Efficacy evaluation and systematic review of supramalleolar osteotomy for treatment of varus-type ankle arthritis

Wang Xue¹, Tiannan Chen², Paerhati Wahafu¹, Fei Li¹, Ayiding Xiahatai¹, Aikeremu Wufuer¹, Yanan Tuo¹, Bo Zhao¹ and Chengwei Wang³

Abstract

**Background:** The current surgical treatment plan for medium-term varus-type ankle arthritis is primarily supramalleolar osteotomy (SMOT), but the reliability of this procedure still lacks high-quality evidence-based medical studies, such as randomized controlled clinical trials and meta-analyses of comparative studies.

**Objective:** The current study explored whether significant differences were present in the clinical effect, reoperation rate, complications, and failure rate of this type of surgery.

**Method:** Two researchers searched the relevant literature in seven databases, including PubMed, Cochrane Library, EMBASE, the China Biomedical Literature Database, the China Academic Journals Full-text Database, the Wanfang database, and the Weipu Chinese Science and Technology Journal Database. The retrieval time spanned the establishment of the specific database up to September 2020, and the literature was screened to determine their final inclusion in the study.

**Results and conclusions:** A total of 20 studies were included, including one Chinese and 19 English language studies. The primary indicators included a definitive effect of SMOT on the treatment of medium-term varus-type ankle arthritis. Concerning secondary indicators, although the surgery effect was satisfactory, some patients may require follow-up surgery, which may be unsuccessful with complications. The study results showed that, based on existing literature reports, the effect of SMOT for varus-type ankle arthritis was a satisfactory surgical method with some clinical value for correcting the ankle force line and relieving or even reversing ankle arthritis. However, its risk of complications and failure rate were comparatively high and, accordingly, requires good preoperative planning and close communication with patients. Due to the limited sample size of this study, more data and longer follow-up times involving this type of surgery should be reviewed to confirm this conclusion.

**Keywords**
varus-type, ankle arthritis, supramalleolar osteotomy, treatment, meta-analysis

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**Introduction**

According to statistics, nearly 1% of adults worldwide suffer from ankle osteoarthritis (OA).¹ Several pathogenic factors are involved in this condition, including congenital abnormalities of the tibia, deformed healing following a distal tibial fracture, distal tibial epiphysis injury, infection, ankle instability, and neuromuscular disease.² Ankle varus

¹Department of Orthopedic Surgery, The Sixth Affiliated Hospital of Xinjiang Medical University, China
²Department Burn Surgery, People’s Hospital, Yueqing County, Wenzhou, China
³The Third Affiliated Hospital of Xinjiang Medical University, China

Corresponding author:
Chengwei Wang, the president of the Third Affiliated Hospital of Xinjiang Medical University, No. 789, Suzhou east street, Xinsi District, Urumqi, Xinjiang Uyghur Autonomous Region 830000, China.
Email: cheng_we151@126.com

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and valgus deformities are the primary manifestations of common ankle malalignment. In patients with symmetric ankle osteoarthritis, it has been reported that varus and valgus ankles account for 70%-80% of symmetric ankle osteoarthritis. Valderrabano et al.4 found that 55% of ankle OA patients had combined ankle varus and 8% had combined ankle valgus.

In 1936, Speed and Boyd5 published a clinical study on designing a method for treating post-ankle trauma deformity and identified three key targets for supramalleolar readjusted surgical procedures as follows: (1) restore the proper force line; (2) restore the proper arrangement of the tibial pitch joint surface; 3) restore the physiological and pain-free activity range of the tibiotalar joint. Subsequently, Takakura and colleagues6 were the first to systematically report the application of SMOT in 1995 and proposed the classification of varus ankle OA. This was mainly classified into four types as follows: stage (1) the joints are parallel, without joint space stenosis, early subchondral osteosclerosis or osteophyte formation; stage (2) the medial joint space is narrow without subchondral bone contact; stage (3) (a) the medial ankle space is occluded, and the subchondral bone contact is medial; (b) subchondral bone contact extends to the fornix of the talus; stage (4) a varus ankle joint with complete bone contact.6,7

In the reports of these scholars, the effect of SMOT on the treatment of medium-term ankle arthritis was predictable. Nonetheless, there are currently no systematic reports that confirm these results. Supramalleolar osteotomy for ankle arthritis still lacks high-quality evidence-based ST, e.g. randomized controlled clinical trials and meta-analyses of comparative studies. Meta-analysis is increasingly being recognized as a key tool for obtaining high-quality evidence.8,9,10 Accordingly, this study adopted a meta-analysis approach to perform a comparative investigation of existing studies to determine whether there were significant differences in clinical scores and reoperation rates: The aim of doing so was to better understand the application of SMOT in varus-type ankle arthritis.

The search was performed in strict accordance with the PICOS (population, intervention, comparison, outcome, study) design principles, and the remaining relevant literature was searched manually. Subject-related terms were combined with free words; the English search terms were ‘supramalleolar osteotomy’, ‘osteotomy’, ‘low tibial osteotomy’ and ‘ankle’, ‘ankle arthrodesis’, ‘ankle osteoarthrosis’, ‘varus ankle’, ‘varus ankle arthritis’, ‘varus ankle osteoarthritis and/or’ ‘treatment’. The Chinese search terms included ‘supramalleolar osteotomy’, ‘ankle arthrodesis’, ‘varus’ and ‘treatment’. The literature search results were not limited in terms of time, country or region. Following an initial electronic search, the authors searched other relevant articles by scanning the bibliographies of all the selected full-text articles.

### Selection criteria

#### Inclusion criteria. The study’s inclusion criteria were as follows: (1) the literature study reported on patients diagnosed with varus ankle arthritis who were treated with SMOT; (2) the study reported on the treatment efficacy of SMOT, preoperative and postoperative effect comparisons, and provided a complete description of various pre-and post-surgery; (3) the study included American Orthopaedic Foot and Ankle Society (AOFAS) scores; (4) the study included pain scores.

#### Exclusion criteria. The study’s exclusion criteria were as follows: (1) repeated studies; (2) case reports, reviews, meta-analyses, editorials, letters, non-English studies, non-human study cohorts/cadaver experimental studies; (3) studies from which data could not be extracted; 4) literature that was not relevant to the current study.

### Data extraction

The data extracted by the researchers included the following: (1) the name of the first author, the publication date, the average age of participants, sample size, patient gender, follow-up time, and the primary indicators (SMOT, varus ankle arthritis) and secondary indicators (complete preoperative and postoperative description, AOFAS score, pain score, postoperative complications elaboration). If disagreement occurred among the researchers during the data extraction process, they sought the help of corresponding authors.

### Statistical analysis

Statistical analysis was performed using the SPSS Statistics 21.0 software program. Measurement data were expressed as $\bar{x} \pm s$, and a paired t-test was used for group comparison;
p < 0.05 was considered to indicate a statistically significant difference.

Results

Literature screening process

Using the electronic system search, a total of 1591 Chinese documents and 3725 foreign language documents were retrieved. Subsequently, reviews, meta-analyses, case reports, books and repeated literature were excluded. Following additional review of the article’s title and abstract, 1590 Chinese documents and 3705 foreign language documents were excluded. After further reading of the full article, one article with incomplete data was excluded. Finally, 20 retrospective study articles that met the study criteria were selected for analysis (see Figure 1).

Characteristics of the included studies

The included papers were all retrospective studies. All 20 studies were published between 2006 and 2019 and included 686 cases of varus ankle arthritis. Follow-up procedures were performed between 27.2 and 97 months. Basic information regarding the included literature is shown in Table 1.

Results of the meta-analysis

The correction effect of supramalleolar osteotomy. All of the included literature data were screened. Three data perspectives were included, i.e. tibial articular surface angle (TAS), tibial lateral surface angle (TLS), and talar tilt angle (TT) data were recorded for comparison. Table 2 shows the differences that were found between these categories.
relevant data were not recorded in some of the studies and were automatically screened out in the SPSS software).

According to the statistical software results, the three perspectives noted above showed significantly better postoperative results compared with before surgery. The TAS improved from 84.2° preoperatively to 91.5° postoperatively ($p < 0.001$), TLS improved from 79.7° (P < 0.002) and TT improved from 9.55° preoperatively to 4.78° ($p < 0.001$). It was concluded that the effect of supramolecular osteotomy on varus ankle arthritis had been clearly indicated.

### Pain score.
The visual analogue scale (VAS) scores in the literature data were included for statistical analysis.

(relevant data were not recorded in some literature and were automatically screened out in the SPSS software)

### Table 1. Basic information of literature.

| First author | Research type | Publication time (year) | Average age (years) | Sex ratio male/female, n | Mean follow-up time (months) | Number of cases/ankle, n | Ankle number | Remarks |
|--------------|---------------|-------------------------|---------------------|--------------------------|-----------------------------|--------------------------|--------------|---------|
| Y. Tanaka7   | Retrospective | 2006                    | 54                  | 0 25                     | 99                          | 25 26                    |              |         |
| Krähenbühl N11 | Retrospective | 2019                    | 54.5                | 31 11                    | 40                          | 44 44                    |              |         |
| Hongmou Z12  | Retrospective | 2016                    | 50.7                | 13 28                    | 36.6                        | 41 41                    |              | 1 person lost 2 person lost |
| Xu Y13       | Retrospective | 2019                    | 53.7                | 3 18                     | 87.7                        | 21 21                    |              |         |
| Zhao HM14    | Retrospective | 2019                    | SMOT3.4; SMOT WITH MDA56.2 | 3 18                     | 87.7                        | 21 21                    |              |         |
| Qu W15       | Retrospective | 2019                    | SMOT5.4; SMOT WITH MDA56.2 | 3 18                     | 87.7                        | 21 21                    |              |         |
| Colin F16    | Retrospective | 2014                    | 50                  | 44 18                    | 42                          | 62 62                    |              |         |
| ZHAO Hongmou17 | Retrospective | 2017                    | TOT48.8; TOT 8; TFOT52.4 | 36.6                        | 41 41                        | 36.6 41                  |              |         |
| Krähenbühl N18 | Retrospective | 2017                    | 50.22               | 73 26                    | 60                          | 99 99                    |              |         |
| Koo JW19     | Retrospective | 2019                    | 58.6                | 2 13                     | 46.3                        | 15 15                    |              |         |
| Lee WC20     | Retrospective | 2011                    | 55.2                | 7 9                      | 27.6                        | 16 16                    |              |         |
| Kim YS21     | Retrospective | 2014                    | 52.2                | 8 21                     | 27.4                        | 29 31                    |              |         |
| Colin F22    | Retrospective | 2014                    | 55                  | 41 11                    | NR                          | 52 52                    |              |         |
| Hintermann B23 | Retrospective | 2017                    | 44                  | NR                       | NR                          | 48 20                    |              |         |
| Knupp M24    | Retrospective | 2011                    | 49                  | NR                       | NR                          | 43 31                    |              |         |
| Scheidegger P25 | Retrospective | 2019                    | 47                  | 27 12                    | 21                          | 39 39                    |              |         |
| Ahn TK26     | Retrospective | 2015                    | 57                  | 3 15                     | 34                          | 18 18                    |              |         |
| Kobayashi H27 | Retrospective | 2016                    | 63                  | 6 19                     | 27.2                        | 25 27                    |              |         |
| Mann HA28    | Retrospective | 2012                    | 47                  | 14 5                     | 27.2                        | 25 27                    |              |         |
| Choi JY29    | Retrospective | 2020                    | 61.5                | 17 14                    | 48.9                        | 31 31                    |              |         |

Note: SMOT: supramalleolar osteotomy; SMOT WITH MDA: supramalleolar osteotomy with medial distraction arthroplasty; TOT: tibia osteotomy; TFOT: tibia and fibula osteotomy

According to the statistical analysis results using the SPSS 21.0 software, the AOFAS score improved from 54.05 preoperatively to 79.67 postoperatively ($p < 0.001$), inferring the conclusion that supramolecular osteotomy benefitted functional improvement in patients with varus ankle arthritis.

### Ankle function score.
The AOFAS scores in the literature data were included for statistical analysis.

(see Figure 2).
### Table 2. Corrective effect of supramolecular osteotomy (SMOT).

#### Paired sample statistics

|                | mean value | N  | Standard value | Standard error of mean |
|----------------|------------|----|----------------|------------------------|
| Right 1 Preoperative TAS | 84.2050    | 20 | 3.67086        | 0.82083                |
| Postoperative TAS            | 91.4950    | 20 | 3.26295        | 0.72962                |
| Right 2 Preoperative TLS     | 79.7333    | 18 | 3.22071        | 0.75913                |
| Postoperative TLS            | 82.1500    | 18 | 2.11639        | 0.49884                |
| Right 3 Preoperative TT      | 9.5500     | 20 | 4.49110        | 1.00424                |
| Postoperative TT             | 4.7750     | 20 | 3.53416        | 0.75001                |

#### Paired sample correlation coefficient

|                | N  | Standard value | Sig. |
|----------------|----|----------------|------|
| Right 1 Preoperative TAS | 20 | 0.041          | 0.863|
| Postoperative TAS      |    |                |      |
| Right 2 Preoperative TLS | 18 | 0.523          | 0.026|
| Postoperative TLS      |    |                |      |
| Right 3 Preoperative TT | 20 | 0.584          | 0.007|
| Postoperative TT      |    |                |      |

#### Paired sample test

|                  | Mean value | Standard value | Standard error of mean | 95% confidence interval of difference | Upper limit | Lower limit | t    | df | Sig(bilateral) |
|------------------|------------|----------------|------------------------|--------------------------------------|-------------|-------------|------|----|----------------|
| Right 1 Preoperative TAS | -7.29000   | 4.0963         | 1.07547                | -9.54098 -5.03902                     | -9.54098    | -5.03902    | -6.778| 19 | 0.000          |
| Postoperative TAS | -2.41667   | 2.77918        | 0.65506                | -3.79872 -1.03461                     | -3.79872    | -1.03461    | -3.689| 17 | 0.002          |
| Right 3 Preoperative TT | 4.77500    | 3.72006        | 0.83183                | 3.03396 6.51604                      | 3.03396     | 6.51604     | 5.740 | 19 | 0.000          |

**Figure 2.** Score of ankle function.
Table 3. Complications of supramalleolar osteotomy (SMOT).

| The first author | Published date | complications |
|------------------|----------------|----------------|
| Krähenbühl N11   | 2019           | One case developed the infection and improved after dressing change and antibiotics. Three fractures showed delayed healing at an average of 4.8 months (Intersection fill is a bone allogeneic graft) |
| Hongmou Z12      | 2016           | Three fractures had delayed healing of up to an average of 6 months (The filling is β-tricalcium phosphate) none |
| Xu Y13           | 2019           | Two cases of needle tract infection occurred in the group of osteotomy combined with medial ankle arthroplasty, and improved after dressing change and antibiotics |
| Zhao HM14        | 2019           | Two cases of needle tract infection occurred in the group of osteotomy combined with medial ankle arthroplasty, and improved after dressing change and antibiotics |
| Qu W15           | 2019           | One case had incision infection, which was improved with dressing change and antibiotics. One patient developed venous thrombosis after surgery, and received relevant symptomatic treatment |
| Colin F16        | 2014           | Ankle fusion was performed in four cases due to persistent arthritis, overcorrection and infection |
| Zhao H17         | 2017           | Due to pain, one patients received AA and the other TAR. |
| Krähenbühl N18   | 2017           | Two cases developed infection after surgery and improved after symptomatic treatment. Three fractures showed delayed healing at an average of 4.8 months (Intersection fill is a bone allogeneic graft) |
| Koo JW19         | 2019           | None |
| Lee WC20         | 2011           | None |
| Kim YS21         | 2014           | None |
| Colin F22        | 2014           | None |
| Hintermann B23   | 2017           | None |
| Knupp M24        | 2011           | None |
| Scheidegger P25  | 2019           | Two patients developed infection and underwent symptomatic treatment. Four patients had delayed fracture healing, two of whom were smokers, and these two patients were renovated and all healed. Eight patients developed ankle fibrosis. Three patients had ankle impact, and underwent surgery for revision |
| Ahn TK26         | 2015           | Nine patients indicated that the pain originated from the internal fixation device and was removed, and six patients indicated the presence of an ankle impact and performed secondary surgery |
| Kobayashi H27    | 2016           | Three cases had internal fixation-associated pain and two cases had subcutaneous hematomata. One incision infection was reported. Due to incision infection to remove internal fixation to external fixation, the postoperative recovery was satisfactory, one person developed tarsal syndrome followed by tarsal loosening, and one person developed internal fixation fracture. After removing internal fixation, the degree was lost by 6° |
| Mann HA28        | 2012           | Four patients had persistent pain symptoms, 2 cases underwent AA and 2 cases TAR |
| Choi JW29        | 2020           | None |
| Y. Tanaka30      | 2006           | Four cases showed bone nonunion, and secondary surgery was performed for improvement |
Based on the statistical analysis conducted using the SPSS software, the VAS pain score decreased from 5.82 preoperatively to 2.45 postoperatively ($p < 0.001$), inferring the conclusion that supramolecular osteotomy is conducive to pain relief in patients with varus ankle arthritis.

**Complications.** A total of 69 patients had related complications in the 12 studies, accounting for 10.35%; these included 9 infections (1.3%), 42 cases with delayed fracture healing (2.5%); 42 cases with symptoms (hematoma, pain, impact, joint fibrosis, tarsus syndrome) (6.1%), 1 case with thrombosis and one patient with an internal fixation fracture. The remaining six articles had no reported complications. **Table 3** shows the details in this regard.

**Revision rate.** Six studies reported 32 patients who underwent amendment surgery (4.7%). The remaining 14 articles reported no such surgeries. The details in this regard are shown in **Table 4**.

**Failure rate.** The total failures included 62 cases in 13 studies (9%). One of the reasons for these failures was the progression of ankle arthritis; a second reason involved persistent symptoms and serious ankle dysfunction. The remaining seven articles did not report any failure rates. **Table 5** shows the details in this regard.

**Discussion**

In the 20 literature studies on varus ankle arthritis, the bulk reported on the progression of ankle arthritis slowing, maintaining its current state, or even indicating reversal. A study by Zhao showed that at an average follow-up of 36.6 months, a total of 22 (57%) cases indicated slowed varus ankle arthritis, 13 (33%) cases remained unchanged, and 4 (10%) cases indicated a worsening condition. A study conducted by Qu showed a mean follow-up time of more than 32.2 months; the arthritis stage was improved in 11 (65%) cases, in which 2 cases ranged from stage 2 to 1, 7 cases ranged from stage 3a to 2, and 2 ranged from stage 3b to stage 3a. Six cases indicated no changes, and there was no aggravated cases. A study conducted by Hintermann had an average follow-up of 4 years, during which time 3 ankles deteriorated by one stage (1 ankle, phase I–II; 2 ankles, phase II–III), 11 ankles improved by one stage (3 ankles, phase II–I; 7 ankles, phase III–II; one ankle, phase IV–III) and 6 ankles were unchanged. In these reports, more than 50% of ankle
arthritis showed improvement, and a small number of patients had made progress.

Although SMOT can delay the progression of ankle arthritis, the surgical failure rate is as high as 9% and cannot be ignored. According to the mid-term follow-up results reported by Krahenbuhl, the 5-year survival rate was 75%, while the 5-year survival rate of stage 3b was only 47%, i.e. the patient was very likely to undergo ankle degeneration within 5 years, or persistent symptoms requiring ankle fusion or an ankle replacement. Kim retrospectively assessed 31 patients who received varus wedge SMOT. In all patients, arthroscopic bone marrow stimulation was performed on the medial cartilage lesions. Secondary arthroscopy revealed progressive ankle degeneration in 13 (42%) patients, while follow-up after 1 year revealed a deterioration in both the VAS and AOFAS scores. For SMOT, cartilage lesions were identified as a risk factor for adverse outcomes. Following the failure, the ankle will be sacrificed to improve function.

The statistical method applied in the present study tested the surgical effect of 20 research papers and found that the TAS, TLS and TT angles had been significantly improved, and the AOFAS and VAS pain scores were also significantly improved and with statistical significance. Accordingly, the effect of this surgery on varus ankle arthritis can be considered as positive. However, the procedure also presents common complications, primarily infection, thromboembolism, incision healing problems (including deep infection) and the delayed/non-healing of the fracture, pain and aggravated symptoms. Complications should be actively treated, based on symptomatic presentation. Early superficial infections can be improved by regular cleaning of the surgery area and dressing changes or the application of antibiotics. However, in the case of deep infections, these should be eradicated; this may require removing internal fixtures and performing surgical debridement to prevent infection.

The reasons for delayed fracture healing or non-healing (up to 22%) included anatomical reduction, periosteal dissection, whether the section was fixed, the osteotomy technique, the bone filling material that was used, and completing early functional exercise. Depending on the patient’s condition, secondary bone grafting surgery should be performed if necessary to accelerate healing of the fracture. If the pain or symptoms worsened and could not improve, final amendment surgery will be required, e.g. joint fusion or replacement.

Supramalleolar osteotomy is an ankle-preserving procedure that is conducted in cases of ankle arthritis; it has good short-and medium-term results in terms of pain relief, improved function, and restoring exercise ability, and can also delay and may even reverse the progress of OA. Concurrently, the procedure requires several surgical techniques with high technical

| The first author | Published date | Failure rate |
|------------------|----------------|--------------|
| Krähenbühl N² | 2019 | Ten operations eventually failed. Eight underwent TAR at an average of 28.8 months, and two had AD within an average of 7.2 months |
| Hongmou Z¹² | 2016 | Two cases underwent AD at 17 and 26 months |
| Xu Y¹³ | 2019 | One case underwent TAR 3 years later |
| Zhao HM¹⁴ | 2019 | Three cases (SMOT) underwent AD at 17.26, and 61 months |
| Qu W¹⁵ | 2019 | None |
| Colin F¹⁶ | 2014 | Four cases underwent AD |
| Zhao H¹⁷ | 2017 | Due to pain, one patient received AA and the other TAR. |
| Krähenbühl N¹⁸ | 2017 | Seventeen operations failed, 3 cases underwent AD and 14 cases underwent TAR |
| Koo JW¹⁹ | 2019 | None |
| Lee WC²⁰ | 2011 | None |
| Kim YS²¹ | 2014 | None |
| Colin F²² | 2014 | None |
| Hintermann B²³ | 2017 | One surgery failed, and TAR was performed |
| Knupp M²⁴ | 2011 | Ten surgeries failed, and TAR or AD was performed |
| Scheidegger P²⁵ | 2019 | Nine cases underwent TAR or AD at 21 months |
| Ahn TK²⁶ | 2015 | One case underwent TAR |
| Kobayashi H²⁷ | 2016 | None |
| Mann HA²⁸ | 2012 | Due to persistent pain, 2 cases underwent AA and 2 cases TAR |
| Choi JY²⁹ | 2020 | None |
| Y. Tanaka³⁰ | 2006 | Two cases failed, and underwent AD |
requirements. Additionally, surgical complications are not uncommon and are accompanied by surgical failure and the need for amendment procedures.\textsuperscript{12,21,35} The current authors considered SMOT to be a viable option when the following symptoms are present: (1) imaging manifestations of varus ankle OA; (2) force line adjustment before and after ankle arthrodesis or joint replacement; (3) distal tibial fracture malunion. Additionally, SMOT can also be used to correct ankle varus caused by ankle instability or congenital ankle varus.

In conclusion, SMOT of the ankle is an effective and reliable ankle-preserving surgery that can correct the displaced ankle force line and the ankle malalignment in the coronal plane. However, we should bear in mind that this procedure cannot relieve the ankle pain completely in varus ankles. Therefore, more high-level studies such as randomized control trials are needed in the future for a more precise assessment of the indications of the procedures to delay or reverse the progress of varus degeneration of the ankle.

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\section*{Authors' contributions}
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\section*{Availability of data and materials}
All data generated or analyzed during this study are included in this published article.

\section*{ORCID iD}
Chengwei Wang \textsuperscript{\textcopyright} https://orcid.org/0000-0001-9324-8184

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