.8 and 14.5 at 6 weeks, 6 months, 1 year and 2 years, respectively, in the implant group compared with 17.2, 11.7, 5.7 and 5.9 in the arthrodesis group; $p<0.0001$, $p<0.000$, $p<0.0011$, $p<0.002$ (Baumhauer, 2016).

In the case series of 60 patients, the mean PROMIS pain interference score was 60 at follow up (mean 15 months), reported as corresponding to mild pain (Cassinelli, 2019). In the case series of 103 patients, the mean pain interference

score reduced from 58.0 to 52.5 (p<0.0001) and pain intensity score reduced from 50.9 to 43.5 (p<0.0001) at follow up (mean 14 months) (Eble, 2020).

In the non-randomised comparative study of 78 patients who had synthetic cartilage implant insertion or cheilectomy, the MOXFQ pain score was 27.5 and 27.2, respectively, after the procedure (p=0.6818) (Brandao, 2020c).

In the case series of 16 patients, the mean PROMIS pain interference score was 63 at follow up (mean 21 months), reported as corresponding to moderate pain (An, 2020).

In the non-randomised comparative study of 181 patients, the mean PROMIS pain interference score improved from 55.6 to 49.4 in patients who had synthetic cartilage implant insertion and from 57.4 to 48.2 in patients who had arthrodesis at final follow up (mean 27 months and 38 months, respectively). The difference between the groups was not statistically significant (Joo, 2021).

In the case series of 90 patients (96 implants), the mean VAS pain score reduced from 7.9 at baseline to 1.5 after the procedure (p<0.001) (Lee, 2021).

Quality of life

In the RCT of 219 patients, the mean FAAM ADL scores reported at 6 weeks, 6 months, 1 year and 2 years were 69.0, 82.7, 88.6 and 90.4 in the implant group compared with 59.6, 89.9, 94.1 and 94.6 in the arthrodesis group (p=0.008, p=0.014, p=0.0176, p=0.082), respectively (Baumhauer, 2016). In the non-randomised comparative study of 78 patients who had synthetic cartilage implant insertion or cheilectomy, the MOXFQ index was 27.0 and 14.1, respectively, after the procedure (p=0.012) (Brandao, 2020c).

Need for further surgery or implant survivorship

In the RCT of 219 patients, 11% (17/152) of patients who had synthetic cartilage implant insertion had the implant removed or another operation at the 2-year follow up. Of these, 14 had conversion to arthrodesis, 1 had joint manipulation for motion, 1 had debridement and implant repositioning and 1 had Moberg osteotomy of the proximal phalanx for improved toe positioning, motion and pain relief (Baumhauer, 2016). In the case series of 119 patients from the implant group of the RCT, 9 (8%) patients had implant removal and conversion to arthrodesis between years 2 and 5. Kaplan−Meier implant survivorship was 85% at 5.8 years of follow up (Glazebrook, 2019).

In the non-randomised comparative study of 72 patients, 1 patient in the implant group had revision to arthrodesis 17 months later because of persistent pain

(Brandao, 2020a). In the non-randomised comparative study of 133 patients, 5% (3/60) of patients who had an implant needed revision surgery compared with 1% (1/73) of patients who did not have an implant (Chrea, 2020).

In the case series of 60 patients (64 implants), reoperation was needed after 20% (13/64) of procedures. This included 5 conversions to fusion, 4 lysis of adhesions, 1 Moberg osteotomy and 3 implant exchanges with bone grafting. Conversion to fusion was done at a mean of 16 months after the implant insertion (Cassinelli, 2019). In the case series of 55 patients, there were 2 revisions at 14 and 17 months, respectively. Of the 55 patients, 15 (27%) had manipulation under anaesthesia and steroid and local anaesthetic injection at 12 weeks after the operation because of stiffness (Brandao, 2020b).

In the case series of 103 patients, the revision rate was 2% (2/103). One patient had a conversion to arthrodesis at 14 months after the index procedure; the implant was noted to be loose, with inflammation and fibrous tissue at the joint. The other patient had a hemiarthroplasty with synthetic cartilage implant, done at 21 months after the operation. The implant was found to have marked loss of contour at the medial aspect of the toe (Eble, 2020).

In the case series of 16 patients, the reoperation rate by 2 years was 38% (6/16), including 2 conversions to fusion (An, 2020).

In the non-randomised comparative study of 181 patients, 3% (2/59) of patients who had a synthetic cartilage implant inserted had the implant removed and conversion to arthrodesis after 12 and 21 months, respectively (Joo, 2021).

In the case series of 90 patients (96 implants), 2% (2/96) of implants were revised to arthrodesis at 13 and 23 months, respectively, after the index procedure (Lee, 2021).

Patient satisfaction

In the case series of 119 patients, 56% (59/105) of patients strongly agreed and 31% (33/105) agreed to the statement that their overall wellbeing had improved. When asked if they would have the procedure again, 93% (99/106) said they would and 7% (7/106) said they would not (Glazebrook, 2019).

In the case series of 60 patients (64 implants), 14% (9/64) of patients were very satisfied, 28% (18/64) were satisfied, 20% (13/64) were neutral, 11% (7/64) were unsatisfied and 27% (17/64) were very unsatisfied after the procedure. The proportion of patients who said they would have the same surgery again was 66% (42/64) (Cassinelli, 2019). In the case series of 55 patients, patient satisfaction was 89% (Brandao, 2020b).

In the case series of 16 patients, the mean satisfaction rating was 2.25 on a 5-point Likert scale (An, 2020).

In the case series of 90 patients (96 implants), patients were very satisfied after 42% (40/96) of implants, satisfied after 32% (31/96), neutral after 8% (8/96), unsatisfied after 8% (8/96) and very unsatisfied after 9% (9/96) of implants (Lee, 2021).

Safety summary

General

In an RCT of 219 patients, the rate of any adverse event was 69% in the implant group and 72% in the arthrodesis group (p=0.727). For any serious adverse event, the rates were 20% and 18%, respectively (p=0.999) (Baumhauer, 2016).

Pain or inflammation

Serious pain at the implant site was reported in 5% (5/112) of patients in a case series of 119 patients. All 5 patients had the implant removed and conversion to arthrodesis, as described in the efficacy section (Glazebrook, 2019).

In a case series of 60 patients (64 implants), 30% (19/64) of implants had advanced imaging workup after the procedure. This was for continued pain, inflammation and further evaluation of the implant and surrounding structures (mean 12 months follow up, range 3 to 30 months). MRIs showed residual capsular inflammation in all patients, bone marrow oedema of the proximal phalanx or metatarsal in 18 patients, and degenerative changes or inflammation at the metatarsosesamoid articulation in 7 patients (Cassinelli, 2019).

In a case series of 16 patients (18 implants) who had postoperative MRI for persistent pain or dysfunction, 78% (14/18) of implants had evidence of fluid around the implant, and all implants had oedema in the bony proximal phalanx, metatarsal and soft tissues (mean follow up 13 months) (An, 2020).

Joint pain and stiffness were reported in 60% (12/20) of patients at 6 months in a case series of 20 patients. This was treated by manipulation under anaesthesia with an intra-articular corticosteroid injection. Swelling was reported by 10% (2/20) of patients. At 12 months, the rate of joint pain and stiffness was 25% (5/20). Transfer metatarsalgia was reported in 1 patient in the same study (Harmer, 2020).

Persistent pain was reported in 12% (7/60) of patients who had cheilectomy and Moberg osteotomy with a synthetic cartilage implant and 11% (8/73) of patients who had cheilectomy and Moberg osteotomy without an implant, in a non-randomised comparative study of 133 patients. This was treated by steroid injections, orthotics or shockwave therapy (Chrea, 2020).

Infection

Infection was reported in 1 patient in the case series of 119 patients. The patient had implant removal, sinus debridement, and removal of tissue from the first metatarsophalangeal (MTP) joint at about 36 months of follow up. A *Staphylococcus aureus* infection was confirmed (Glazebrook, 2019).

Infection needing antibiotics was reported in 5% (3/60) of patients who had an implant inserted and no patients who had cheilectomy and Moberg osteotomy without an implant, in the non-randomised comparative study of 133 patients (Chrea, 2020).

In a review of the FDA MAUDE database, there were 4 reports of infection associated with synthetic cartilage implant insertion. The implant was removed in 3 patients, 2 of whom had an antibiotic spacer inserted. One patient had oral antibiotics (Metikala, 2020).

Component loosening or subsidence

In the review of the FDA MAUDE database, there were 16 reports of subsidence associated with synthetic cartilage implant insertion. A secondary procedure was described in 11 of the 16 reports, including 6 conversions to fusion (Metikala, 2020).

In the case series of 60 patients, 1 patient had subsidence of the implant below the cortical bone of the metatarsal head with resultant bony contact between the proximal phalanx and metatarsal head. The patient had implant removal and conversion to fusion. In the same study, a second patient had revision for continued pain, inflammation, and suspected implant subsidence. The implant had subsided and was damaged, and pathology was consistent with foreign body giant cell reaction and neovascularisation. A bone mineral density scan showed that the patient had osteopenia (Cassinelli, 2019).

Component fracture

In the review of the FDA MAUDE database, there were 9 reports of ‘fragmentation’ associated with synthetic cartilage implant insertion. Three implants were removed, there were 2 revisions to an unspecified implant,

1 implant was removed and replaced with another synthetic cartilage implant, 1 was converted to first MTP joint fusion, 1 had the fragmented portion replaced and the same device reimplanted, and 1 had an unknown outcome (Metikala, 2020).

Bony reactions

Bony reactions were reported in 50% (48/97) of patients after a mean follow up of 5.8 years in the case series of 119 patients. These reactions included erosion (2%), cystic changes (21%), loss of cortical margins (25%) and osteolysis (2%) (Glazebrook, 2019).

In the review of the FDA MAUDE database, there were 3 reports of erosion associated with synthetic cartilage implant insertion (Metikala, 2020).

Other

Intraoperative metatarsal fracture during insertion of the implant was reported in 1 patient in the case series of 103 patients. This was treated at the time with open reduction and internal fixation (Eble, 2020).

Severe erosive wear of a synthetic cartilage implant 2 years after implantation was described in a case report. The patient needed a lengthening arthrodesis to correct malalignment (Reddy, 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, the professional experts did not describe any additional anecdotal or theoretical adverse events.

The evidence assessed

Rapid review of literature

The medical literature was searched to identify studies and reviews relevant to synthetic cartilage implant insertion for first metatarsophalangeal joint osteoarthritis (hallux rigidus). The following databases were searched, covering the period from their start to 28 September 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 shown in the following table 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 first metatarsophalangeal joint osteoarthritis.
Intervention/test	Synthetic cartilage implant insertion.
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 about 800 patients who had synthetic cartilage insertion for first MTP joint osteoarthritis, from 1 RCT (described in 2 papers), 4 non-randomised comparative studies, 7 case series and 1 case report (Baumhauer, 2016; Goldberg, 2017; Glazebrook, 2019; Cassinelli, 2019; Brandao, 2020a; Chrea, 2020; Eble, 2020; An, 2020; Brandao, 2020b; Harmer, 2020; Brandao, 2020c; Reddy, 2021, Joo, 2021; Lee, 2021). A review of the FDA MAUDE database, which describes 49 adverse events associated with the procedure, is also included (Metikala, 2020).

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 synthetic cartilage implant insertion for first metatarsophalangeal joint osteoarthritis (hallux rigidus)

Study 1 Baumhauer JF (2016)

Study details

Study type	RCT
Country	UK and Canada (12 centres)
Recruitment period	2009 to 2012
Study population and number	n=219 (132 randomised to hydrogel implant, 65 randomised to arthrodesis and 22 non-randomised hydrogel implant) Patients with advanced great toe arthritis
Age and sex	Mean age: 57 years (hydrogel implant), 55 years (arthrodesis); 79% (142/180) female
Patient selection criteria	Inclusion criteria included: 18 years or older, degenerative or post-traumatic arthritis of the first MTP joint and a candidate for arthrodesis with grade 2, 3 or 4 according to Coughlin and Shurnas, preoperative visual analogue scale pain score 40 or above, presence of good bone stock, with less than 1 cm osteochondral cyst and without need for bone graft. Exclusion criteria included: active bacterial infection of the foot, additional ipsilateral lower limb pathology that needs active treatment, bilateral arthritis of the first MTP joint that needs simultaneous treatment of both MTP joints, previous cheilectomy resulting in inadequate bone stock, inflammatory arthropathy, gout, any significant bone loss, avascular necrosis, or large osteochondral cyst of the first MTP joint, lesions greater than 10 mm in size, hallux varus to any degree or hallux valgus more than 20°, physical conditions that would tend to eliminate adequate implant support, chronic anticoagulation for a bleeding disorder or has taken anticoagulants within 10 days before surgery, cancer diagnosis in previous 2 years and chemotherapy treatment or radiation to the lower extremity to be treated, suspected allergic reaction to polyvinyl alcohol, muscular imbalance, peripheral vascular disease that prohibits adequate healing or a poor soft-tissue envelope in the surgical field, absence of musculoligamentous supporting structures or peripheral neuropathy, any medical condition that makes the patient unsuitable for inclusion in the study in the opinion of the investigator, comorbidity that reduces life expectancy to less than 36 months, pregnancy or planning to become pregnant during the course of the study, breastfeeding, or not using contraception and childbearing age, history of substance abuse, prisoner or ward of the state.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US. The implant was seated to allow for 1 to 2 mm to extend beyond the adjacent native cartilage of the metatarsal head. The patient could bear weight immediately and begin range of

	motion exercises at 1 week as tolerated. Skin sutures were removed at 2 to 3 weeks, at which time the patient could return to wearing his or her regular shoes. Arthrodesis: the proximal phalanx was positioned in slight dorsiflexion or valgus and stabilised with crossed screws or plate and screws. The patient's foot was immobilised in a cast or boot. Weight bearing was delayed until 2 to 6 weeks after the procedure at the discretion of the surgeon.
Follow-up	2 years
Conflict of interest/source of funding	The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of the article. Two authors reported personal fees or grants from Cartiva Inc. during the conduct of the study, 1 of whom also reported consultancy fees from DJO, Nextremity Solutions, Ferring Pharm, and Wright Medical. Five authors report grants or fees or other funds from Carticept. One author reported consulting and grant fees from Integra and Depuy.

Analysis

Follow-up issues: A total of 236 patients were originally enrolled in the study; 17 withdrew before randomisation (leaving 197 randomised patients and 22 non-randomised patients) and 17 withdrew after randomisation (2% [2/132] in the implant group and 23% [15/65] in the arthrodesis group). Of the 202 treated patients, 3% (5/152) who had the implant and 6% (3/50) who had arthrodesis were lost to follow-up. Of the 5 patients lost to follow-up in the implant group, 2 were in the randomised group and 3 were in the non-randomised group of training patients.

Study design issues: Prospective, randomised, multicentre, non-inferiority study. Patients were randomised within 72 hours of surgery (method of randomisation not described). Of the 152 patients who had the implant, 22 were training patients and were not randomised. The primary endpoint of the study was a composite of 3 outcomes (pain, function and safety). A successful outcome was defined as improvement (decrease) from baseline in VAS pain of 30% or more at 12 months, maintenance of function from baseline in Foot and Ankle Ability Measure (FAAM) sports subscore at 12 months and absence of major safety events. The sample size was based on an 80% effect size at a 1-sided significance level of $p<0.05$ (n=210). Non-inferiority of the implant to arthrodesis was considered statistically significant if the 1-sided 95% lower confidence interval was greater than the equivalence limit (<15%). An intent to treat (ITT) analysis was done for all randomised patients and a modified intent to treat (mITT) analysis was done for all randomised and treated patients using last observation carried forward for missing data.

Study population issues: There were no statistically significant differences in the baseline characteristics of age, gender, height, weight, body mass index, VAS, FAAM ADL, SF-36 physical functioning, or hallux rigidus grade between treatment groups. Overall 30% of patients had grade 2 osteoarthritis, 54% had grade 3 and 16% had grade 4 (on the Coughlin and Shurnas scale from 0 to 4, where 0 represents normal radiographic findings and no pain and 4 represents substantial joint-space narrowing and nearly constant pain, including definite pain at mid-range of passive motion, and substantial stiffness).

Other issues: It appears that clinical outcomes were only reported for patients who retained their implant at follow-up, although this is not explicitly stated in the paper.

Key efficacy findings

Number of patients analysed: 197 randomised (132 hydrogel implant, 65 arthrodesis) and 22 non-randomised (hydrogel implant)

Primary effectiveness endpoint analyses (composite of pain, function [FAAM sports] and safety at 12 months)

Analysis population (n)	Implant (%)	Arthrodesis (%)	1-sided 95% lower bound (%)	Non-inferiority p value
ITT (I:132; A:65)	79	62	5.52	<0.001
mITT (I:130, A:50)	80	80	-10.50	<0.0075

Alternate effectiveness endpoint analyses in mITT population

Effectiveness endpoint components	Implant (%)	Arthrodesis (%)	1-sided 95% lower bound (%)	Non-inferiority p value
VAS, FAAM ADL, and safety – 12 months	84.5	85.1	-10.63	1.00
VAS, FAAM sports, and safety – 24 months	80.0	78.7	-10.17	0.835
VAS, FAAM ADL, and safety – 24 months	80.5	78.7	-9.64	0.832

FAAM sports scores by treatment group over time in mITT population

Visit	Implant Mean (SD), n Med (min, max)	Arthrodesis Mean (SD), n Med (min, max)	t-test p value	Wilcoxon p value
Baseline	36.9 (20.9), 127 34.4 (0, 100)	35.6 (20.5), 50 31.3 (0, 87.5)	0.694	0.505
2 weeks	18.4 (18.3), 127 12.5 (0, 75)	7.8 (12.4), 47 3.1 (0, 46.9)	0.000	0.000
6 weeks	39.5 (26.3), 126 35.7 (0, 100)	22.4 (22.5), 49 20.3 (0, 81.3)	<0.0001	0.000
6 months	66.6 (26.3), 120 65.6 (0, 100)	78.6 (23.8), 42 79.7 (0, 100)	0.01	0.005
1 year	75.8 (24.8), 120 81.2 (0, 100)	84.1 (16.9), 43 90.6 (28.1, 100)	0.043	0.098
2 years	79.5 (24.6), 113 87.5 (0, 100)	82.7 (20.5), 41 90.6 (28.1, 100)	0.461	0.437

FAAM ADL scores by treatment group over time in mITT population

Visit	Implant Mean (SD), n Med (min, max)	Arthrodesis Mean (SD), n Med (min, max)	t-test p value	Wilcoxon p value
Baseline	59.4 (16.9), 129 58.3 (7.1, 100)	56.0 (16.8), 50 54.9 (22.6, 95.2)	0.222	0.152
2 weeks	48.8 (21.6), 126 47.6 (2.4, 100)	40.3 (20.7), 47 39.3 (7.5, 84.2)	0.021	0.023
6 weeks	69.0 (19.0), 126 69.6 (19.0, 100)	59.6 (24.8), 48 63.1 (10.7, 100)	0.008	0.032
6 months	82.7 (17.5), 123 88.1 (22.6, 100)	89.9 (12.4), 43 95.2 (50.0, 100)	0.014	0.01
1 year	88.6 (14.4), 123 95.0 (27.4, 100)	94.1 (6.8), 43 95.2 (71.4, 100)	0.0176	0.066
2 years	90.4 (15.0), 116 96.4 (29.8, 100)	94.6 (7.1), 41 96.4 (69.0, 100)	0.082	0.524

SF-36 Physical Functioning scores by treatment group over time in mITT population

Visit	Implant Mean (SD), n Med (min, max)	Arthrodesis Mean (SD), n Med (min, max)	t-test p value	Wilcoxon p value
Baseline	52.4 (22.8), 130 50 (0, 100)	49.8 (23.6), 50 40 (15, 100)	0.499	0.352
6 weeks	60.7 (23.7), 128 60 (10, 100)	44.7 (26.8), 49 45 (0, 100)	0.000	0.000
6 months	72.3 (26.3), 124 80 (0, 100)	82.8 (22.4), 43 90 (5, 100)	0.021	0.014
1 year	78.9 (22.7), 123 90 (5, 100)	83.7 (24.9), 43 95 (0, 100)	0.247	0.064
2 years	83.2 (20.9), 116 95 (25, 100)	85.1 (19.5), 41 95 (5, 100)	0.613	0.597

VAS pain scores by treatment group over time in mITT population

Visit	Implant Mean (SD), n Med (min, max)	Arthrodesis Mean (SD), n Med (min, max)	t-test p value	Wilcoxon p value
Baseline	68.0 (13.9), 130 68.3 (27.8, 100)	69.3 (143), 50 70 (38, 97.5)	0.571	0.529
6 weeks	33.2 (24.7), 128 27.4 (0, 96)	17.2 (17.6), 48 11.5 (0, 71.8)	<0.0001	0.000
6 months	28.9 (27.8), 124 20.5 (0, 97)	11.7 (18.3), 43 4.3 (0, 74.8)	0.000	0.000
1 year	17.8 (23.0), 123 9.0 (0, 91)	5.7 (8.5), 43 2.5 (0, 56.5)	0.0011	0.000
2 years	14.5 (22.1), 116 5.0 (0, 94)	5.9 (12.1), 41 1.5 (0, 70)	0.002	0.005

Active peak dorsiflexion angles by treatment group over time in mITT population

Visit	Implant Mean (SD), n Med (min, max)	Arthrodesis Mean (SD), n Med (min, max)	t-test p value	Wilcoxon p value
Baseline	22.7 (11.2), 130 20 (0, 58)	22.9 (11.2), 50 20 (5, 50)	0.910	0.965
6 weeks	25.1 (10.8), 127 25 (5, 55)	13.0 (9.0), 48 14.5 (0, 26)	<0.0001	0.000
6 months	28.1 (9.8), 124 30 (5, 60)	14.9 (8.6), 44 15 (0, 30)	<0.0001	0.000
1 year	28.8 (11.2), 123 30 (5, 60)	16.0 (7.3), 43 15 (0, 35)	<0.0001	0.000
2 years	29 (11.9), 114 30 (5, 60)	15.1 (8.4), 41 16 (0, 35)	<0.0001	0.000

Implant removal or reoperation in implant group=11.2% (17/152)

- Implant removal and conversion to arthrodesis=9.2% (14/152) (conversion to arthrodesis was considered to be straightforward and resulted in 86% reduction in pain and 39 point increase in function)
- Joint manipulation for motion=0.7% (1/152)
- Debridement of the joint for scar and synovitis and implant repositioning=0.7% (1/152)
- Moberg osteotomy of the proximal phalanx for improved toe positioning, motion, and pain relief=0.7% (1/152)

There were 7 (14%) procedures for hardware removal in the arthrodesis group.

Key safety findings

Adverse events in safety population

	Implant (n=152)			Arthrodesis (n=50)			
	Events	n	%	Events	n	%	p value
Any adverse event	245	105	69.1	72	36	72.0	0.727
Treatment emergent event	102	67	44.1	32	21	42.0	0.870
Nontreatment emergent event	143	73	48.0	40	26	52.0	0.745
Any serious adverse event	37	30	19.7	12	9	18.0	0.999
Treatment emergent event	17	17	11.2	4	4	8.0	0.605
Nontreatment emergent event	20	14	9.2	8	5	10.0	0.999

Study 2 Goldberg A (2017)

Study details

Study type	RCT (same trial as reported in Baumhauer JF, 2016)
Country	UK and Canada (12 centres)
Recruitment period	2009 to 2012
Study population and number	n=219 (132 randomised to hydrogel implant, 65 randomised to arthrodesis and 22 non-randomised hydrogel implant) Patients with advanced great toe arthritis
Age and sex	Mean age: 57 years (hydrogel implant), 55 years (arthrodesis); 79% (142/180) female
Patient selection criteria	Inclusion criteria included: 18 years or older, degenerative or post-traumatic arthritis of the first MTP joint and a candidate for arthrodesis with grade 2, 3 or 4 according to Coughlin and Shurnas, preoperative visual analogue scale pain score 40 or above, presence of good bone stock, with less than 1 cm osteochondral cyst and without need for bone graft. Exclusion criteria included: active bacterial infection of the foot, additional ipsilateral lower limb pathology that needs active treatment, bilateral arthritis of the first MTP joint that needs simultaneous treatment of both MTP joints, previous cheilectomy resulting in inadequate bone stock, inflammatory arthropathy, gout, any significant bone loss, avascular necrosis, or large osteochondral cyst of the first MTP joint, lesions greater than 10 mm in size, hallux varus to any degree or hallux valgus more than 20°, physical conditions that would tend to eliminate adequate implant support, chronic anticoagulation for a bleeding disorder or has taken anticoagulants within 10 days before surgery, cancer diagnosis in previous 2 years and chemotherapy treatment or radiation to the lower extremity to be treated, suspected allergic reaction to polyvinyl alcohol, muscular imbalance, peripheral vascular disease that prohibits adequate healing or a poor soft-tissue envelope in the surgical field, absence of musculoligamentous supporting structures or peripheral neuropathy, any medical condition that makes the patient unsuitable for inclusion in the study in the opinion of the investigator, comorbidity that reduces life expectancy to less than 36 months, pregnancy or planning to become pregnant during the course of the study, breastfeeding, or not using contraception and childbearing age, history of substance abuse, prisoner or ward of the state.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US. The implant was seated to allow for 1 to 2 mm to extend beyond the adjacent native cartilage of the metatarsal head. The patient could bear weight immediately and begin range of motion exercises at 1 week as tolerated. Skin sutures were removed at 2 to 3 weeks, at which time the patient could return to wearing his or her regular shoes. Arthrodesis: the proximal phalanx was positioned in slight dorsiflexion or valgus and stabilised with crossed screws or plate and screws. The patient's foot was immobilised in a cast or boot. Weight bearing was delayed until 2 to 6 weeks after the procedure at the discretion of the surgeon.

Follow-up	2 years
Conflict of interest/source of funding	One or more of the authors has received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article. The authors disclosed receipt of research and institutional support, consulting fees and support for travel expenses from Cartiva Inc. for the research, authorship, and/or publication of this article.

Analysis

Follow-up issues: A total of 236 patients were originally enrolled in the study; 17 withdrew before randomisation (leaving 197 randomised patients and 22 non-randomised patients) and 17 withdrew after randomisation (2% [2/132] in the implant group and 23% [15/65] in the arthrodesis group). Of the 202 treated patients, 3% (4/152) who had the implant and 6% (3/50) who had arthrodesis were lost to follow-up. Of the 4 patients lost to follow-up in the implant group, 1 was in the randomised group and 3 were in the non-randomised group of training patients.

Study design issues: Prospective, randomised, multicentre, non-inferiority study. Patients were randomised within 72 hours of surgery (method of randomisation not described). Of the 152 patients who had the implant, 22 were training patients and were not randomised. The purpose of this study was to evaluate the longitudinal data from the original RCT, to determine the association between numerous patient factors and the success or failure of these procedures. The original trial was powered for non-inferiority to demonstrate equivalence of the 2 procedures, so it may not be sufficiently powered for some patient factors. A patient's outcome was deemed successful if composite primary endpoint criteria for clinical success were met at 24 months, namely: 1) VAS pain reduction ≥30%; 2) maintenance or improvement in function; 3) freedom from radiographic complications; and 4) no secondary surgical intervention. Final outcome data were assessed in the modified intent to treat population.

Study population issues: Patient demographics and baseline outcome measures were similar for both groups.

Key efficacy findings

Number of patients analysed: 176 (129 synthetic cartilage implant, 47 arthrodesis)

Success rates stratified by patient factors

Patient variable	Stratification	Synthetic cartilage implant % success	p value	Arthrodesis % success	p value	p value between groups
Coughlin hallux rigidus grade	2	72.2% (26/36)	0.364	66.7% (12/18)	0.331	0.759
	3	83.6% (61/73)		85.0% (17/20)		0.999
	4	80.0% (16/20)		88.9% (8/9)		0.999
Preoperative hallux valgus angle	0 to <15°	80.2% (81/101)	0.797	82.4% (28/34)	0.429	0.999
	15° to 20°	78.6% (22/28)		69.2% (9/13)		0.698
Preoperative active peak dorsiflexion	40° to 60°	70.0% (7/10)	0.308	50.0% (2/4)	0.357	0.580
	30° to <40°	77.3% (17/22)		90.0% (9/10)		0.637
	>10° to <30°	77.8% (56/72)		80.1% (21/26)		0.999
	≤10°	92.0% (23/25)		71.4% (5/7)		0.201
Gender	Female	77.9% (81/104)	0.405	80.6% (29/36)	0.679	0.817
	Male	88.0% (22/25)		72.7% (8/11)		0.343
Age	≥65 years	90.9% (20/22)	0.243	100% (9/9)	0.172	0.999
	<65 years	77.6% (83/107)		73.7% (28/38)		0.659
Body mass index	<30 kg/m^2	80.9% (76/94)	0.629	76.9% (30/39)	0.667	0.640
	≥30 kg/m^2	77.1% (27/35)		87.5% (7/8)		0.999
Duration of symptoms before surgery	<24 months	66.7% (10/15)	0.183	100% (3/3)	1.00	0.522
	≥24 months	81.6% (93/114)		77.3% (34/44)		0.655
Previous first MTP joint surgery	Yes	66.7% (8/12)	0.259	100% (4/4)	0.564	0.516
	No	81.2% (95/117)		76.7% (33/43)		0.513
Preoperative pain VAS score	Mild (0 to <40 mm)	50.0% (1/2)	0.196	50.0% (1/2)	0.140	0.999
	Moderate (40 to 58 mm)	88.9% (24/27)		100% (8/8)		0.999
	Severe (>58 to 100 mm)	78.0% (78/100)		75.7% (28/37)		0.819

Study 3 Glazebrook M (2019)

Study details

Study type	Case series (patients who had implant insertion as part of Motion RCT)
Country	UK and Canada (12 centres)
Recruitment period	2009 to 2013
Study population and number	n=119 Patients who had synthetic cartilage implant hemiarthroplasty for advanced hallux rigidus
Age and sex	Mean 58 years (range 30 to 79); 78% (87/112) female
Patient selection criteria	Patients included in the original study were at least 18 years old and had been diagnosed with Coughlin grade 2, 3 or 4 hallux rigidus.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US. The implant was seated to allow for 1 to 2 mm to extend beyond the adjacent native cartilage of the metatarsal head. The patient could bear weight immediately and begin range of motion exercises at 1 week as tolerated. Skin sutures were removed at 2 to 3 weeks, at which time the patient could return to wearing regular shoes.
Follow-up	Mean 5.8 years
Conflict of interest/source of funding	The authors received research and institutional support, consulting fees and support for travel expenses from Cartiva Inc. Twelve authors reported personal fees and/or grants from Cartiva during the conduct of the study and 2 authors reported personal fees from Carticept.

Analysis

Follow-up issues: Of the original 152 patients who had the implant inserted, 14 had the implant removed and conversion to arthrodesis and 3 were lost to follow-up during the first 24 months. Of the 135 patients eligible to be included in this 5-year follow-up study, 17 (13%) could not be contacted (the implant status was known for 7 of these patients); 5 patients declined to participate, and 1 patient died. The study population therefore included 74% (112/152) of the original cohort and 83% (112/135) of eligible patients. Clinical outcomes were available for 106 patients at last follow-up (6 patients who underwent implant removal and revision were excluded).

Study design issues: Prospective, multicentre case series of patients treated as part of an RCT. The primary outcome was implant survival at a minimum of 5 years. Primary endpoint analyses included the 112 patients in the analysis set plus the 7 patients not enrolled in the follow-up study but for whom the device status was known (which included 3 implant removals). A target sample size of 115 was calculated to give 80% power to reject the null hypothesis that the implant removal rate from 2 to 5 years is 23.5% or greater, versus the alternative hypothesis that the implant removal rate is less than 23.5%. Clinical outcomes were summarised for patients who retained their implant.

Study population issues: The patient cohort enrolled in the 5-year follow-up study was older (58.2±8.8 years) than the 40 patients who were not enrolled (54.3±7.4 years, p=0.004) and they had a lower mean VAS score at baseline (67.0±14.4 compared with 72.4±12.2, p=0.031).

Key efficacy findings

- Number of patients analysed: 119

Clinical outcome measures – change from preoperative to final follow-up (mean 5.8 years) among patients free from implant removal

Outcome	n	mean±SD	range	99% CI
VAS pain, mm	106	-57.9±18.6	-96.0, -3.0	-65.2 to -53.5
FAAM ADL, points	105	33.0±17.6	-8.3, 92.9	28.6 to 37.5
FAAM sports, points	104	47.9±27.1	-25.0, 100	39.3 to 57.1
FAAM ADL, current level of function, %	104	33.3±22.5	-29.0, 90.0	25.0 to 40.0
FAAM sports, current level of function, %	103	39.2±31.2	-70.0, 100	25.0 to 50.0

Patients with a clinically significant improvement in outcome at mean follow-up of 5.8 years after implant insertion among patients free from implant removal

	Number of patients (%)	99% CI
Pain VAS ≥30% decrease	103/106 (97.2%)	90.8% to 100%
FAAM ADL ≥8 points increase	95/105 (90.5%)	81.7% to 100%
FAAM sports ≥9 points increase	97/104 (93.3%)	85.3% to 100%

Active MTP joint peak dorsiflexion an active MTP joint natural dorsiflexion were maintained at 5.8 years. The postoperative axial MTP joint alignment was a mean of 8.2° (±5.7) (range 0 to 20°).

When patients were asked if their overall wellbeing had improved, 56.2% (59/105) strongly agreed and 31.4% (33/105) agreed.

When asked if they would have the procedure again, 93.4% (99/106) stated they would and 6.6% (7/106) stated they would not.

Implant survival

- Implant survival rate at 24 months=90.8% (138/152)
- Between years 2 and 5, 7.6% (9/119) patients had implant removal and conversion to arthrodesis (upper bound of 1-sided 95% confidence interval [CI] was 11.3%). In a sensitivity analysis, the upper bound of the1-sided CI remained below 23.5% (the null hypothesis) even when all missing values were defined as failures.
- Of the 9 patients who had implant removal, 8 were successfully converted to arthrodesis with no additional complications.
- Kaplan-Meier implant survivorship at 5.8 years follow-up=84.9%

Key safety findings

Adverse events

- Serious pain at implant site=4.5% (5/112) (all patients had implant removal and conversion to arthrodesis, as described in efficacy section). One of these patients had a second operation for hardware removal after fusion.
- One patient had implant removal, sinus debridement, and removal of tissue from the first MTP joint at about 36 months' follow-up and a *Staphylococcus aureus* infection was confirmed.

Bony reactions at 5.8 years:

- Erosion=2.1% (2/97)
- Cystic changes=20.6% (20/97)
- Loss of cortical margins=24.7% (24/97)
- Osteolysis=2.1% (2/97)
- Any bony reaction=49.5% (48/97)
- No bony reaction=50.5% (49/97)

No evidence of avascular necrosis, device migration or fragmentation was observed upon independent radiographic review.

1 patient developed a radiolucency of ≤2 mm at the bone implant surface between 2 and 5.8 years follow-up.

Study 4 Cassinelli S (2019)

Study details

Study type	Case series
Country	US
Recruitment period	2016 to 2018
Study population and number	n=60 (64 implants) Patients who hallux rigidus that had not responded to conservative management
Age and sex	Mean 62 years (range 38 to 86); 87% (52/60) female
Patient selection criteria	Inclusion criteria: patients diagnosed with hallux rigidus that had failed nonoperative management, with a minimum 12-month clinical or telephone follow-up. Exclusion criteria: patients with hallux valgus angle >20°, concomitant bunion correction, peripheral vascular disease, prior fusion of the ankle, hindfoot or midfoot, inflammatory arthropathy, or peripheral neuropathy. No patient had concomitant bilateral synthetic cartilage implantation.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US. An 8- or 10-mm implant was used and seated to allow the implant to sit about 2 to 2.5 mm proud relative to the articular surface. With the initial patients, plantar stripping of the metatarsal head and sesamoids was done when 70° of dorsiflexion was not achieved. This technique was abandoned because of early postoperative stiffness seen at follow-up. Subsequently, when necessary, a Moberg closing wedge osteotomy of the proximal phalanx was done. Additional forefoot or hindfoot procedures were done as necessary. Patients were placed in a postoperative shoe and were allowed weight bearing as tolerated. Sutures were removed 2 weeks after the procedure and the patient transitioned to a regular shoe as swelling and pain permitted.
Follow-up	Mean 18.5 months (range 12 to 30)
Conflict of interest/source of funding	No financial support was received for the research, authorship, or publication of the article. One author reported stock in Paragon 28, speaking for Stryker and Editor-in-Chief of Foot & Ankle International, outside the submitted work. One author reported personal fees from Extremity Medical, outside the submitted work.

Analysis

Follow-up issues: Clinical and telephone follow-up were available for all patients, but some outcomes were only available at the most recent clinical follow-up for 66% (42/64) and 63% (40/64) of implants.

Study design issues: Retrospective, single centre case series of consecutive patients. Outcomes included the Patient Reported Outcomes Measurement Information System (PROMIS) physical function score, PROMIS pain interference score and patient satisfaction (measured on a 1 to 5 point satisfaction scale).

Study population issues: 23% of patients had previously had surgery on the hallux. Of the 64 implants, 18 (25%), 40 (60%) and 8 (13%) were classified as grade 2, 3 and 4 hallux rigidus respectively, according to the Coughlin and Shurnas grading system.

Other issues: 45% (29/64) of implant insertions had at least 1 additional procedure done at the same time (11 Moberg osteotomy, 3 medial eminence resection, 3 hindfoot or ankle procedures, 14 'other forefoot' procedures including lesser hammer toe correction, web space neurolysis, plantar fibroma excision and nail margin ablation).

Key efficacy findings

- Number of patients analysed: 60 (64 implants)
- Mean PROMIS pain interference score at follow-up (mean 15 months)=60 (mild pain); range 2 to 30; n=40
- Mean PROMIS physical function score at follow-up (mean 15 months)=42 (mild dysfunction); range 2 to 30; n=42
- Proportion of patients who would have the same surgery again=65.6% (42/64)
- Proportion of patients who would rather have had arthrodesis=10.9% (7/64)
- Reoperation=20% (13/64) (conversion to fusion [5 patients], lysis of adhesions [4 patients], Moberg osteotomy [1 patient], and implant exchange with bone grafting for impinging soft tissue or implant subsidence [3 patients]). Conversion to fusion was done at a mean of 16.4 months postoperatively (range 10 to 26 months).

Satisfaction rates

- Very unsatisfied=26.6% (17/64)
- Unsatisfied=10.9% (7/64)
- Neutral=20.3% (13/64)
- Satisfied=28.1% (18/64)
- Very satisfied=14.1% (9/64)

Postoperative corticosteroid injection=52% (33/64) (mean 7.6 months after the procedure)

Patient-reported restricted hallux MTP range of motion needing the use of a dynamic splinting device after the procedure=14% (9/64)

Key safety findings

30% (19/64) of implants had advanced imaging workup after the procedure for continued pain, inflammation and further evaluation of the implant and surrounding structures (mean 12 months follow-up, range 3 to 30 months). MRIs showed residual capsular inflammation in all patients, bone marrow oedema of the proximal

phalanx or metatarsal in 18 patients, and degenerative changes or inflammation at the metatarsosesamoid articulation in 7 patients.

In 1 patient who had implant removal and conversion to fusion, the implant had subsided below the cortical bone of the metatarsal head with resultant bony contact between the proximal phalanx and metatarsal head.

A second patient had revision for continued pain, inflammation, and suspected implant subsidence. The implant had subsided and was damaged and pathology was consistent with foreign body giant cell reaction and neovascularisation. A bone mineral density scan revealed the patient to have osteopenia.

Study 5 Brandao B (2020a)

Study details

Study type	Non-randomised comparative study
Country	UK
Recruitment period	Not reported
Study population and number	n=72 (30 implant insertion, 42 arthrodesis) Adults with symptomatic hallux rigidus
Age and sex	Mean age: 57 years (implant), 64 years (arthrodesis); 69% (50/72) female
Patient selection criteria	Inclusion criteria included adult patients over 18 years old with symptomatic hallux rigidus who had primary synthetic cartilage implant hemiarthroplasty or arthrodesis. Patients with previous surgery on the first metatarsal and patients with traumatic osteoarthritis were excluded.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US.
Follow-up	Mean 18 months (range 12 to 30) for implant group; mean 19 months (range 14 to 36) for arthrodesis group
Conflict of interest/ source of funding	None

Analysis

Follow-up issues: Patients were only included if they had at least 1 year follow-up.

Study design issues: Single centre non-randomised comparative study. First MTP joint arthritis was graded preoperatively according to the Hattrup and Johnson classification (scale 1 to 3, where 1 is mild changes with minimal osteophytosis, grade 2 is moderate changes including narrowing of the joint with osteophytosis of the metatarsal head or phalanx and subchondral sclerosis or cysts, and grade 3 is severe arthritis with loss of joint space, marked osteophytosis and subchondral bone changes). The main outcome measure was sporting ability evaluated using the FAAM sports subscale.

Study population issues: Of the 30 patients in the implant group, 0 had grade 1 arthritis, 9 (30%) had grade 2 and 21 (70%) had grade 3. In the arthrodesis group, 3 (7%) had grade 1 arthritis, 17 (40%) had grade 2 and 22 (52%) had grade 3. In the implant group, most patients participated in walking (63%) followed by gym sports (26%) and running sports (11%). In the arthrodesis group, gym sports (48%) and walking (43%) were the most popular sporting activities followed by running sports (9%).

Other issues: Dorsiflexion was not evaluated because there was no funding for patients to return to the clinic.

Key efficacy findings

- Number of patients analysed: 72 (30 implant, 42 arthrodesis)

Mean postoperative FAAM Sports scores

- Implant=76.4% (SD ±16.6)
- Arthrodesis=80.9% (SD ±21.9), p>0.3

Adjusting the results for age (<55 and >55) and gender (male or female) showed no statistically significant results.

Reoperation

- Revision to arthrodesis in implant group=3.3% (1/30) (because of persistent pain at 17 months after implant insertion)

Key safety findings

No safety data were reported.

Study 6 Chrea B (2020)

Study details

Study type	Non-randomised comparative study
Country	US
Recruitment period	2016 to 2018
Study population and number	n=133 (60 cheilectomy and Moberg osteotomy with synthetic cartilage implant insertion, 73 cheilectomy and Moberg osteotomy alone) Adults with moderate to advanced hallux rigidus
Age and sex	Mean age: 56 years (range 25 to 75); 73% (97/133) female
Patient selection criteria	Inclusion criteria: patients with moderate to advanced hallux rigidus. Patients were excluded if they had prior surgical treatment for their condition or if they had cheilectomy alone, with or without implant. Patients who had the implant alone were also excluded. Patients with little to no motion at the first MTP joint and with advanced arthritis on plain film radiographs had MTP fusion and so were not included. Patients who had insufficient follow-up or were missing baseline functional outcome scores were excluded.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US. All patients had cheilectomy and Moberg osteotomy with or without synthetic cartilage implant insertion. In those patients who also had an implant, the procedure was modified to include a limited cheilectomy. Of the 60 patients who had an implant, 3 had an 8-mm implant and 57 had a 10-mm implant. The implant was placed in the metatarsal head 2 mm beyond the margin of the metatarsal head. Patients could bear weight immediately or were limited for the first 2 weeks to allow the incision to heal. Sutures were removed 2 to 3 weeks postoperatively and patients were transitioned into regular shoe wear.
Follow-up	Mean 28 months (range 16 to 46) for patients with implants and mean 37 months (range 19 to 48) for patients with cheilectomy and osteotomy alone.
Conflict of interest/ source of funding	1 author reported 'other' potential conflict of interest from Wright Medical, outside the submitted work.

Analysis

Follow-up issues: The cheilectomy and osteotomy alone group had a longer follow-up period than the group who also had an implant inserted.

Study design issues: Retrospective non-randomised comparative study. The severity of hallux rigidus was assessed using the Coughlin and Shurnas classification system. Patient-reported outcomes were assessed using Patient-Reported Outcomes Measurement Information System (PROMIS) scores. Higher scores indicate greater physical function, pain interference, pain intensity, global health, and depression.

Study population issues: Patients had grade 2, 3, or 4 osteoarthritis based on combined radiologic and clinical examination.

Key efficacy findings

- Number of patients analysed: 133 (60 cheilectomy and Moberg osteotomy with implant, 73 cheilectomy and Moberg osteotomy without implant)

Comparison of PROMIS scores between treatment groups

Domain	Preoperative score (± SD)	Postoperative score (± SD)	p value	Score change (± SD)
Physical function				
Implant group	44.6 (± 8.2)	48.8 (± 8.0)	<0.01	+3.6 (± 6.2)
No implant group	45.0 (± 6.3)	51.8 (± 8.7)	<0.01	+7.1 (± 8.5)
p value	0.763	0.043		0.011
Pain interference				
Implant group	58.9 (± 6.5)	51.2 (± 8.4)	<0.01	-7.2 (± 8.6)
No implant group	58.1 (± 5.7)	49.4 (± 9.6)	<0.01	-9.1 (± 9.2)
p value	0.466	0.248		0.268
Pain intensity				
Implant group	51.6 (± 6.1)	43.4 (± 8.7)	<0.01	-7.5 (± 7.7)
No implant group	49.9 (± 6.7)	39.9 (± 8.3)	<0.01	-10.2 (± 8.6)
p value	0.139	0.019		0.086
Global physical health				
Implant group	46.9 (± 7.5)	51.9 (± 8.7)	<0.01	+5.1 (± 7.2)
No implant group	47.3 (± 7.4)	53.8 (± 8.2)	<0.01	+6.7 (± 7.2)
p value	0.765	0.216		0.229
Global mental health				
Implant group	53.1 (± 8.1)	54.0 (± 8.8)	0.245	+1.1 (± 5.3)
No implant group	54.1 (± 8.9)	55.5 (± 8.8)	0.074	+1.0 (± 6.9)
p value	0.507	0.352		0.948
Depression				
Implant group	46.9 (± 7.7)	47.6 (± 6.4)	0.509	+0.4 (± 5.9)
No implant group	47.4 (± 8.5)	46.9 (± 8.3)	0.611	-1.9 (± 10.0)
p value	0.750	0.606		0.148

Revision rate

- Implant group=5.0% (3/60)
- No implant group=1.4% (1/73)

In the implant group, revisions were needed at 14, 22 and 33 months respectively after the index surgery. In 1 patient, there was inflammation and fibrous tissue at the MTP joint with loosening of the implant; the implant was removed and a conversion to arthrodesis and bone grafting were done. A second patient presented with pain and there was wearing of the medial aspect of the implant; the implant was removed, and a revision hemiarthroplasty was done. The third patient presented with persistent pain and a hyperdorsiflexed hallux; the patient had revision to correct the hyperdorsiflexion.

In the group of patients who had cheilectomy and Moberg osteotomy without an implant, the patient who needed a revision was diagnosed with a metabolic bone disorder concurrently managed by a metabolic bone specialist and rheumatologist. She had revision cheilectomy with synthetic cartilage implant insertion at 21 months after the index procedure. The patient subsequently developed persistent pain and an MRI scan showed a stable implant with significant oedema 8 months after the revision procedure. She had 2 rounds of shockwave therapy as well as ultrasound-guided injection of the first MTP.

Key safety findings

Persistent pain (treated by steroid injections, orthotics or shockwave therapy):

- Implant group=11.7% (7/60)
- No implant group=11.0% (8/73), p=0.90

Postoperative infection needing antibiotics:

- Implant group=5.0% (3/60)
- No implant group=0% (0/73), p=0.05

Study 7 Eble S (2020)

Study details

Study type	Case series
Country	US
Recruitment period	2017 to 2018
Study population and number	n=103 Patients with hallux rigidus
Age and sex	Mean 58 years (range 26 to 76); 72% (74/103) female
Patient selection criteria	Patients treated with or without concurrent Moberg osteotomy were eligible for inclusion. Patients who had a polyvinyl alcohol hydrogel implant for a condition other than hallux rigidus were excluded.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Wright Medical Group, US. A 10-mm implant was used in 66 patients, and an 8-mm implant in 7 patients. The implant was placed into the implant delivery system and seated in the metatarsal head protruding 2 mm above the metatarsal head. A soft dressing with postoperative shoe or splint was applied. Patients could immediately bear weight or were limited for the first 2 weeks to allow the incision to heal. Sutures were removed 2 to 3 weeks postoperatively and patients were transitioned into regular shoe wear. 71% (52/73) of patients had concurrent Moberg osteotomy.
Follow-up	Mean clinical follow-up=26.2 months (range 14 to 36)
Conflict of interest/ source of funding	None

Analysis

Follow-up issues: Of the 103 patients, 90 (87.4%) had baseline PROMIS scores, and 81.1% (73/90) of these had minimum 1-year postoperative scores, 70.9% (73/103) of patients had both preoperative and postoperative scores.

Study design issues: Retrospective case series. Patient-reported outcome scores and clinical outcomes were assessed.

Population issues: Of the 73 patients with PROMIS scores, 10 had had a prior procedure of the first MTP, and 52 had concurrent Moberg osteotomy at the time of synthetic cartilage implant insertion. There may be some patient overlap with Chrea et al. (2020).

Key efficacy findings

- Number of patients analysed: 103

Baseline and postoperative PROMIS scores (n=73); mean follow-up=14 months

PROMIS Domain	Mean baseline score	Clinical interpretation of baseline score	Mean postoperative score	Clinical interpretation of postoperative score	p value
Physical function	44.7	Mild functional impairment	48.2	Normal range	0.009
Pain interference	58.0	Mild pain symptoms	52.5	Normal range	<0.0001
Pain intensity	50.9	Normal range	43.5	Normal range	<0.0001
Global physical health	46.9	Normal range	50.8	Normal range	0.006
Global mental health	53.3	Very good function	54.2	Very good function	0.499
Depression	47.1	Normal range	47.7	Normal range	0.632

Comparison of patients who had concurrent Moberg osteotomy with those who did not

PROMIS Domain	Timepoint	Moberg (n=46)	No Moberg (n=17)	p value
Physical function	Mean baseline	45.8	44.4	0.53
	Mean postoperative	50.0	46.5	0.12
	Mean change	+4.2	+2.1	0.28
Pain interference	Mean baseline	58.1	57.3	0.65
	Mean postoperative	50.7	54.9	0.05
	Mean change	-7.3	-2.4	0.03
Pain intensity	Mean baseline	48.7	50.8	0.43
	Mean postoperative	41.1	46.1	0.02
	Mean change	-10.2	-4.9	0.05
Global physical health	Mean baseline	46.9	46.3	0.83
	Mean postoperative	52.7	48.3	0.09
	Mean change	+5.2	+1.8	0.12
Global mental health	Mean baseline	52.5	53.5	0.73
	Mean postoperative	54.9	54.3	0.83
	Mean change	+1.7	+0.7	0.57
Depression	Mean baseline	45.0	47.3	0.37
	Mean postoperative	46.8	48.7	0.35
	Mean change	-0.6	+1.4	0.46

- **Revision surgery=1.9% (2/103)**

Both revisions were for persistent pain. The first was a conversion to arthrodesis at 14 months after the index procedure; the implant was noted to be loose, with inflammation and fibrous tissue at the joint. The second revision was a hemiarthroplasty with synthetic cartilage implant, done at 21 months postoperatively. The implant was found to have marked loss of contour at the medial aspect of the toe.

- Therapeutic steroid injection=5.8% (6/103); between 2 and 11 months postoperatively.
- Symptom-specific orthotics=5.8% (6/103); between 3 and 6 months postoperatively.

Key safety findings

- MRI scans done on 21.4% (22/103) of patients with persistent postoperative pain showed persistent oedema surrounding the implant (including the 2 patients who had a revision procedure).
- One patient had an intraoperative metatarsal fracture during insertion of the implant, which was treated at the time with open reduction and internal fixation.
- Minor wound complications=2.9% (3/103)

Study 8 An T (2020)

Study details

Study type	Case series
Country	US
Recruitment period	2016 to 2018
Study population and number	n=16 (18 implants) Patients who had MRI for persistent pain after synthetic cartilage insertion for hallux rigidus
Age and sex	Mean 61 years; 81% (13/16) female
Patient selection criteria	Inclusion criteria: patients who had synthetic cartilage implant insertion for hallux rigidus after nonoperative management had failed, and who had postoperative MRI for persistent pain or dysfunction at the metatarsophalangeal joint. Patients who had staged bilateral surgery were included in MRIs were available for both feet. Exclusion criteria: diagnosis other than hallux rigidus, hallux valgus angle greater than 20°, concomitant bunion correction, peripheral vascular disease, prior fusion procedures of the ankle, hindfoot, or midfoot, inflammatory disease, peripheral neuropathy.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Wright Medical Group, US. Of the 18 implants, 17 were 10 mm implants and 1 was an 8 mm implant.
Follow-up	Mean 13 months for MRI imaging, mean 21 months for clinical follow-up data
Conflict of interest/ source of funding	The authors received no financial support for the research, authorship and publication of the article. One author reported stock in Paragon 28, speaking for Stryker and Editor-in-Chief of Foot & Ankle International, outside the submitted work. One author reported personal fees from Extremity Medical, outside the submitted work.

Analysis

Follow-up issues: There were 60 patients who met the inclusion and exclusion criteria. Of these, 16 patients had persistent symptoms at the surgical site that prompted advanced imaging and therefore qualified for study inclusion. Of the 16 patients, 14 had follow-up plain radiographs available for review (mean 13 months, range 2 to 25). Clinical follow-up data were also available for 14 of the 16 patients (16 out of 18 implants).

Study design issues: Retrospective single centre case series. The main aim of the study was to characterise radiological findings of the synthetic cartilage implant and surrounding tissues. Clinical outcomes included Patient Reported Outcome Measures Informational System (PROMIS) physical function and pain interference scores. Patient satisfaction and revision surgical procedures, including conversions to fusion, were collected by telephone interviews by a study member not involved with the synthetic cartilage implant insertion surgery. The single 8 mm implant was excluded from the MRI measurement analysis.

Key efficacy findings

- Number of patients analysed: 16 (18 implants)
- Mean PROMIS physical function score=41 (range 27 to 56) (reported as corresponding to moderate physical dysfunction)
- Mean PROMIS pain interference score=63 (range 50 to 74) (reported as corresponding to a moderate level of pain interfering with daily activities)
- Median satisfaction rating (5-point Likert scale)=2
- Mean satisfaction rating (5-point Likert scale)=2.25

Reoperation within 2 years of implant insertion=38% (6/16):

- Revision synthetic cartilage implant at 16 months
- Lysis of adhesions and manipulation under anaesthesia at 6 months and lysis of adhesions and Moberg osteotomy at 12 months
- Revision synthetic cartilage implant and bone grafting at 17 months
- Conversion to fusion at 26 months
- Revision synthetic cartilage implant and Moberg osteotomy at 12 months
- Conversion to fusion at 10 months

Progression of osteoarthritis at the hallux MTP joint=100% (16/16)

Key safety findings

- Mean medial joint space reduced from 2.3 mm immediately after the procedure to 0.4 mm at final follow-up ($p<0.001$).
- Mean lateral joint space reduced from 2.1 mm immediately after the procedure to 0.6 mm at final follow-up ($p<0.001$).
- 78% (14/18) of implants had evidence of fluid around the implant and all implants had oedema in the bony proximal phalanx, metatarsal and soft tissues.
- Of the 17 implants with an MRI, the mean implant diameter was 9.7 mm. There was a mismatch between the implant and the bony channel, which measured a mean of 11.2 mm in diameter. The mean implant height was 9.5 mm and the mean bony depth was 9.7 mm, so the implant had often subsided below the subchondral bone of the metatarsal head.

Study 9 Brandao B (2020b)

Study details

Study type	Case series
Country	UK
Recruitment period	Not reported
Study population and number	n=55 Patients with symptomatic hallux rigidus
Age and sex	Mean 56 years; 75% (41/55) female
Patient selection criteria	Inclusion criteria included adult patients over 18 years old with symptomatic hallux rigidus who had a primary synthetic cartilage implant procedure. Patients with previous surgery to the 1st metatarsal or traumatic osteoarthritis were excluded.
Technique	Device: Cartiva Synthetic Cartilage Implant Preparation of the metatarsal head included removal of dorsal osteophytes. The implant was inserted using press fit technique and was left at least 3 mm proud. Intraoperatively, the aim was to achieve 90° of dorsiflexion.
Follow-up	Mean 21 months (range 12 to 38)
Conflict of interest/ source of funding	None

Analysis

Follow-up issues: No losses to follow-up were described.

Study design issues: Single centre prospective case series. First metatarsophalangeal joint arthritis was graded preoperatively according to the Hattrup and Johnson classification. The aim of the study was to analyse the efficacy of the procedure using patient reported outcome measures. Outcomes were evaluated using the FAAM ADL subscale and the MOXFQ.

Population issues: Of the 55 patients, 14 (25%) had grade 2 or moderate arthritis and 41 (75%) had grade 3 or severe arthritis at baseline.

Key efficacy findings

- Number of patients analysed: 55

Mean FAAM ADL scores

Mean objective scores improved from 64% at baseline to 87% postoperatively ($p<0.0001$).
Subjective scores of functionality improved from 41% to 87%.

Mean MOXFQ scores

Domain	Baseline	Postoperative	p value
MOXFQ Index	58	24	<0.0001
Walking or standing	58	25	<0.02
Pain	66	25	<0.02
Social interaction	46	20	<0.02

3 patients with psoriatic inflammatory arthritis and 1 patient with primary severe sesamoid osteoarthritis showed little improvement or deteriorated postoperatively.

Patient satisfaction=89.4%

The authors noted that there was some dissatisfaction among the patients who enjoyed wearing high heeled shoes, because they were unable to do so after the procedure.

Reoperation

There was 1 revision to another synthetic cartilage implant at 14 months postoperatively with use of calcaneal bone graft, as the implant had sunk into the metatarsal. The patient was a 30 year old white female ballet dancer with grade 2 osteoarthritis with evidence of osteopenia and a body mass index of 18.

There was 1 revision to arthrodesis at 17 months postoperatively in a 61 year old black male patient with grade 2 osteoarthritis. The patient had experienced increasing pain and reduced range of motion.

27.3% (15/55) of patients had manipulation under anaesthesia and steroid and local anaesthetic injection at 12 weeks postoperatively because of stiffness.

Key safety findings

There were no complications, including infection, wound breakdown or material failure.

Study 10 Harmer J (2020)

Study details

Study type	Case series
Country	UK
Recruitment period	2016 to 2017
Study population and number	n=20 (17 first MTP joint, 2 second and 1 third) Patients with painful moderate to severe arthritic degeneration of a MTP joint
Age and sex	Mean 51 years (range 35 to 72); 85% (17/20) female
Patient selection criteria	Inclusion criteria: patients over the age of 18 and who had synthetic cartilage implant insertion for painful moderate to severe arthritic degeneration of a MTP joint. Patients with early arthritic degeneration with minimal cartilage loss or those who had not previously had conservative care or had marked transverse plane deformity were not offered the procedure.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US.
Follow-up	Mean 19 months (range 11 to 24)
Conflict of interest/ source of funding	Not reported

Analysis

Follow-up issues: 10% (2/20) of patients were lost to follow-up at 12 months. All patients had postoperative x-ray evaluation at 6 months.

Study design issues: Retrospective, single centre case series. All outcome data were collected using the PASCOM-10 audit database, an online resource for reporting clinical and patient reported outcomes. This includes a patient satisfaction questionnaire (PSQ-10). The Manchester Oxford Foot/Ankle Questionnaire (MOXFQ) was used for patient-reported outcomes.

Population issues: Of the 20 patients, 3 had arthritis in a lesser MTP joint. Of the 17 patients with first MTP joint arthritis, 8 (47%) had hallux rigidus stage 2, 8 (47%) had stage 3 and 1 (6%) had stage 4, according to the Coughlin and Shurnas classification system.

Other issues: the authors noted that they stopped doing the procedure because of cost and suboptimal results noted at early follow-up, which is why the sample size is so small.

Key efficacy findings

- Number of patients analysed: 20

Summary of mean MOXFQ and PSQ-10 scores

Domain	Pre-op	6 months post-op	Score change	12 months post-op	Score change	Minimal clinical important difference
Walking	67	47	20	33	34	16
Pain	80	45	35	32	48	12
Social	60	33	27	20	40	24
PSQ-10		76		78		

Further descriptive data from PSQ-10 questionnaires showed that at 6 months after the procedure, 65% of patients felt that their original complaint was now better or much better, while 4 (20%) patients felt their foot condition had deteriorated. At 12 months, 60% of patients felt better or much better and only 1 patient reported a deterioration in their foot condition.

20% of patients noticed an improvement in joint range of motion at 12 months, 80% had no improvement or a deterioration in joint range of motion.

At 6 months, 80% of patients felt that their original expectations had been met or partly met and 95% reported that they would be prepared to have the same surgery again. This reduced to 75% and 80% respectively by 12 months.

x-ray evaluation at 6 months typically showed marked narrowing of the joint space, proximal impaction of the synthetic cartilage implant into the head of the metatarsal and there was significant arthritic involvement of the sesamoid apparatus.

- **Revision at 6 months for implant failure=15% (3/20)** (1 first MTP joint arthrodesis, 1 first MTP joint primus implant, 1 second MTP joint interplex Rod)
- **Revision at 12 months for implant failure=10% (2/20)** (both first MTP joint arthrodesis)
- **Total revision rate=25%**

Key safety findings

Complications at 6 months

- Joint pain and stiffness=60% (12/20) (treated by manipulation under anaesthesia with an intra-articular corticosteroid injection)
- Swelling=10% (2/20)
- Transfer metatarsalgia=5% (1/20)

Complications at 12 months

- Joint restriction=20% (4/20)
- Joint pain and stiffness=25% (5/20)

Study 11 Metikala S (2020)

Study details

Study type	Case series - US Food and Drug Administration's (FDA) Manufacturer and User Facility Device Experience (MAUDE) database
Country	US
Recruitment period	2016 to 2018
Study population and number	n=49 adverse events Reports of adverse events associated with the Cartiva device
Age and sex	Not reported
Patient selection criteria	The MAUDE database was retrospectively investigated to identify the adverse reports of Cartiva, which was registered with the product code: PNW (Prosthesis, Metatarsophalangeal Joint Cartilage Replacement Implant). Duplicate reports were excluded.
Technique	Device: Cartiva or Synthetic Cartilage Implant (Wright Medical). The most common implant size was 10 mm (19 reports) followed by 8 mm in 2 but unknown in the remaining 28 events.
Follow-up	Not reported
Conflict of interest/source of funding	One of the 6 authors reported personal fees from Wright Medical, Stryker, and Kinos, outside the submitted work. The remaining authors declared no conflict of interest.

Analysis

Follow-up issues: Follow-up period is not routinely reported on the MAUDE database.

Study design issues: The US FDA MAUDE database was used to review voluntary reported adverse event reports associated with synthetic cartilage implant insertion. The MAUDE database does not report the total incidence of implant insertion.

Other issues: Although the total number of procedures is unknown, the authors noted that nearly 22,400 devices (unpublished company data) have been implanted during the 3 years of the study period.

Key efficacy findings

No efficacy data were reported.

Key safety findings

Adverse reports (n=49)

35 events mentioned further surgery at a mean interval of 4.75 months.

- Subsidence, n=16 (reported terms: subsided device, sunk prosthesis, recessed implant, receded with bone-on-bone); 6 were converted to first MTP joint fusion, 1 implant removal with bone grafting and interpositional arthroplasty, 1 resection of prominent bone edges with reimplantation of the same device, 2 revisions using a different arthroplasty device, 1 implant removal only. No information was available for the remaining 5 reports of implant subsidence.
- Fragmentation, n=9 (reported terms: broken device, torn implant, fragmented device); 3 implants were removed, there were 2 revisions to an unspecified implant, 1 implant was removed and replaced with another Cartiva implant, 1 was converted to first MTP joint fusion, the fragmented portion was replaced and the same device reimplanted in 1 and the outcome was unknown for 1.
- Erosion, n=3 (reported terms: eroded bone, fractured metatarsal); 2 were treated by bone grafting, 1 fracture was converted to an unspecified alternate procedure.
- Infection, n=4; 1 was managed by oral antibiotics and 1 was treated by removal of the implant. The remaining 2 reports of infection were salvaged by implant removal with the placement of an antibiotic spacer, but no details were available on further care.
- Foreign body reaction, n=1
- Unspecified, n=16 (reports stated that postoperative symptoms occurred but with no additional detail on the status of the implant or bone. The most common symptoms was persistent pain. Other symptoms included lack of motion, deformity, postoperative discomfort, redness, skin sloughing, drainage, and chronic regional pain syndrome.)

Summary of secondary procedures cited in 35 of 49 reports

Secondary procedure	Number of reports	Mean interval (months)
Conversion to first MTP joint fusion	10	5.5
Removal of Cartiva implant	7	4
Revision to another Cartiva implant	4	1.5
Revision to an alternate implant	5	8
Revision to an alternate procedure	2	Unspecified
Debridement and reimplantation of same Cartiva	2	Unspecified
Cartiva removal and bone grafting	2	7
Cartiva removal and antibiotic spacer	2	2.5
Bone grafting and interpositional arthroplasty	1	Unspecified

Study 12 Brandao B (2020c)

Study details

Study type	Non-randomised comparative study
Country	UK (single centre)
Recruitment period	Not reported
Study population and number	n=78 (55 implant insertion, 23 cheilectomy) Adults with symptomatic hallux rigidus
Age and sex	Mean age: 56 years (implant), 58 years (cheilectomy); 77% (60/78) female
Patient selection criteria	Adult patients over 18 years of age with symptomatic hallux rigidus who had primary synthetic cartilage implant interpositional arthroplasty or cheilectomy surgery were included. Patients with previous surgery to the first metatarsal or hallux valgus with underlying arthritis were excluded.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US.
Follow-up	Mean 21 months (range 12 to 38) for implant group; mean 69 months (range 50 to 90) for arthrodesis group
Conflict of interest/ source of funding	None

Analysis

Follow-up issues: Follow-up times varied between the 2 groups.

Study design issues: Prospective, single centre non-randomised comparative study. Patients were assigned to either group based on patient and surgeon preference. The 2 groups were operated on by the same 3 surgeons at the same centre. The aim was to analyse the efficacy of the synthetic cartilage interpositional arthroplasty compared with cheilectomy in the treatment of hallux rigidus using patient reported outcome measures. The MOXFQ was used to evaluate patient reported outcomes and the FAAM sports subscale was used to assess sporting ability outcomes at a minimum of 1 year after the procedure. No preoperative scores were taken so the relative improvements after surgery could not be compared. In both groups, a small percentage of patients did not routinely participate in sporting activities and were therefore excluded from the FAAM sports assessment.

Study population issues: In the implant group, 14 (25%) patients had Hattrup and Johnson grade 2 (moderate) arthritis and 41 (75%) patients had grade 3 (severe) arthritis. In the cheilectomy group, 5 (22%) patients had grade 1 (mild), 10 (44%) had grade 2 (moderate) and 8 (13%) patients had grade 3 (severe) arthritis.

Key efficacy findings

- Number of patients analysed: 78 (55 implant, 23 cheilectomy)

MOXFQ scores after the procedure (higher scores indicate poorer quality of life)

Procedure	Pain	Walking or standing	Social interaction	MOXFQ index
Synthetic cartilage implant	27.52	28.76	23.88	27.00
Cheilectomy	27.17	6.83	8.15	14.13
p value	0.6818	0.00054	0.00308	0.01242

Mean postoperative FAAM Sports scores

- Implant (n=30) = 74.9%
- Cheilectomy (n=19) = 82.7%, p=0.11

Recovery and return to function times were comparable with no statistically significant difference.

Patient satisfaction with both techniques was high.

Key safety findings

There were no perioperative complications. None of the patients needed revision surgery.

Study 13 Reddy S (2021)

Study details

Study type	Case report
Country	US
Recruitment period	Not reported
Study population and number	n=1 A patient who had early catastrophic wear of a synthetic cartilage implant
Age and sex	68 year old woman
Patient selection criteria	Not applicable
Technique	Bilateral 10-mm synthetic cartilage implant insertion.
Follow-up	2 years
Conflict of interest/ source of funding	None

Key safety findings

The patient presented with bilateral grade 3 hallux rigidus. Her past medical history included hypertension and scleroderma. She had tried conservative measures, including shoewear modifications, nonsteroidal medication, and cortisone injections. She wished to maintain joint mobility and was reluctant to have an arthrodesis. She chose to have a synthetic cartilage implant inserted in both feet concurrently.

Her initial postoperative course was unremarkable, except for a left second metatarsal shaft fracture sustained when she inadvertently stepped on a piece of wood. Radiographs taken at this time demonstrated joint space loss within both hallux MTP articulations. She began to notice increasing pain at her 1-year follow up visit and had intra-articular cortisone injections bilaterally, with limited relief. She tried to manage her symptoms conservatively but had progressive difficulty with activity and with shoewear, as well as increasing stiffness of both joints. Two year follow up radiographs demonstrated progressive deterioration of the left hallux MTP joint with shortening of the hallux and an elevatus deformity. The patient chose to have bilateral hallux MTP arthrodesis. Evaluation of the left hallux demonstrated severe erosive wear of the bearing surface of the synthetic cartilage implant, with bone loss of the medial aspect of the base of the proximal phalanx, erosion of the subchondral plate, and exposure of underlying trabecular bone. The implant was noted to be well fixed. There were no clinical signs of infection. A hallux MTP arthrodesis using a lengthening tricortical allograft and iliac crest bone marrow aspirate concentrate was done to restore length. The implant was noted to have subsided on the right without wear of the implant. Both sides had healed at the 3-month follow-up, with improved overall pain and function.

The authors noted that the reason for the catastrophic wear observed in this case is unclear, though likely related to the bone loss observed within the base of the proximal phalanx resulting from osteolysis.

Study 14 Joo P (2021)

Study details

Study type	Non-randomised comparative study
Country	US
Recruitment period	2015 to 2019
Study population and number	n=181 (59 implant insertion, 122 arthrodesis) Patients with advanced hallux rigidus
Age and sex	Mean age: 57 years (implant), 61 years (arthrodesis), p<0.01; 77% (140/181) female
Patient selection criteria	Both treatment options were offered to patients after August 2016, when the implant became available for use in the US. Synthetic cartilage implant insertion was generally not recommended for patients who had inflammatory arthropathy (gout or rheumatoid arthritis), severely limited range of motion (dorsiflexion less than 20 degrees), severe osteoporosis, presence of a large cyst, avascular necrosis, malalignment as with a bunion deformity, or peripheral neuropathy. As the decision was mutually made, patients who wanted to retain the great toe motion preferred the implant over arthrodesis. Patients who were unwilling to take the potential risk of implant failure elected to have arthrodesis. Patients who had concomitant multidigit hammertoe or hallux valgus correction, and history of extensive foot or ankle surgery were excluded.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Cartiva Inc., US. Among the patients who implant insertion, 12 (20%) had a concurrent Moberg osteotomy. 3 (5%) of the implant insertions and 46 (38%) of the arthrodesis procedures were done with other minor procedures of the lesser toes, including up to 2 concurrent hammertoe corrections, hardware removal, and calcaneal bone graft harvest.
Follow-up	Overall mean time from surgery to final follow-up was 33 months (range 14 to 59). Mean follow up for implant group: 27 months (range 14 to 40) Mean follow up for arthrodesis group: 38 months (15 to 59), p<0.01
Conflict of interest/ source of funding	One author reported personal fees from Stryker, outside the submitted work.

Analysis

Follow-up issues: Of the 181 patients called for final follow-up, 101 (56%) completed the final phone survey and were included for secondary postoperative analysis. The response rate in the implant group was 50% compared with 68% in the arthrodesis group.

Study design issues: Retrospective, non-randomised comparative study. Electronic medical charts of all patients who met the criteria were reviewed to identify operative complications and other concomitant procedures. Patient data was included if a preoperative PROMIS t score and at least 1 postoperative t score were available, and the patient was at least 12 months from surgery. The patients were then contacted by telephone to obtain final PROMIS Physical Function and Pain Interference t scores. Callers had training and

used standardised scripts to avoid bias. All data obtained were secured directly with patients. Three calls were attempted, and only patients who answered within the 3 attempts were included in this study.

Study population issues: At baseline, PROMIS Physical Function t scores were statistically significantly higher in the implant cohort compared to the arthrodesis cohort, with average t scores of 47.1 and 43.9, respectively (p=0.01). Baseline PROMIS Pain Interference t scores were similar between groups, with an average of 55.6 in the implant cohort and 57.4 in the arthrodesis cohort (p=0.07).

Other issues:

Key efficacy findings

- Number of patients analysed: 181 (59 synthetic cartilage implant insertion, 122 arthrodesis)

Mean PROMIS Physical Function scores

	Synthetic cartilage implant insertion			Arthrodesis			
Follow up	**Score**	**n**	**95% CI**	**Score**	**n**	**95% CI**	**p**
Preoperative	47.1	59	45.1 to 49.1	43.9	122	42.5 to 45.3	<0.01
0 to 15 days	36.6	42	34.2 to 38.8	31.0	84	29.4 to 32.6	<0.01
1 month	40.6	30	38.0 to 43.2	35.2	62	33.4 to 37.0	<0.01
3 months	45.8	27	43.0 to 48.6	43.5	58	41.6 to 45.4	0.17
6 months	49.6	9	44.6 to 54.7	42.0	26	39.1 to 44.9	<0.01
Final follow up	51.4	40	48.8 to 53.9	45.9	60	43.9 to 47.9	<0.01

Mean PROMIS Pain Interference scores

	Synthetic cartilage implant insertion			Arthrodesis			
Follow up	**Score**	**n**	**95% CI**	**Score**	**n**	**95% CI**	**p**
Preoperative	55.6	59	53.6 to 57.6	57.4	122	56.0 to 58.8	0.07
0 to 15 days	62.5	42	60.3 to 64.8	63.9	84	62.3 to 65.5	0.33
1 month	56.2	30	53.7 to 58.8	57.4	62	55.6 to 59.1	0.49
3 months	54.5	27	51.7 to 57.3	54.6	58	52.7 to 56.5	0.94
6 months	49.5	9	44.4 to 54.6	56.5	26	53.6 to 59.3	0.02
Final follow up	49.4	40	46.9 to 51.9	48.2	61	45.9 to 50.5	0.49

Key safety findings

Proportion of patients with 'significant' pain at follow up

- Implant=10.0% (4/40)
- Arthrodesis=8.2% (5/61), p=0.76

Complications

- Implant=3.4% (2/59); both patients had the implant removed and conversion to arthrodesis after 12 and 21 months.
- Arthrodesis=2.5% (3/122); there were 2 hardware failures with revision at 12 and 36 months after initial surgery and 1 hardware removal because of pain 22 months after surgery.

Study 15 Lee W (2021)

Study details

Study type	Case series
Country	US
Recruitment period	2017 to 2019
Study population and number	n=90 (96 implants) Patients with hallux rigidus
Age and sex	Mean 54.4 years (range 27 to 74); 88% (84/96) female
Patient selection criteria	Inclusion criteria: at least 18 years old, diagnosed with hallux rigidus, had synthetic cartilage implant insertion procedure, and at least 1 year out from surgery at the time of study initiation. Patients who had a previous synthetic cartilage implant insertion procedure for hallux rigidus or polyvinyl alcohol hydrogel implantation for lesser MTP joints were excluded from the study.
Technique	Implant: Cartiva Synthetic Cartilage Implant, Wright Medical, US.
Follow-up	Mean 26.4 months (range 12 to 39)
Conflict of interest/ source of funding	One author reported being a consultant for Wright Medical, outside the submitted work.

Analysis

Follow-up issues: An additional 2 patients (4 implants) declined to join the study, and 24 patients (24 implants) could not be reached for the survey.

Study design issues: Single-centre, retrospective case series. Charts were reviewed for perioperative patient data. A questionnaire was designed to evaluate patient satisfaction, self-reported clinical improvement, and changes in sporting ability after the procedure. The questionnaire was administered by telephone survey by an author who was not involved in perioperative patient care. There may be some recall bias because patients were asked to evaluate their previous clinical status as well as their status at present. Preoperative and postoperative pain VAS score and PROMIS-10 scores were also collected for each patient.

Population issues: Mean body mass index at baseline was 25.1 kg/m^2 (range 19.4 to 37.6). Review of preoperative foot radiographs identified 14 cases of grade 1 (15.9%) hallux rigidus, 33 cases of grade 2 (34.4%), 33 cases of grade 3 (34.4%), and 8 cases of grade 4 (8.3%). The mean hallux valgus angle was 11.9 degrees (range 1.2 to 24.1).

Key efficacy findings

- Number of patients analysed: 90 (96 implants)

At final follow-up, the mean PROMIS-10 physical health T-score was 54.2 ± 8.3 points (range 26.7 to 67.6), which corresponds to a label of “very good” and the mean PROMIS-10 mental health T-score was 57.4 ± 7.8 (range 31.3 to 67.6), corresponding to a label of “excellent.”

Mean VAS pain scores

- Baseline=7.9 ± 1.8 (range 2 to 10)
- Postoperative=1.5 ± 2.5 (range 0 to 10), p<0.001

Range of motion, n (%)

- Better than before surgery=68.8% (66/96)
- Worse than before surgery=23.9% (23/96)
- Same as before surgery=7.3% (7/96)

Self-reported clinical improvement, n (%)

- Much improved=55.2% (53/96)
- Improved=26.0% (25/96)
- Same=8.3% (8/96)
- Worse=7.3% (7/96)
- Much worse=3.1% (3/96)

Satisfaction, n (%)

- Very satisfied=41.7% (40/96)
- Satisfied=32.3% (31/96)
- Neutral=8.3% (8/96)
- Unsatisfied=8.3% (8/96)
- Very unsatisfied=9.4% (9/96)

Time to new normal, n (%)

- 0 to 3 months=25.0% (24/96)
- 3 to 6 months=17.7% (17/96)
- 6 to 12 months=34.4% (33/96)
- More than 12 months=10.4% (10/96)
- Never=10.4% (10/96)
- Not sure=2.1% (2/96)

Intention to have the same surgery again under the same circumstances, n (%)

- Yes=75.0% (72/96)
- No=22.9% (22/96)
- Unsure=3.1% (3/96)

Would recommend the same surgery to family and friends, n (%)

- Yes=69.8% (67/96)
- No=17.7% (17/96)
- Unsure=12.5% (12/96)

Statistically significant differences between the satisfied and unsatisfied subgroups were found in preoperative corticosteroid injection use (21.1% compared with 41.1%, p=0.029) and preoperative VAS pain score (8.2 compared with 7.1, p=0.036).

Sports activity

Sports activity level	Preoperative	Postoperative
None	7/96 (7.3%)	3/96 (3.1%)
Low impact	57/96 (59.4%)	55/96 (57.3%)
Mid impact	17/96 (17.7%)	18/96 (18.8%)
High impact	15/96 (15.6%)	20/96 (20.8%)

Key safety findings

Postoperative complications and reoperations

- Revision to arthrodesis=2.1% (2/96); at 13 months and 23 months after index procedure.
- Reoperation other than revision=2.1% (2/96); both were tibial sesamoidectomy
- Wound dehiscence=2.1% (2/96); managed with dressing changes only

Validity and generalisability of the studies

- One randomised controlled trial (RCT) was identified, which included data from the UK.
- One of the case series reported longer term follow-up of patients who were originally included in the RCT (Glazebrook, 2019).
- Different systems were used to grade the degree of osteoarthritis. The RCT included patients with grade 2, 3 and 4 osteoarthritis according to the Coughlin and Shurnas system.
- In some studies, patients had other procedures done on the first MTP joint at the same time as the implant insertion.
- Some of the adverse events reported in the review of the FDA MAUDE database may also be included in the published literature.
- The longest mean follow-up was 5.8 years.

Existing assessments of this procedure

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

Related NICE guidance

Below is a list of NICE guidance related to this procedure.

Interventional procedures

- Metatarsophalangeal joint replacement of the hallux. NICE interventional procedures guidance 140 (2005). Available from http://www.nice.org.uk/guidance/IPG140

NICE guidelines

- Osteoarthritis: care and management. NICE clinical guideline 177 (2014). Available from http://www.nice.org.uk/guidance/CG177

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.

Twelve professional expert questionnaires for synthetic cartilage implant insertion for first metatarsophalangeal joint osteoarthritis (hallux rigidus) were submitted and can be found on the NICE website.

Patient commentators' opinions

NICE's Public Involvement Programme was unable to gather patient commentary for this procedure.

Company engagement

A structured information request was sent to 1 company who manufactures a potentially relevant device for use in this procedure. NICE received 1 completed submission.

Issues for consideration by IPAC

No additional issues.

References

An TW, Cassinelli S, Charlton TP et al. (2020) Radiographic and magnetic resonance imaging of the symptomatic synthetic cartilage implant. Foot and Ankle International 41: 25–30

Baumhauer JF, Singh D, Glazebrook M et al. (2016) Prospective, randomized, multi-centered clinical trial assessing safety and efficacy of a synthetic cartilage implant versus first metatarsophalangeal arthrodesis in advanced hallux rigidus. Foot and Ankle International 37: 457–69

Brandao B, Aljawadi A, Poh ZE et al. (2020a) Comparative study assessing sporting ability after Arthrodesis and Cartiva hemiarthroplasty for treatment of hallux rigidus. Journal of Orthopaedics 18: 50–52

Brandao B, Aljawadi A, Hall A et al. (2020b) Cartiva case series: The efficacy of the cartiva synthetic cartilage implant interpositional arthroplasty at one year. Journal of Orthopaedics 20: 338–41

Brandao B, Hall A, Aljawadi A et al. (2020c) Joint sparing management of hallux rigidus: Cartiva SCI vs cheilectomy a comparative review. Journal of Orthopaedics 21: 401-405

Cassinelli SJ, Chen S, Charlton TP et al. (2019) Early outcomes and complications of synthetic cartilage implant for treatment of hallux rigidus in the United States. Foot and Ankle International 40: 1140–48

Chrea B, Eble SK, Day J et al. (2020) Comparison between polyvinyl alcohol implant and cheilectomy with Moberg osteotomy for hallux rigidus. Foot and Ankle International 41: 1031–40

Eble SK, Hansen OB, Chrea B et al. (2020) Clinical outcomes of the polyvinyl alcohol (PVA) hydrogel implant for hallux rigidus. Foot and Ankle International 41: 1056–64

Glazebrook M, Blundell CM, O'Dowd D et al. (2019) Midterm outcomes of a synthetic cartilage implant for the first metatarsophalangeal joint in advanced hallux rigidus. Foot and Ankle International 40: 374–83

Goldberg A, Singh D, Glazebrook M et al. (2017) Association between patient factors and outcome of synthetic cartilage implant hemiarthroplasty vs first metatarsophalangeal joint arthrodesis in advanced hallux rigidus. Foot and Ankle International 38:1199–206

Harmer JL, Maher AJ (2020) A 12-month review of patients with advanced metatarsophalangeal joint osteoarthritis undergoing synthetic cartilage hemi implant arthroplasty. Foot & Ankle Online Journal doi:10.3827/faoj.2020.1301.0003

Joo PY, Baumhauer JF, Waldman O et al. (2021) Physical function and pain interference levels of hallux rigidus patients before and after synthetic cartilage implant vs arthrodesis surgery. Foot and Ankle International 42:1277–86

Lee W, Prat D, Wapner KL et al. (2021) Patient satisfaction following hallux rigidus treatment with a synthetic cartilage implant. Foot & Ankle Specialist doi:19386400211001993

Metikala S, Mahmoud K, O'Connor KM et al. (2020) Adverse events related to Cartiva hemiarthroplasty of first metatarsal: an analysis of reports to the United States Food and Drug Administration. Foot & Ankle Specialist doi:1938640020943715

Reddy SC (2020) Early Catastrophic Failure of a synthetic cartilage implant for hallux rigidus. Foot & Ankle Specialist 14:74–8

Literature search strategy

Databases	Date searched	Version/files
Cochrane Database of Systematic Reviews – CDSR (Cochrane Library)	28/09/2021	Issue 9 of 12, September 2021
Cochrane Central Database of Controlled Trials – CENTRAL (Cochrane Library)	28/09/2021	Issue 9 of 12, September 2021
MEDLINE (Ovid)	28/09/2021	1946 to September 27, 2021
MEDLINE In-Process (Ovid) & Medline ePub ahead (Ovid)	28/09/2021	1946 to September 27, 2021
EMBASE (Ovid)	28/09/2021	1946 to September 27, 2021

Trial sources searched

- Clinicaltrials.gov
- ISRCTN
- WHO International Clinical Trials Registry

Websites searched

- National Institute for Health and Care Excellence (NICE)
- NHS England
- Food and Drug Administration (FDA) - MAUDE database
- Australian Safety and Efficacy Register of New Interventional Procedures – Surgical (ASERNIP – S)
- Australia and New Zealand Horizon Scanning Network (ANZHSN)
- General internet search

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

Literature search strategy

Number	Search term
1	Metatarsophalangeal Joint/
2	Toe joint/
3	((metatars* adj4 phalangeal) or metatarsophalangeal or metatarso-phalangeal).tw.
4	(MTP or MTPJ).tw.
5	(big toe* or great toe*).tw.
6	or/1-5
7	Hallux Valgus/
8	hallux rigidus/
9	hallux limitus/
10	(hallux valgus or hallux rigidus or hallux limitus).tw
11	or/7-10
12	Arthroplasty/
13	Arthroplasty, Replacement/
14	Hemiarthroplasty/
15	Joint Prosthesis/
16	polyvinyl alcohol/
17	(arthroplast* or hemiarthroplast* or joint prosthe*).tw.
18	surg* reconstruct*.tw
19	((synthetic or artificial* or hydrogel* or polymer gel or polyvinyl or biomaterial*) adj4 (device or replace* or reconstruct* or implant* or insert* or prosthe*)).tw.
20	SCI.tw.
21	or/12-20
22	6 or 11
23	21 and 22
24	Cartiva*.tw.
25	23 or 24

26	animals/ not humans/
27	25 not 26
28	limit 27 to english language

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 the key evidence
Akoh CC, Chena J, Kadakia R et al. (2020) Adverse events involving hallux metatarsophalangeal joint implants: Analysis of the United States Food and Drug Administration data from 2010 to 2018, Foot and Ankle Surgery, https://doi.org/ 10.1016/j.fas.2020.05.002	Case series	Among 64 reported hallux MTPJ implant adverse events, 15 (23.4%) were associated with synthetic cartilage implants. Of the 15 events, 5 were inflammation and 5 were component loosening or subsidence. There were 2 reports each of infection and component fracture and 1 report of dislocation.	Another review of the FDA MAUDE database is included (Metikala S, 2020).
Baumhauer JF, Daniels T, Glazebrook M (2019) New technology in the treatment of hallux rigidus with a synthetic cartilage implant hemiarthroplasty. The Orthopedic Clinics of North America 50: 109–118	Review	Synthetic cartilage implant surgery is an excellent option for the patient with great toe arthritis and good alignment of the toe who wishes to retain first metatarsophalangeal motion and obtain 90% improved pain relief and function. Patients with osteoporosis, osteopenia, or bone defects from surgery or disease may not maintain the implant position due to poor bone quality, resulting in less than desired outcomes. Despite this being a straightforward surgery, patients need to be aware that the pain relief may not begin until 3+ months after surgery because this procedure	Review mainly focuses on technique. The relevant cited studies have been included.

		does require bone resection and implant placement.	
Baumhauer JF, Marcolongo M (2016) The science behind wear testing for great toe implants for hallux rigidus. Foot and Ankle Clinics 21: 891–902	Review	A variety of implant materials have been tried to decrease pain and improve function after cartilage repair. The hydrogel made of polyvinyl alcohol and saline is a unique material used as an implant in the great toe for advanced stage arthritis.	Review mainly focuses on wear testing. The relevant cited studies have been included.
Baumhauer JF, Singh D, Glazebrook M et al. (2017) Correlation of hallux rigidus grade with motion, VAS pain, intraoperative cartilage loss, and treatment success for first MTP joint arthrodesis and synthetic cartilage implant. Foot and Ankle International 38: 1175–82	RCT (Motion study) n=202 FU=24 months	Irrespective of the grade, positive outcomes were demonstrated for both fusion and synthetic cartilage implant. Clinical symptoms and signs should be used to guide treatment, rather than a grade consisting of radiographic, symptoms, and range of motion factors.	Subanalysis of RCT already included (Baumhauer et al., 2016), which focuses on use of grading system for hallux rigidus.
Bernasconi A, De Franco C, Iorio P et al. (2020) Use of synthetic cartilage implant (Cartiva R) for degeneration of the first and second metatarsophalangeal joint: what is the current evidence? Journal of Biological Regulators and Homeostatic Agents 34: 15–21	Review	Although some studies suggest that the use of Synthetic Cartilage Implant (Cartiva) is effective in the treatment of hallux rigidus in providing symptoms relief without sacrifice of joint motion, the redundancy of cohorts reported in studies and the frequency of conflict of interest reported by authors weaken the strength of evidence available and warrant further studies.	Review
Carpenter B, Klemeyer L (2020) Motion preservation in hallux rigidus after failure of hydrogel implantation: treatment considerations and a report of 2 cases. The	Case series n=2	Revision of failed hydrogel implants to arthrodesis can be performed through various first MTP fusion techniques or with a fourth-generation threaded hemiarthroplasty.	Study describes treatment of 2 patients who had a failed

Journal of Foot & Ankle Surgery 59: 162–8			hydrogel implant.
Chang TJ (2018) The role of polyvinyl alcohol in cartilage repair of the ankle and first metatarsophalangeal joint. Clinics in Podiatric Medicine and Surgery 35: 133–43	Review	The Cartiva implant is an exciting option in dramatically diminishing patient symptoms in advanced stages of hallux rigidus as well as allowing continued joint motion. It is a procedure that does not burn many bridges in case a future revision to an arthrodesis is necessary	Review mainly focuses on technique. The relevant cited studies have been included.
Daniels TR, Younger ASE, Penner MJ et al. (2017) Midterm outcomes of polyvinyl alcohol hydrogel hemiarthroplasty of the first metatarsophalangeal joint in advanced hallux rigidus. Foot and Ankle International 38: 243–47	Case series n=27 FU=mean 5 years	Postoperative active MTP natural joint dorsiflexion and peak MTP dorsiflexion were mean 18.2 (range, 10.0-30.0) and 29.7 (range, 10.0-45.0) degrees, respectively. Pain VAS, SF-36 PCS, FAAM ADL, and FAAM Sports scores demonstrated clinically and statistically significant improvements. Radiographically, no patient demonstrated changes in implant position, implant loosening or subsidence, or implant wear. One implant was removed because of persistent pain and converted to fusion 2 years after the procedure.	A more recent report with more patients is included (Glazebrook et al., 2019).
Davies MB, Roberts VI, Chadwick C et al. (2020) Revision of synthetic cartilage implant hemiarthroplasty of the great toe to metatarsophalangeal joint arthrodesis: technique and indications. Techniques in Foot and Ankle Surgery 19: 48–55	Case series n=3	There were no complications in the 3 patients who had conversion of synthetic cartilage implant hemiarthroplasty to arthrodesis. Revision surgery of this implant is not technically challenging and has minimal or modest bone loss compared to the techniques described in the literature for other devices.	Study describes revision surgery of 3 patients after implant failure.
Galois L, Hemmer J, Ray V et al. (2020) Surgical options for hallux rigidus: state of the art and review of the	Review	Newer techniques of interpositional arthroplasty as well as new hemi-arthroplasty designs, including synthetic	The relevant cited studies

literature. European Journal of Orthopaedic Surgery and Traumatology 30: 57–65		cartilage implants, offer promising options for preservation of motion. The choice of procedure is based on the condition of the joint, patient's goals and expectations of the surgical outcome, and patient's motivation.	have been included.
Glazebrook MA (2019) Cartiva hemi arthroplasty for treatment of Hallux Rigidus: Surgical technique, evidence and tips and tricks. Fuss und Sprunggelenk 17: 28–32	Review	Recently a motion sparing surgical treatment option with Cartiva hemiarthroplasty for treatment of Hallux Rigidus has been proven to be as safe and effective as arthrodesis in a level I randomised controlled trial. Further, subsequent studies have shown that safety and efficacy of Cartiva hemiarthroplasty has been sustained to mid term follow-up out to five years.	The relevant cited studies have been included.
Glazebrook M, Younger ASE, Daniels TR et al. (2018) Treatment of first metatarsophalangeal joint arthritis using hemiarthroplasty with a synthetic cartilage implant or arthrodesis: A comparison of operative and recovery time. Foot and Ankle Surgery 24: 440–47	Retrospective case control study n=202 FU=24 months	First MTP joint hemiarthroplasty with a synthetic cartilage implant took less operative time and resulted in faster recovery than arthrodesis.	Subanalysis of RCT already included (Baumhauer et al., 2016), which focuses on operative and recovery time.
Lunati M, Mahmoud K, Kadakia R et al. (2021) Complications associated with the surgical management of hallux rigidus. The Orthopedic Clinics of North America 52: 291–96	Review	The early literature supports the use of synthetic cartilage implants with low rates of complications (<10%); however, later studies revealed less successful results with higher rates of revision and postoperative pain.	Review
Shi E, Todd N, Rush S et al. (2019) First metatarsophalangeal joint space area decreases within	Case series n=27	The difference between the preoperative joint space and the second postoperative joint	Studies with more patients or longer

1 month after implantation of a polyvinyl alcohol hydrogel implant: a retrospective radiographic case series. The Journal of Foot & Ankle Surgery 58: 1288–92	FU=5 to 12 weeks	space was not statistically significant (p=0.398). There was 1 revision to arthrodesis at 5 months postoperatively because of persistent pain.	follow-up are included.
Shimozono Y, Hurley ET, Kennedy JG (2020) Early failures of polyvinyl alcohol hydrogel implant for the treatment of hallux rigidus. Foot and Ankle International doi: 10.1177/1071100720962482	Case series n=11 FU=mean 21 months	The mean VAS score showed improvement from 4.1 to 3.0 (p=0.012). On postoperative plain radiographs, implant subsidence was observed in 60% (6/10) at 4 weeks after surgery and 90% (9/10) at the final follow-up. 50% (5/10) showed radiologic lucency around the implant. 40% (4/10) had erosion of the proximal phalanx of the great toe. 4 patients (36%) reported no improvement at the final follow-up, which were considered as failures. 3 patients needed additional surgery related to the implants. An additional patient is waiting for an implant revision.	Studies with more patients or longer follow up are included.
Smyth NA, Murawski CD, Hannon CP et al. (2020) The use of a synthetic cartilage implant for hallux rigidus: a systematic review. Foot & Ankle Specialist 1938640020937160	Systematic review 7 studies	Seven studies met the inclusion criteria, 6 of these were derived from a single randomised controlled trial. A moderate recommendation can be given for the use of a polyvinyl alcohol implant for hallux rigidus based on short-term outcomes. A limited recommendation can be given for the use of a polyvinyl alcohol implant for hallux rigidus based on mid-term outcomes.	No meta-analysis. All the studies are included in the overview.
Younger A, Glazebrook M, Daniels T et al. (2021) First Metatarsophalangeal joint polyvinyl alcohol hydrogel implant hemiarthroplasty: current operative technique.	Review	In patients with pain localised within the first MTP joint, normal bone stock, and a well-aligned MTP joint, PVA hydrogel implant hemiarthroplasty resulted in reduced pain and improved function.	Review

Techniques in Foot & Ankle Surgery		The outcomes of PVA hydrogel implant hemiarthroplasty need to continue to be monitored and compared against the alternatives of fusion or cheilectomy in isolation. Monitoring of retrieved implants to determine wear characteristics and causes of failure will assist in determining if osteolysis of the bone or degradation of the implant are observed.	
Younger ASE, Baumhauer JF (2013) Polyvinyl alcohol hydrogel hemiarthroplasty of the great toe: Technique and indications. Techniques in Foot and Ankle Surgery 12: 164–69	Review	Potential complications of surgery include wound healing problems, implant subsidence, metatarsal head fracture, dorsal medial great toe numbness, and persistent pain. The procedure preserves more bone, maintains motion in the joint, reduces rehabilitation time, and enables patients to return to normal activity sooner than with fusion. Although early results are promising, further studies currently underway are required to determine the factors associated with success.	Review mainly focuses on technique.
Zanzinger C, Harrasser N, Gottschalk O et al. (2021) One-year follow-up results with hydrogel implant in therapy of hallux rigidus: case series with 44 patients. Zeitschrift fr Orthopdie und Unfallchirurgie DOI 10.1055/a-1365-9655	Case series n=44 Follow up: 1 year	The overall survival rate of the implant was 93% at 12 months. The VAS, European Foot and Ankle Society and American Orthopaedic Foot and Ankle Society scores showed a statistically significant improvement in comparison to the preoperative condition. The mobility of the MTP joint showed no increase. Patients with a medium osteoarthritis grade and a medium level of clinical restraint showed the greatest improvement in relation to their preoperative condition.	Small case series with short follow up.