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ORTHOPAEDIC SURGERY

Supramalleolar osteotomies for ankle arthritis: a systematic review

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Abstract

Introduction We investigated the mid-term outcomes of supramalleolar osteotomies regarding "survivorship" [before ankle arthrodesis (AA) or total ankle replacement (TAR)], complication rate and adjuvant procedures required.

Material and methods PubMed, Cochrane and Trip Medical Database were searched from January 01, 2000. Studies reporting on SMOs for ankle arthritis, in minimum of 20 patients aged 17 or older, followed for a minimum of two years, were included. Quality assessment was performed with the Modified Coleman Methodology Score (MCMS). A subgroup analysis of varus/valgus ankles was performed.

Results Sixteen studies met the inclusion criteria, with 866 SMOs in 851 patients. Mean age of patients was 53.6 (range 17–79) years, and mean follow-up was 49.1 (range 8–168) months. Of the arthritic ankles (646 ankles), 11.1% were classified as Takakura stage I, 24.0% as stage II, 59.9% as stage III and 5.0% as stage IV. The overall MCMS was 55.2 ± 9.6 (fair). Eleven studies (657 SMOs) reported on "survivorship" of SMO, before arthrodesis (2.7%), or total ankle replacement (TAR) (5.8%) was required. Patients required AA after an average of 44.6 (range 7–156) months, and TAR after 36.71 (range 7–152) months. Hardware removal was required in 1.9% and revision in 4.4% of 777 SMOs. Mean AOFAS score was 51.8 preoperatively, improving to 79.1 postoperatively. Mean VAS was 6.5 preoperatively and improved to 2.1 postoperatively. Complications were reported in 5.7% (44 out of 777 SMOs). Soft tissue procedures were performed in 41.0% (310 out of 756 SMOs), whereas concomitant osseous procedures were performed in 59.0% (446 out of 756 SMOs). SMOs performed for valgus ankles failed in 11.1% of patients, vs 5.6% in varus ankles ($p < 0.05$), with disparity between the different studies.

Conclusions SMOs combined with adjuvant, osseous and soft tissue, procedures, were performed mostly for arthritic ankles of stage II and III, according to the Takakura classification and offered functional improvement with low complication rate. Approximately, 10% of SMOs failed and patients required AA or TAR, after an average of just over 4 years (50.5 months) after the index surgery. It is debatable whether varus and valgus ankles treated with SMO reveal different success rates.

Keywords Ankle arthritis · Osteotomy · Distal tibial · Supramalleolar · Reconstructive surgery · Joint-preserving surgery · Realignment surgery

Introduction

Ankle osteoarthritis (OA) is usually post-traumatic and often associated with chronic instability, malalignment and incongruity of the tibiotalar joint [1, 2]. D'ambrosi et al. showed that ankle OA should be considered a serious disease with major implications, such as cancer, heart disease or diabetes [3]. Surgical management of advanced ankle degeneration includes ankle arthrodesis (AA), total ankle replacement (TAR), but also joint preserving procedures [4]. Arthrodesis, performed with contemporary techniques, has quite high success rates, at the expense of sacrificing tibiotalar joint motion [5]. This leads to some functional impairment and

The study was performed in compliance with ethical standards.

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may contribute to adjacent joints degeneration in the long term [6]. TAR is gaining in popularity, and current implant designs are better than older ones, with long-term survivorship rates of aprox. 85% at 10 years [7], however, still lower compared to that of hip and knee replacements [7]. If we take into consideration that patients with ankle OA are on average younger than those with hip and knee OA, ankle joint preserving surgery seems to be an attractive option, to postpone the need for arthrodesis or TAR [8, 9].

Distal tibial corrective osteotomies have a central role as an ankle joint preserving surgery, in the presence of malalignment, joint incongruity and asymmetrical degeneration, and can be performed, in combination with arthroscopic procedures and ligament repairs [8, 9]. These techniques have been evolving during the last two decades. The ideal joint-preserving surgery should address both deformity correction and deforming forces neutralization, with a combination of bone and soft tissue procedures [10].

In the present systematic review of the literature, we investigated the mid- and long-term outcomes of distal tibial osteotomies combined with adjuvant procedures, regarding function, "survivorship" (before AA or TAR is required), and complications.

Methods

Protocol

The systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for meta-analyses of interventional studies [11].

Search strategy and selection criteria

We searched PubMed, Cochrane and Trip Medical Database with the following key phrases: "supramalleolar osteotomy", "distal tibial osteotomy", "realignment surgery" and "ankle arthritis". We did not apply any language restrictions and included all relevant articles from January 01, 2000 up to August 01, 2022. We also hand-searched the reference lists of identified trials and reviews, for further references, including those published in grey literature and unpublished trials. The relevant search details are displayed on Supplementary File Table 1. This study is registered with PROSPERO, number CRD42021271054.

Eligibility criteria

Included studies reported on outcomes of at least twenty patients, followed for an average of at least two years.

Types of studies

Randomized or nonrandomized, prospective or retrospective cohort, case series or case control studies were included. Reviews, case reports, scientific meeting abstracts, animal studies, commentaries, were excluded, same as studies published in a language other than English. In the absence of randomized trials the best available level of evidence on this subject may be provided by a systematic review and meta-analysis of the observational studies, which is presented in the present review article.

Types of patients

Patients aged 17 or older, of any gender or race, diagnosed with ankle arthritis regardless of etiology and arthritis staging were included.

Types of interventions

All patients included were treated with SMO as primary procedure (combined with adjuvant, osseous and/or soft tissue procedures, simultaneously).

Types of outcome measures

Primary outcome of the systematic review was the time interval between the SMO and potential subsequent AA or TAR (survivorship).

Secondary outcomes were the complications reported, the need for revision surgery and unplanned procedures and patients' functional outcome, following SMO for the management of ankle joint degeneration.

Data analysis

Two independent researchers (PC, NG) screened all abstracts identified in the initial search, excluded studies in violation of the inclusion criteria and assessed the risk of bias. Full-text articles were subsequently reviewed in duplicate, and, in cases of disagreement, consensus was achieved through discussion. We transferred all relevant titles and abstracts to Mendeley Desktop Version 1.19.4 for further assessment. An electronic, predesigned data abstraction form, designed in Microsoft Excel 2020, was used to record patient and study characteristics, including authors' name, year of publication, number of patients, number of ankles treated, age and gender of patients, length of follow-up, body side (right/left), Takakura stage of arthritis, type of osteotomy, any kind of additional procedures performed simultaneously, time interval between SMO and AA or TAR, complications, need for revision surgery, radiological and functional evaluation, varus/valgus deformity. If not reported, corresponding authors were contacted to obtain these baseline characteristics.

Subgroup analysis

A subgroup analysis was performed regarding varus/valgus deformity and the survivorship, functional outcomes and unplanned procedures after supramalleolar osteotomies.

Quality assessment

The methodological quality of the included studies was evaluated according to a Modified Coleman Methodology Score, as described by Hendrickx et al. [12]. The total score on the Modified Coleman Methodology Score ranges from 0 to 100, corresponding to either poor (0–49 points), fair (50–69 points), good (70–84 points) or excellent (85–100 points) quality.

Statistical analysis

Statistical analysis was performed using Jamovi Version 1.2.27.0. Continuous variables were extracted and analyzed as the mean and standard deviation (SD). The SD was calculated from the available data, according to a previously validated formula [13]: (higher range value–lower range value)/4. If the SD could not be calculated using this approach, the highest SD was used. Random effects model was used for data synthesis. For nominal and ordinal variables, we used frequencies and percentages. Comparison of categorical was performed with the Chi-square test (χ^2) with Yates correction. We assumed a p value less 0.05 to be statistically significant.

Results

Study selection

The search of PubMed, Cochrane and Trip Medical Database produced a total of 489 publications. After exclusion of 19 duplicate titles, 470 abstracts were selected for review. Of these, 114 full-text articles were selected for formal review. Following review of full-text articles, 16 studies met the inclusion criteria for qualitative analysis [14–29]. For details on the study selection process and the PRISMA flowchart, see Fig. 1.

Critical appraisal

The overall Modified Coleman Methodology Score was 55.2 ± 9.6 (fair). Methodology was "good" in two studies [22, 26], "fair" in ten studies [14–20, 23, 24, 27], and "poor" in four [21, 25, 28, 29]. The comprehensive risk of bias assessment is depicted in Table 1**.**

Studies' characteristics and patients' demographics

Sixteen studies met the inclusion criteria, including a total of 866 SMOs in 851 patients. Patients' mean age was 53.6 (range 17–79) years. Mean follow-up time was 49.1 (range 8–168) months. All but three studies were retrospective [20, 22, 26]. Almost all studies used the Takakura classification to describe the stage of arthritis, albeit not all data could be extrapolated. Of the arthritic ankles, 11.1% were classified as stage I (72 out of 646), 24.0% as stage II (155 out of 646), 59.9% as stage III (387 out of 646) and 5.0% as stage IV (32 out of 646). There was a male predominance with 56.0% of the patients being male. The right ankle was operated on in 51.4% of the cases. Studies characteristics and patients' demographics are presented in Table 2**.**pt patients, ot osteotomies, y years, m, male, f female, r right, l left, mo months, r range, sI stage I, sII stage II, sIII stage III, sIV stage IV, mow medial opening wedge, mc medial closing, low lateral opening wedge, lc lateral closing,mtpp medial tibial plafond-plasty, vr varus, vl valgus, smot supramalleolar osteotomy, AOFAS American Orthopedic Foot and Ankle Society ankle-hind foot scale, TAS tibial articular inferior surface, TLS tibial lateral surface, TT talar tilt, ROM range of motion, TC tibiocrural angle, AOS Ankle Osteoarthritis Scale, TMM tibial axis–medial malleolus angle, VAS visual analog scale, CORA center of rotation and angulation, SF-36 Short Form-36, HAA hindfoot alignment angle, MTD-P medial talar dome and the plafond angle, TMAA tibiomedial malleolar angle, HMA hindfoot moment arm, HAR hindfoot alignment ratio, FAAM-ADL Foot and Ankle Ability Measure activity of daily living

Primary outcomes

Eleven studies [15, 18–23, 26–29] reported on SMO failure and subsequent need for AA or TAR, in 649 patients (657 osteotomies) with mean age of 50.7 years (Table 3). Overall, SMOs failed in 8.5% (56 out of 657 osteotomies). AA was required in 2.7% (18 out of 657), and TAR in 5.8% (38 out of 657) patients, during a mean follow-up period of 51.6 months. Patients required AA after an average of 44.6 (range 7–156) months, and TAR after 36.1 (range 7–152) months.

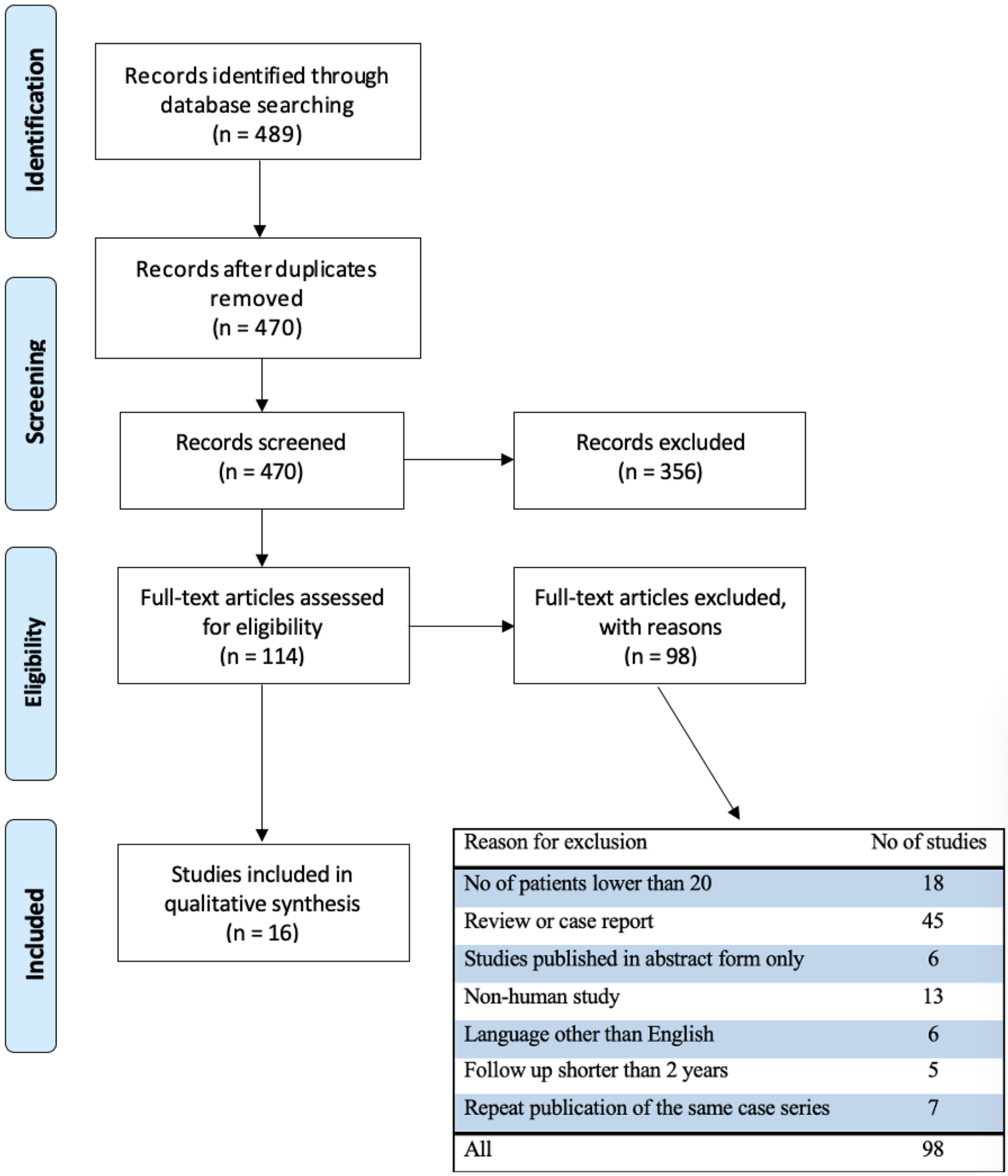

Fig. 1 PRISMA flowchart of the literature search and reasons for exclusion of full-text studies

Secondary outcomes

AOFAS score as functional outcome measure was used in all but one study [17], however, AOFAS scores could be not extrapolated from two studies [15, 28]. The sum of SMOs used for calculations was 697. Mean value was 51.8 preoperatively and improved to 79.1 postoperatively (Fig. 2). Visual Analog Score (VAS) for pain was also used, and weighted data from nine studies (300 SMOs) were extrapolated [16, 18–22, 24, 27, 29]. Mean value was 6.5 preoperatively and improved to 2.1 postoperatively (Fig. 3). All studies, but two [14, 24], reported complications and unplanned procedures. Complications occurred in 5.7% (44 out of 777 SMOs) with impaired union being the most common 54.5% (24 out of 44). Unplanned procedures were performed in 6.3% (49 out of 777 of SMOs). Hardware removal was required in 1.9% (15 out of 777 of SMOs), and revision surgery in 4.4% (34 out of 777 of SMOs) (Table 4). Additional procedures were

Table 1 Risk of bias assessment according to the Modified Coleman Methodology Score

Modified Coleman Methodology Score				Pagenstert et a. 2007	Pagenstert et a. 2009	Colin et al. 2014	Hongmou et al. 2016	Kobayachi et al. 2016	Hintermann et al. 2017	Krahenbuhl et al. 2017	Kim et al. 2019	Xu et al. 2019	Zhao et al. 2019	Choi et al. 2020	Lim et al. 2021	Suh et al. 2021	Harada et al. 2021	Ahn et al. 2022	Yang et al. 2022
1	Study size—number of patients (*N*)	*N* > 120	10	0	0	7	4	0	0	10	4	0	0	0	0	4	4	0	4
		N 81–120	7																
		N 40–80	4																
		N < 40 or not stated	0																
2	Mean follow-up	> 6 years	5	3	3	3	3	0	5	3	3	5	0	3	0	3	3	0	0
		3–6 years	3																
		< 3 years, not stated, or uncleap	0																
3	Percent of patients with follow-up (radiographic and clinical)	> 90%	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
		80–90%	3																
		< 80%	0																
4	Number of interventions per group	One intervention in all patients in each group	10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
		Multiple interventions but consistent among all patients in each group	5																
		Unclear, unreported, or multiple interventions among patients in the same group	0																
5	Type of study	Randomized control trial	15	10	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0
		Prospective cohort study	10																
		Retrospective cohort study	0																

Table 1 (continued)

Modified Coleman Methodology Score				Pagenstert et a. 2007	Pagenstert et a. 2009	Colin et al. 2014	Hongmou et al. 2016	Kobayachi et al. 2016	Hintermann et al. 2017	Krahenbuhl et al. 2017	Kim et al. 2019	Xu et al. 2019	Zhao et al. 2019	Choi et al. 2020	Lim et al. 2021	Suh et al. 2021	Harada et al. 2021	Ahn et al. 2022	Yang et al. 2022
6	Diagnostic certainty (diagnosis confirmed by defined PE findings or MRI)	In all	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
		In > 80%	3																
		In < 80%, instated, or unclear	0																
7	Description of surgical technique	Technique stated with necessary details to repeat	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5
		Technique named without elaboration	3																
		Not stated or unclear	0																
8	Description of postoperative rehabilitation	Well described with > 80% patient compliance	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5
		Well described with 60–80% patient compliance, or described without complete detail	3																
		Protocol not reported < 60% patient compliance	0																
1	Outcome criteria	Outcome measures clearly defined	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 1 (continued)

Modified Coleman Methodology Score				Pagenstert et a. 2007	Pagenstert et a. 2009	Colin et al. 2014	Hongmou et al. 2016	Kobayachi et al. 2016	Hintermann et al. 2017	Krahenbuhl et al. 2017	Kim et al. 2019	Xu et al. 2019	Zhao et al. 2019	Choi et al. 2020	Lim et al. 2021	Suh et al. 2021	Harada et al. 2021	Ahn et al. 2022	Yang et al. 2022
		Timing of outcome assessment clear	2	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Use of outcome criteria with reported good reliability	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Use of outcome with good sensitivity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2	Procedure for assessing outcomes	Subjects recruited	5	-	-	-	-	-	5	5	-	-	-	-					
		Independent investigator (2 for radiographic, 2 for clinical)	4	-	-	-	4	-	4	4	4	-	4	4	4	4	-	-	-
		Written assessment	3	3	-	-	-	3	3	3	3	-	-	3	3	-	-	3	3
		Patient centered data collected	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	Description of subject selection process	Selection criteria reported and unbiased	5	5	-	5	5	5	5	-	5	5	5	5	5	5	5	5	5
		Recruitment rate reported and > 80%	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Eligible subjects not included in the study satisfactorily accounted for	5	5	-	5	-	-	5	5	-	5	-	5	5	5	-	-	-
Total				**62**	**39**	**58**	**54**	**46**	**75**	**74**	**57**	**53**	**47**	**58**	**55**	**59**	**50**	**46**	**50**
				Fair	Poor	Fair	Fair	Poor	Good	Good	Fair	Fair	Poor	Fair	Fair	Fair	Fair	Poor	Fair

Table 2 Studies' characteristics and patients' demographics

Year	Study	No of ot	No of pt	Age (y)	Follow-up (mo)	Type of ot	Varus/ valgus	No of Takakura classification	Sex (m/f)	Side (r/l)	Type of radiological evaluation	Type of functional evaluation
2007	Pagenstert et al	35	35	43 (r, 26–48)	60 (r, 36–126)	mow/-mc/-low/-lc/smot	13vr, 22vl	–	26 m, 9f	–	TAS, TLS, TT, TC, malleolar angle, calcaneocrural angle	AOFAS, VAS, ROM, ankle stability, Outerbridge grade, Takakura score
2009	Pagenstert et al	22	22	47 (r, 29–67)	54 (r, 36–78)	mc-smot	22vl	14sI, 3sII, 5sIII	–	–	–	AOFAS, VAS, Takakura score
2014	Colin et al	83	83	45 (r, 17–79)	42 (r, 12–168)	mow/-mc/-low/-lc/smot	62vr, 21vl	–	59 m, 24f	–	TAS, TLS, TT, Meary angle	AOFAS, Takakura angle score, sidewalk sign
2016	Hongmou et al	41	41	50.7 (r, 32–71)	36.6 (r, 17–61)	mow-smot	41vr	14sII, 27sIII	14 m, 27f	–	TAS, TT, TC, TLS	AOFAS, AOS pain&function, ROM, Maryland foot score
2016	Kobayachi et al	27	25	63 (r, 28–79)	27.3(r, 14–45)	mow-smot (mortise-plasty)	25vr	9sII, 18sIII	6 m, 19f	–	TAS, TT, TMM, TLS, mortise width	AOFAS, VAS, ROM, Takakura angle score, japanese sitting style
2017	Hintermann et al	20	20	44 ± 12 (r, 17–60)	70.8 ± 25.2 (r, 8–134.4)	Mtpp &mow-smot	20vr	3sI, 6sII, 9sIII, 2sIV	12 m, 8f	–	CORA, TAS, TLS,TT, varus tilt, moment arm of calcaneus	AOFAS, VAS, ROM
2017	Krahenbuhl et al	298	294	49,74	60 ± 44.4	mow/-mc/-low/-lc/smot	99vr, 195vl	55sI, 99sII, 104sIII, 17sIV	204 m, 90f	137r, 157 m	TAS, TLS, TT, TTS	AOFAS, VAS, AOS pain&function&alignment
2019	Kim et al	58	53	52.3 ± 7.6 (r, 39–68)	62.4 ± 4.2 (r, 48–72)	mow-smot	53vr	–	27 m, 26f	27r, 31 l	TAS, TLS, TT	AOFAS, VAS
2019	Xu et al	21	21	53.7 ± 5.8 (r, 39–61)	87.7 ± 19.5 (r, 61–125)	mow-smot	21vr	21sIII	3 m, 18f	13r, 8 l	TAS, TLS, TT	AOFAS, VAS, SF-36, AOS
2019	Zhao et al	34	34	54.8(r, 23–77)	47.74	mow-smot	34vr	32sIII, 2sIV	11 m, 23f	32r, 11 l	TAS, TT, TLS, TC, TMM, HFA	AOFAS, ROM, AOS

Table 2 (continued)

Year	Study	No of ot	No of pt	Age (y)	Follow-up (mo)	Type of ot	Varus/ valgus	No of Takakura classification	Sex (m/f)	Side (r/l)	Type of radiological evaluation	Type of functional evaluation
2020	Choi et al	31	31	61.5 ± 7.3	48.9 ± 19.4 (r, 24–84)	mow-smot	31vr	–	17 m, 14f	18r, 13 l	TAS, TT, TCA, MTD-P gap, TMAA, TLS, HAA, HAR, talar center migration, talar dome center migration	AOFAS, FAAM-ADL
2021	Lim et al	29	28	58.2 (r, 34–72)	35.3 (r, 12–93)	mow-smot	28vr	5sII, 24sIII	–	–	TAS, TT, TLS, mean opening-wedge angle, mean wedge height, mean osteotomy level, mean tibial oblique osteotomy angle	AOFAS, VAS, ROM, patient satisfaction score, modified Outerbridge classification
2021	Suh et al	48	47	53.5 (r, 31–68)	48 (r, 24–99.6)	mow-smot	47vr	7sII, 41sIII	–	–	TAS, TT, TTS, TLS, talofibular UG, talofibular LG, LG-UG	AOFAS, VAS
2021	Harada et al	52	52	66	46 ± 23	mow-smot	52vr	2sII, 39sIII, 11sIV	11 m, 41f	-	TAS, MMA, TLS, TAA, TTS	Japanese Society for Surgery of the Foot Ankle/Hindfoot Scale (JSSF scale)
2022	Ahn et al	26	24	58 ± 7 (r, 50–70)	26 ± 3 (r, 21–33)	mow-smot	24vr	10sII, 26sIII	5 m, 19f	–	TAS, TTS, TLS, International Cartilage Repair Society, HR	AOFAS, VAS, ROM

Table 2 (continued)

Year	Study	No of ot	No of pt	Age (y)	Follow-up (mo)	Type of ot	Varus/ valgus	No of Takakura classification	Sex (m/f)	Side (r/l)	Type of radiological evaluation	Type of functional evaluation
2022	Yang et al	41	41	56.4 ± 11.7	32.9 ± 7.4	mow-smot	41vr	–	27 m, 14f	24r, 17 l	TAS, TLS, TT	AOFAS, VAS, ROM, patient satisfaction score

reported in all but four studies [16, 17, 19, 24]. Concomitant soft tissue surgeries were performed in 41.0% (310 out of 756 of SMOs) with lateral ligaments reconstruction being the most common (47.7%; 148 out of 310). Concomitant osseous procedures were performed in 59.0% (446 out of 756 of SMOs). Fibular osteotomy was performed in 46.6% (208 out of 446) and calcaneal osteotomy in 21.7% (97 out of 446) (Table 5).

Subgroup analysis

There were 591 patients with varus deformity and 260 patients with valgus deformity. Three studies included both varus and valgus ankles [15, 20, 26], whereas twelve studies exclusively varus ankles [14, 16–19, 22–25, 27–29] and one study valgus deformities, only [21]. The majority (195 out of 260) of valgus ankles were derived from a single study [26].

Failures (requiring ankle arthrodesis or arthroplasty) after SMOs was 5.6% (29 out of 516 SMOs) in varus and 11.1% (24 out of 217 SMOs) in valgus ankles [(χ^2 (1, $N = 733$), 5.9523, $p = 0.014 < 0.05$)]. After SMO failure, it was more likely to perform TAR in preoperatively varus ankles 8.3% (18 out of 217 SMOs) versus 3.3% (17 out of 516 SMOs) in preoperatively valgus ankles [(χ^2 [(1, $N = 733$), 7.3365, $p = 0.007 < 0.05$)]. Conversion to AA was 2.8% (6 out of 217 SMOs) for varus ankles and 2.3% (12 out of 516 SMOs) for valgus ankles [(χ^2 [(1, $N = 733$), 0.008, $p = 0.93 > 0.05$)].

The mean pre-operative AOFAS score for varus ankles was 53.2 and the post-operative was 80.1 ($p < 0.001$, $n = 492$ SMOs). Valgus ankles had a mean pre-operative AOFAS score of 53.2 and a post-operative of 74.2 ($p < 0.001$, $n = 238$ SMOs). Pre-operatively, varus ankles had a mean VAS score of 5.9, whereas the post-operative score was 2.3 ($p < 0.001$, $n = 333$ SMOs). Valgus ankles had a mean pre-operative VAS of 4.7 and a post-operative VAS of 2.9 ($p < 0.001$, $n = 217$ SMOs). Mean values of AOFAS and VAS scores were presented in the individual studies, so pooled statistics to assess statistical significance could not be calculated.

Complication rate was 6.1% (30 out of 494 SMOs) for varus deformities, versus 5.5% (12 out of 238 SMOs) valgus deformities [(χ^2 [(1, $N = 732$), 0.3156, $p = 0.57 > 0.05$)]. The rate of unplanned procedures after SMO for varus ankles was 8.9% (44 out of 494 SMOs) versus 10.5% (25 out of 238 SMOs) for valgus ankles [(χ^2 [(1, $N = 732$), 0.3111, $p = 0.58 > 0.05$)].

Discussion

The present systematic review of the literature identified fourteen studies reporting outcomes in 866 patients undergoing 851 SMOs, combined with 777 adjuvant procedures for ankle arthritis. We found that SMO can be considered

Table 3 Studies reporting on SMO "survivorship" before arthrodesis or arthroplasty was needed

Study	Number of patients	Number of SMO	Age (years)	Follow-up (months)	Failures	MCMS
Pagenstert et al. 2007	35	35	43	60	3/35 (8.6%)	62
Pagenstert et al. 2009	22	22	47	54	2/22 (9.1%)	39
Colin et al.	83	83	45	42	4/83 (4.8%)	58
Hongmou et al.	41	41	50.7	36.6	2/41 (4.9%)	54
Hintermann et al	20	20	44	70.8	1/20 (5%)	75
Krahenbuhl et al.	294	298	49.7	60	38/294 (12.9%)	74
Xu et al.	21	21	53.7	87.7	1/21 (4.8%)	53
Zhao et al	34	34	54.8	47.7	3/34 (8.8%)	47
Lim et al.	28	29	58.2	35.3	0/29 (0.0%)	55
Suh et al	47	48	53.5	48	2/48 (4.2%)	59
Ahn et al.	24	26	58	26	0/26 (0.0%)	46
Overall	**649**	**657**	**50.7 ***	**51.6 ****	**56/657 (8.5%)**	–

*The average age in years for these eleven studies

**The average follow-up in moths for these eleven studies

SMO supramalleolar osteotomies, MCMS Modified Coleman Methodology Score

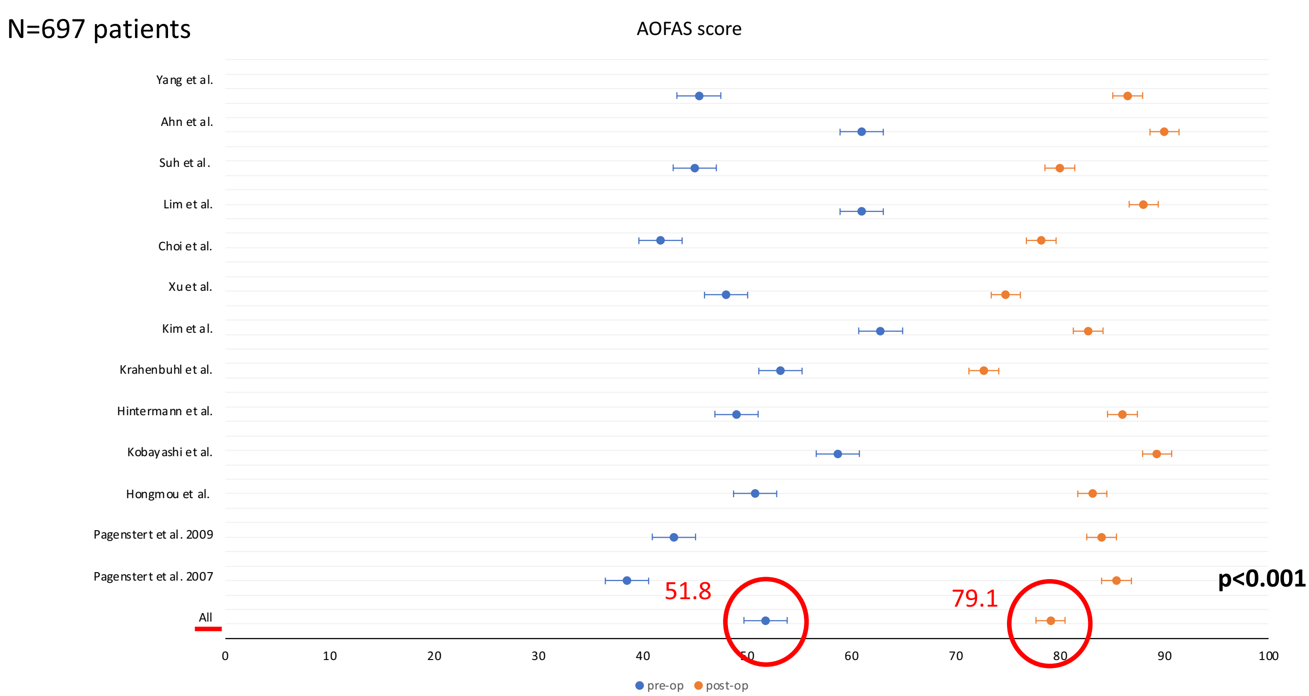

Fig. 2 The statistically significant difference in AOFAS score pre-operatively and post-operatively

a viable option for the management of ankle arthritis, not requiring revision surgery for 5 years in the vast majority of patients, offering improvement of function, with low complication rates.

Eleven studies reported "survivorship" of SMO, before conversion to AA or TAR [15, 18–23, 26–29], and only three of those were prospective studies [20, 22, 26]. According to our analysis, 56 out of 657 SMOs (8.5%) failed and patients required AA or TAR, after an average of just over 4 years (51.6 months) after the index surgery. In the largest prospective study of 294 patients, the 5-year osteotomy survival rate was 88% (95% CI 84–92%) [26]. The latter seems to support the theoretical concept that joint preserving realignment surgery may restore near normal ankle biomechanics, slowing down the degenerative process, off-loading the damaged cartilage and offering pain relief and functional improvement [20, 30–33]. According to Krahenbuhl et al. [26], the rate of revision surgeries has a bimodal distribution (2 and 12 years

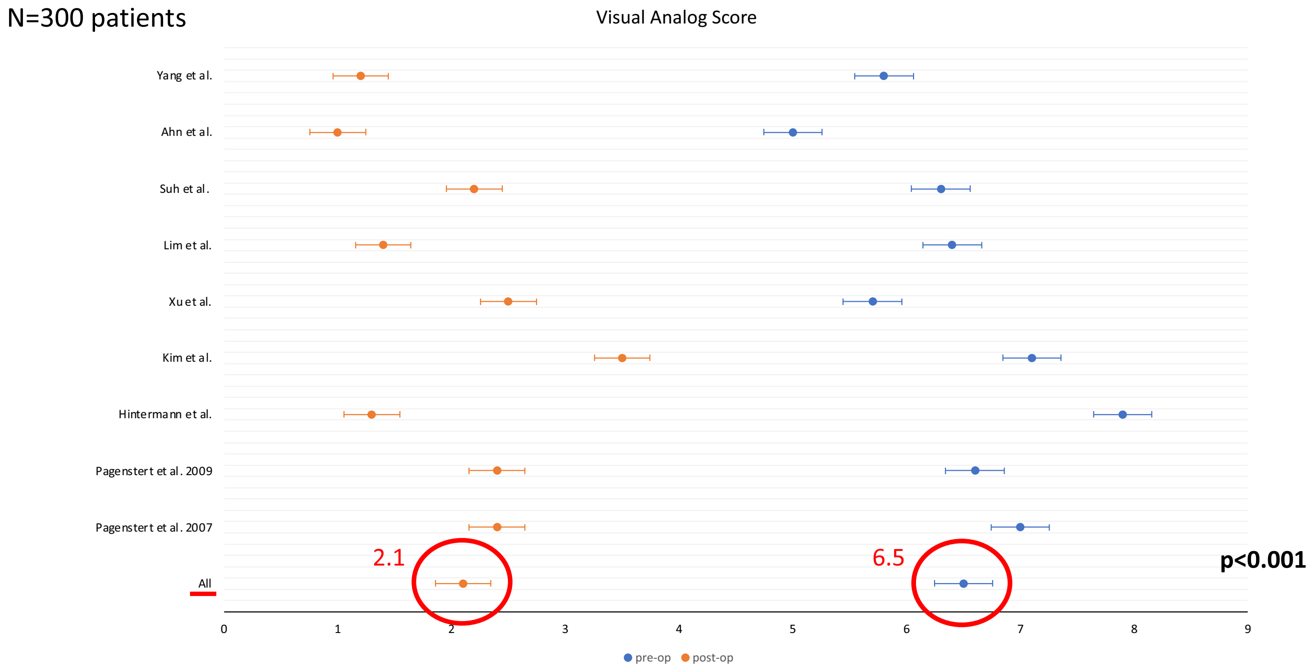

Fig. 3 The statistically significant difference in VAS score pre-operatively and post-operatively

Table 4 Complications and unplanned procedures of supramalleolar osteotomies

Study (*N* = 777 ot)	Complications				Unplanned procedures	
	Scar dehiscence	Hematoma	Infection	Non-/-mal-union	Plate removal	Revision
Pagenstert et al. 2007	0	0	1	1	7	7
Pagenstert et al. 2009	0	0	0	2	-	1
Colin et al.	1	0	2	2	2	1
Hongmou et al.	0	0	0	0	0	0
Kobayashi et al.	0	2	1	0	1	0
Hintermann et al.	0	0	0	0	5	0
Krahenbuhl et al.	0	0	5	7	0	7
Kim et al.	–	–	–	–	–	–
Xu et al.	0	0	0	0	0	0
Zhao et al.	0	0	2	0	0	0
Choi et al.	–	–	–	–	–	–
Lim et al.	0	0	1	3	0	0
Suh et al.	0	0	0	2	0	0
Harada et al.	0	0	0	1	0	0
Ahn et al.	0	0	0	1	0	0
Yang et al.	3	0	2	2	0	0
Total	**4 (0.5%)**	**2 (0.3%)**	**14 (1.8%)**	**24 (3.1%)**	**15 (1.9%)**	**34 (4.4%)**

ot osteotomies

after the corrective osteotomy) and has attributed the early rise in revision surgeries to vague patient selection and the late one to the progression of ankle OA. Furthermore, should TAR be required patients may benefit from previous realignment surgery, as TAR performed in well-aligned feet is less challenging and has been associated with better outcomes [32, 34–38]. The only comparative study of SMOs versus AA showed improvements in function, pain, alignment, and quality of life after surgery for both treatment in cases of advanced arthritis [39]. However, patients in the AA group

Table 5 The number and diversity of additional soft and osseous procedures that accompanied supramalleolar osteotomies

Additional procedures			No of procedures
Soft tissue procedures	Ligmaments	Medial ligament reconstruction	43
		Lateral ligament reconstruction	148
	Tendons	Achilles tendon lenghtening	14
		PL/PB tendon revision	31
		TA/TP tendon revision	25
		Cheilectomy	49
Osseous procedures	Ankle	Fibular ot	208
		Medial distraction ot	16
		Contra ankle ad	1
	Calcaneus/Hindfoot	Calcaneal ot	97
		Subtalar ad	23
		Cc distraction ad	5
		Subtalar arthrolysis	2
	Midfoot	Talonavicular ad	1
		1st cuneiform ot	2
		5th metatarsocuboid ad	1
	Forefoot	Metatarsal ot	21
	Cartilage	Intra-articular debridement	28
		Subchondral drilling	41

PL peroneus longus, PB peroneus brevis, TA tibialis anterior, TP tibialis posterior, cc calcanealcuboid, ad arthrodesis, ot osteotomy

reported better pain relief, had a lower reoperation rate, and better hindfoot alignment during a short- to mid-term follow-up time [39].

In contrast to osteoarthritis (OA) of the hip or knee, the etiology at the ankle is posttraumatic in the majority of patients [1, 40, 41]. It becomes symptomatic after 12 to 15 years [42] and usually affects relatively young patients [42]. This underlines the importance of long-lasting treatment options for this patients' group. Although AA and TAR show good short- and mid-term results [6, 43, 44], AA may lead to debilitating adjacent joint OA [6], and TAR has shown up to a 12% rate of metal component revision and an 18% rate of polyethylene bearing failure after 4.3 ± 3 and 5.2 ± 2.1 years [44]. Our review demonstrated that SMO can be considered a viable alternative, especially for younger patients [26]. It preserves the native ankle joint for some years, whilst avoiding serious complications. Hardware removal was part of the treatment protocol in the largest study included in this review [26], thus it was not counted as "unplanned procedure" in our analysis. It is debatable whether hardware removal should be electively planned, for existing hardware not to compromise secondary surgery (i.e., AA, or TAR), should it be required [45]. On the other hand, planned hardware removal exposes asymptomatic or minimally symptomatic patients to the risks of surgery.

Multiple additional procedures were necessary to achieve deformity correction and soft tissue balancing of the ankle. Concomitant soft tissue procedures were performed in 41.0% of cases undergoing SMO. Lateral ligaments reconstruction was required in approximately half of those patients. Concomitant osseous surgery (other than SMO) was also required in 59.0% of SMOs, with fibular osteotomy required in 46.6% and calcaneal osteotomy in approximately 21.7% of those SMOs. Severe ankle deformities cannot be corrected adequately by a singular osteotomy requiring concomitant proximal corrections and hindfoot osteotomies [10]. This is probably indicative of the heterogeneity of clinical and radiographic features of arthritic ankles, and the fact that individualized preoperative planning and extensive surgeons' expertise are essential. It is beyond the scope of this systematic review—and probably invalid based on available data—to analyze the effect of different procedures on radiographic and clinical outcomes.

All studies reported improved functional results after SMO. Pain relief, the main goal of surgery for arthritis was achieved according to the reported data [20, 21, 31, 33, 46–48]. There was heterogeneity regarding reported outcomes. AOFAS hindfoot score was the one consistently reported, showing significant improvement after surgery. We have to note, however, that AOFAS is not a validated outcome score, and may not be the appropriate tool to evaluate these patients, as there are concerns for potential bias, whilst it is psychometrically limited [19, 49, 50]. Indeed there is a policy statement from the AOFAS research committee recommending against use of this instrument published in 2011 [22, 51]. Other (e.g., Maryland foot score, or SF-36) outcome measures were also used, albeit in a limited number of patients. D'ambrosi et al. measured physical impairment with SF-12 and demonstrated that is equivalent to that reported by patients affected by tumors [3].

Approx. 60% of treated ankles were classified as stage III and 25% as stage II, according to the Takakura classification. Only the largest study in the literature [26], did relevant analysis to show that younger patients with stage IIIA arthritis, benefitted the most from SMO. The Takakura classification, however, does not take into consideration the overall foot deformity, the condition of foot joints (other than the ankle) or ligaments and tendons, and thus the need for adjuvant procedures.

We used a Modified Coleman Methodology Score (MCMS) (Table 1), to evaluate the quality of the studies. Out of a total of possible 100 points, 4 studies [21, 25, 28, 29] scored below 50, 10 [14–20, 23, 24, 27] between 53 and 62, and 2 [22, 26] scored 75 and 74 points, respectively. The latter two were the best studies according to the MCMS, and one of those [26] included almost half of all patients included for analysis in this review. Thus, the results of this analysis are largely influenced by a single (but, fortunately, the best) scientific published study. This increases the reliability of data analysis, but also means that overall results are skewed by one large study and may not pragmatically reflect results of these procedures performed by lower volume surgical groups.

As only eleven studies reported SMO "survivorship" in a total of 649 patients (657 SMOs) [15, 18–23, 26–29], the study by Krahenbuhl et al. [26]included approximately 50% of those (Table 3). Interestingly, Krahenbuhl et al. performed a Kaplan–Meier survivorship analysis reported a 5-year failure rate of 12% [26], whilst five of the remaining (smaller) studies [15, 18, 22, 23, 27] reported failure rates of approximately 5%, three studies approximately 9% [20, 21, 28] and two studies reported no failure [19, 29]. This may, however, reflect the fact that some patients included in those studies were followed for a shorter period of time. Extrapolation of results should, therefore, be made with caution, and take into consideration the strengths and limitations of the individual studies.

Our subgroup analysis showed that varus deformities were more common compared to valgus (591 vs 260 ankles, respectively), with most valgus deformities deriving from a single study [26]. Interestingly, SMOs for valgus deformities failed almost twice as frequently, compared to varus ones (11.1% vs 5.6%, $p=0.014$). Most SMOs in varus ankles that failed were converted to TAR (8.3% vs 3.3%, $p=0.007$), whereas conversion to AA was similar for varus and valgus preoperative deformities (2.8% vs 2.3%, $p=0.93$). It is difficult to interpret these findings with confidence, as failures may, also, have been related to the degree of degeneration of the tibiotalar joint, the age and other characteristics of the individual patients, and such analysis cannot be performed based on the data reported by the individual studies. There seems to be some disparity in the failure rate of valgus ankles between the included studies. Although pooled statistics showed overall higher failure rate in valgus ankles, we have to highlight that most valgus ankles (195 out of 260) were derived from the study by Krahenbuhl et al. and these authors reported the contrary. Namely, that varus ankles had a higher rate of revision surgery in their cohort of patients, and this was attributed to the advanced stage of OA most of varus ankles exhibited prior to SMO [26]. These authors suggested that varus deformity is, probably, better tolerated by patients, and therefore the sought a surgical solution when arthritic stages were more advanced, compared to those with valgus deformities. Thus, it could be the heterogeneity of phenotypes (e.g., severity of joint degeneration, ligamentous insufficiency, overall foot deformity) of included valgus ankles in the different studies and, probably, the different surgical treatment strategies that caused this disparity. Our results also showed that failure of SMO in valgus ankles was less likely to be converted to TAR. This may reflect the fact that some valgus deformities may have been associated with medial instability, deltoid ligament insufficiency, and/or flatfoot deformity and treating surgeons felt that AA was the safer option. Varus ankles revealed similar, but slightly better, AOFAS and VAS scores, after SMO, compared to valgus ones. These differences, not reaching statistical significance, could be attributed to the greater ROM benefit in varus corrected ankles compared to valgus ones, as Pagenstert et al. showed that patients with preoperative hindfoot varus experienced greater ankle and subalar ROM benefit [20].

Limitations of this study include: (a) fair overall methodological quality of the included studies; (b) heterogeneity of study designs, which allowed limited quantitative analysis; (c) there was no analysis of the radiologic parameters; (d) use of AOFAS (not validated, outdated) for functional evaluation; (e) nearly half of the patients included in this systematic review were from a single study [26], (f) there was no distinction between varus and valgus ankle arthritis, and (g) none of the studies included a comparison to other treatment options. On the other hand, strengths of this study include: (a) strict inclusion and exclusion criteria; (b) critical appraisal of the evidence by two independent authors and (c) average follow-up of at least two years in the included studies.

Overall, we believe that the present study revealed reliable and representative data regarding the medium-term success of SMOs performed for ankle arthritis, based on level IV evidence. Future clinical research could include prospective studies, with standardized treatment and research protocols, use validated outcome measures, and aim at assessment of long-term outcomes.

Conclusions

Supramalleolar osteotomies combined with adjuvant, osseous and soft tissue, procedures, were performed mostly for arthritic ankles of stage II and III, according to the Takakura classification, offering functional improvement. Low complication rates were reported, whilst approx. 10% of patients had to undergo arthrodesis or ankle arthroplasty in the medium term. Varus deformities were more common, but it is debatable whether SMOs offer better outcomes in varus compared to valgus ankles. Prospective, well designed clinical studies including validated patient-reported outcome measures, with longer follow-up, are needed.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Not required.

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