

Title	Impact of combining medial capsule interposition with modified scarf osteotomy for hallux valgus	
Author(s)	Ebina, Kosuke; Hirao, Makoto; Tsuboi, Hideki et al.	
Citation	Modern Rheumatology. 2020, 30(1), p. 204–210	
Version Type	АМ	
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1 2	1	Original Article
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- This article contains 6 figures and 2 tables.
- Funding:

The authors declare they have no specific funding for this study.

37 ABSTRACT

Objectives

To clarify the effect of combining medial capsule interposition with modified scarf osteotomy for hallux valgus.

41 Methods

A multicenter, retrospective study included 64 cases [59 osteoarthritis patients (excluding rheumatoid arthritis); age 68.8 years, range 40 to 93 years) of modified scarf osteotomy which were performed from 2013 to 2017 and followed for 26.6 (range, 13 to 50) months. Patients were treated by either (1) without medial capsule interposition (33 cases) or (2) combined with interposition (31 cases) at each senior surgeon's discretion. The Japanese Society for Surgery of the Foot (JSSF) hallux metatarsophalangeal-interphalangeal scale was evaluated along with radiographic parameters (hallux valgus angle, first and second metatarsals intermetatarsal angles, and Hardy grade).

Results

All JSSF scale and radiographic parameters were similar at baseline and significantly improved at final follow-up in both groups (pre-operation vs. final follow-up: P<0.001). However, compared to without interposition group, interposition group showed significantly higher improvement in the JSSF scale (pre-operation to final follow-up: *P*-value between the two groups at final follow-up) for pain (without interposition: 19.4 to 34.2, interposition: 18.4 to 37.1; *P*=0.02), function (without

55	interposition: 20.8 to 33.6, interposition: 18.3 to 36.6; P=0.005), total score (without interposition:
56	41.5 to 81.8, interposition: 38.5 to 88.5; $P < 0.001$), and the metatarsophalangeal joint space (without
57	interposition: 1.4 to 1.5 mm, interposition: 1.6 to 2.6 mm; $P < 0.001$) with significant correlation
58	between the total JSSF score ($r=0.40$; $P=0.001$).
59	Conclusions
60	Combining medial capsule interposition with modified scarf osteotomy significantly improved
61	mid-term clinical outcomes.
62	
63	Keywords:
64	Hallux valgus, Interposition arthroplasty, Modified Scarf osteotomy
65	
66	INTRODUCTION
67	A recent report demonstrated that the prevalence of radiographic hallux valgus reached 29.8% in an
68	aged cohort (≥65 years) [1], and hallux valgus deformity and the related pain itself impair physical
69	function [2]. The scarf osteotomy is reported as one of the most reliable joint-preserving hallux valgus
70	surgical interventions recommended for the correction of moderate-to-severe hallux valgus deformity
71	[3, 4]. However, some patients develop progressive osteoarthritis (joint space narrowing) after scarf
72	osteotomy [3], so alternative treatment options may be required, especially in severe cases. Good

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clinical outcomes of capsular interposition arthroplasty for hallux rigidus have been reported [5, 6]. In $\mathbf{74}$ addition, the adductor hallucis tendon, which is usually dissected from the hallux proximal phalanx in scarf osteotomy, supports the longitudinal arch (oblique head) and the transverse arch (transverse head). Therefore, we hypothesized that combining medial capsular interposition of the hallux (suturing to the adductor hallucis tendon) with modified scarf osteotomy may improve clinical outcomes, such as pain reduction and maintaining the longitudinal and transverse arches. We have recently reported that this procedure was effective in severe hallux valgus deformity in patients with rheumatoid arthritis [7-9]. The purpose of this study was to clarify the usefulness of combining medial capsular interposition with modified scarf osteotomy for hallux valgus patients (excluding rheumatoid arthritis) by comparing the mid-term clinical outcomes of cases treated with and without medial capsular interposition.

85 MATERIALS AND METHODS

86 Patients and clinical assessment

A multicenter, retrospective, observational study identified 73 osteoarthritis (excluding rheumatoid arthritis) cases (67 patients) who had undergone modified scarf osteotomy in 5 institutes by senior rheumatoid surgeons from 2013 to 2017. Nine cases (8 patients) were excluded for incomplete data and less than 12 months' follow-up, and there was no other selection bias in collecting patients' data.

followed for a mean of 26.6 (range, 13 to 50) months were enrolled. Patients were treated by either (1) without medial capsule interposition (without interposition group, 33 cases, age 65.5 years, follow-up 25.7 months) or (2) combined with medial capsule interposition (interposition group, 31 cases, age 72.3 years, follow-up 27.5 months) depending on each senior surgeon's discretion such as age, severity of hallux valgus, and learning skill of each surgeon.

Finally, a total of 64 cases (59 patients, 53 females; mean age 68.8 years, range 40 to 93 years)

Patients were evaluated by scores of the Japanese Society for Surgery of the Foot (JSSF) hallux metatarsophalangeal-interphalangeal scale, which was established by modifying the American Orthopaedic Foot and Ankle Society (AOFAS) scale and the Japanese Orthopaedic Association's foot rating (JOA) scale [10, 11]. The validity and inter- and intra-clinician reliability of JSSF scale for evaluating hallux valgus has been demonstrated [11]. In addition, pre-operative and postoperative radiographic parameters were also evaluated. The hallux valgus angle (HVA), first metatarsal and second metatarsal (M1M2) angle, first metatarsal and fifth metatarsal (M1M5) angle, and the joint space of the hallux MTP joint (mm) were defined on anteroposterior weight-bearing radiographs performed pre-operatively and postoperatively, as previously described [12].

51 106 This study was conducted in accordance with the ethical standards of the Declaration of Helsinki, and 54 107 it was approved by the Institutional Ethical Review Board at each center. Informed consent was obtained from each individual patient included in the study.

Operative Technique Representative pre-operative and postoperative radiographs are shown in Figure 1. The amount of first metatarsal bone resection was determined to be equal to the length of overlap between the first metatarsal bone and the basal phalanx bone in the longitudinal direction as measured on a pre-operative foot radiograph in the standing position (Fig. 1a). The hallux MTP joint gap was measured by the minimum distance between the proximal joint line at the axis of the basal phalanx bone and the first metatarsal head on foot radiographs in the standing position, pre-operatively (Fig. 1b) and postoperatively (Fig. 1c). Patients were treated by modified scarf osteotomy of the hallux with the medial longitudinal approach, as previously described [9, 13]. A longitudinal incision was made in the medial aspect of the first metatarsal (Fig. 2a), and the medial capsule was opened with a 10-mm-wide and 40-mm-long flap (Fig. 2b). The osteotomy was parallel to the sole of the foot, and both distal and proximal bone fragments were partially resected owing to the measurements on pre-operative radiographs (Fig. 2c). The distal bone fragment was laterally shifted and then fixed with 3 or 4 AcuTwist® Acutrak® 2.0-mm headless compression screws (Acumed USA, Hillsboro, OR) (Fig. 2d). Next, a longitudinal dorsal incision

126 dissected from the base of the hallux proximal phalanx, and marked by 3-0 PDS suture to avoid its

(about 20 mm) was made between the first and second metatarsals. The adductor hallucis tendon was

 $1 \ 127$ shortening (Fig. 3a). The capsule between the first metatarsal and the lateral sesamoid was split longitudinally from the proximal phalanx to the middle of the first metatarsal shaft [9]. The medial eminence of the first metatarsal head was minimally excised, and a capsule hole was made in the lateral side of the hallux MTP joint (Fig. 3b). Next, when performing interposition, the flap of the 11 130 14 131 capsule was interposed into the hallux MTP joint (Fig. 3c), and it was then sutured to the adductor hallucis tendon that was dissected from the hallux proximal phalanx (Fig. 3d). Finally, the medial 21 133 capsule was sutured after some shrinkage due to the interposition of the 10-mm-wide flap into the ²⁴ 134 hallux MTP joint, with the expectation of producing the force needed for varus directions of the hallux [7-9]. When not performing interposition, the medial capsule flap was sutured to the remaining capsule or periosteum with appropriate traction, and the dissected adductor hallucis tendon was 31 136 ³⁴ 137 detached or sutured to the lateral capsule of the hallux. A modified metatarsal shortening offset osteotomy was performed in the lesser toes when required, 41 139 such as rigid claw toes [7, 9, 14]. An Akin osteotomy of the hallux proximal phalanx was performed if ⁴⁴ 140 the valgus or pronation deformity was not adequately corrected by modified scarf osteotomy. 48 141 Range-of-motion exercises for the hallux MTP joint were started one day after the operation, and full weight-bearing was allowed 2 to 2.5 weeks postoperatively, after fitting for an arch support. 51 142 ⁵⁴ 143 58 144 **Statistical analysis**

 $1 \ 145$ Differences between each study group were tested using the Mann-Whitney U test or the chi-squared 4 146 test. Changes in each score from pre-operative to postoperative at specified time points were compared using the nonparametric Wilcoxon signed-rank test. Spearman correlation coefficients were calculated 11 148 for the hallux MTP joint gap (mm) and the JSSF function score or the total JSSF score. A post-hoc 14 149 calculation was performed to examine adequate sample size. Results are expressed as means \pm standard deviation (range). A P value < 0.05 indicated significance. All tests were performed using 21 151 IBM SPSS Statistics version 22 software (IBM, Armonk, NY, USA). 24 152 RESULTS A post-hoc power analysis in comparing total JSSF score at final follow-up (effect size 0.88, a error $31 \ 154$ 34 155 0.05, power 0.8) revealed sufficient sample size as n=22 in each group, which demonstrated adequate sample size of this study. 41 157 The clinical characteristics of each group at baseline are shown in Table 1. Generally, both groups 44 158 showed similar baseline clinical scores and radiographic parameters, although age was significantly older in the interposition group than in the without interposition group (72.3 vs. 65.5 years: P=0.014). 51 160 The representative radiographs of both groups are shown in Fig. 4. Patients who underwent scarf ⁵⁴ 161 osteotomy without interposition showed a stable joint space (Fig. 4a), while patients with interposition showed an enlarged joint space until final follow-up (Fig. 4b). Operation-related outcomes are shown

1 163 in Table 2 and Fig. 5. On radiographic evaluation, compared to the without interposition group, the interposition group showed a significantly larger hallux MTP joint gap at both postoperative 1 week (1.8 vs. 3.8 mm; P<0.001) and final follow-up (1.5 vs. 2.6 mm; P<0.001) (Fig. 5a). Concerning clinical scores, compared to the without interposition group, the interposition group showed $\texttt{11} \ \texttt{166}$ 14 167 significantly higher JSSF pain score (34.2 vs. 37.1; P=0.02), function score (33.6 vs. 36.6; P=0.005 / subscale score of range of motion; 5.8 vs. 7.1; P=0.03), and total score (81.8 vs. 88.5; P=0.0008), 21 169 while no significant difference was observed in the alignment score (13.9 vs. 14.8; P=0.10) at final 24 170 follow-up (Table 2). Focusing on the changes of clinical scores, compared to the without interposition group, the interposition group showed significantly higher improvement of the JSSF function score $31 \ 172$ (12.7 vs. 18.4; P<0.001 / subscale score of range of motion; -1.2 vs. 1.1; P<0.001) (Fig. 5b) and the ³⁴ 173 total JSSF score (40.3 vs. 50.0; P=0.0029) (Fig. 5c). No significant difference was observed in HV angle, M1M2 angle, M1M5 angle, and sesamoid Hardy 41 175 grade throughout this period (Table 2). Even when focused on only severe cases (baseline HV angle > 44 176 40°), these tendencies were similar (Supplemental Table 1). Finally, the correlation between the hallux MTP joint gap and the clinical scores were evaluated (Fig. 6). Significant correlations were observed between the hallux MTP joint gap and the JSSF function 51 178 54 179 score (r=0.52; P<0.001) and the total JSSF score (r=0.40; P=0.0011) at final follow-up. None of the patients in both groups underwent reoperation during the follow-up period.

As far as we know, this is the first report to demonstrate the clinical effects of combining medial capsule interposition with modified scarf osteotomy of the hallux valgus, by comparing cases with and without medial capsular interposition.

Adam et al. reported that scarf osteotomy for adult hallux valgus showed good results, with 94% $\texttt{21} \hspace{0.1in} 187$ patient satisfaction [15], although some patients developed progressive arthritis [3]. From this point of 24 188 view, we developed medial capsular interposition of the hallux, aiming to improve clinical outcomes, such as preserving joint space, pain reduction, and maintaining the longitudinal and transverse arches 31 190 [7-9]. In this study, all of the JSSF scores (total, pain, function, and alignment scores) and radiographic ³⁴ 191 assessment parameters (HV, M1M2, M1M5 angle, Hardy grade) improved postoperatively in both the without and the with interposition groups (P < 0.001, respectively), suggesting the promising effects of 41 193 the modified scarf osteotomy procedure in hallux valgus treatment. Of note, although the alignment ⁴⁴ 194 score and other bony alignment parameters (HV, M1M2, M1M5 angle, Hardy grade) were similar between the groups, the interposition group showed further higher JSSF pain, function, and total 51 196 scores, and a larger hallux MTP joint gap compared to the without interposition group. These results 54 197 indicate that medial capsule interposition may contribute to additional pain reduction and functional recovery, although boney alignment may be mainly determined by the osteotomy procedure, not by the

Concerning interposition techniques, many previous reports demonstrated their efficacy in the treatment of hallux rigidus. Hamilton et al. demonstrated suturing the extensor hallucis brevis tendon to the flexor hallucis brevis tendon [16] and Aynardi et al. demonstrated good outcomes for the same procedure (patient-reported outcome was good or excellent in 89.5%, with mean follow-up of 62.2 months) [5]. Recently, Vulcano et al. also reported the good-long term outcomes (patient satisfaction of 92.9%, with a mean follow-up of 11.3 years) of this procedure [6], suggesting the long-term

efficacy of capsular interposition. A previous report demonstrated that interpositioned-capsule remained as fibrocartilage tissue by biopsy examination [5], which may contribute to pain reduction and improvement of range of motion by preserving sliding surface of articular cartilage in present study.

As for other interposition materials, Coughlin et al. reported excellent functional results when hallux rigidus was treated with interposition arthroplasty using autologous gracilis tendon, which was used as a rolled bundle graft [17]. However, a recent report demonstrated that this rolled tendon allograft for salvage surgery of hallux rigidus showed a high rate of complications [18], and this procedure also poses an additional burden, such as harvesting healthy autologous tissue with another incision. Concerning hallux valgus treatment, there have been only a few reports demonstrating the effects of

216 interposition. Schulz et al. concluded that resection-interposition arthroplasty is an inadequate

procedure in cases with early arthritis or a positive metatarsal index, and it may show good results if resection of the first phalanx does not exceed one third of the length [19]. Taken together, medial capsule interposition with joint-preserving arthroplasty of the hallux valgus may have some benefits without additional burden. This procedure may also be effective in reefing the medial capsule to strengthen medial tension. There are several limitations in this study. First, this was a retrospective, non-randomized study, and the selection of the methods was dependent on each surgeon's discretion, which resulted in higher age of the interposition group. Second, the follow-up period was relatively short, and whether these effects

5 may continue in longer period should be evaluated in future study, because the difference of joint gap 6 between the groups tend to decrease at final follow-up. Third, in regards to the assessment of

27 longitudinal arch, we failed to collect enough data of lateral standing radiograph, which should be

evaluated in future study.

In conclusion, combining medial capsule interposition with modified scarf osteotomy for hallux
 valgus significantly improved clinical outcomes and the MTP joint space compared to no interposition

231 in mid-term follow-up.

233 ACKNOWLEDGEMENTS

The authors would like to thank Dr. Shigeyoshi Tsuji, Dr. Koichiro Takahi, Dr. Hajime Owaki, Dr.

1 235 Yasuo Kunugiza, Dr. Akihide Nampei, and Dr. Yoshio Nagayama for their excellent cooperation in
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CONFLICT OF INTEREST

No benefits in any form have been received or will be received from a commercial party related
directly or indirectly to the subjects of this article.

42 FIGURE LEGENDS

Figure 1. (a) The amount of bone resection (arrow 1) is determined to be equal to the length of overlap between the first metatarsal bone and the basal phalanx bone in the longitudinal direction as measured on radiographs in the standing position. The hallux metatarsophalangeal joint gap is measured by the minimum distance between the proximal joint line at the axis of the basal phalanx bone and the first metatarsal head on radiographs in the standing position, (b) pre-operatively (arrow 248 2) and (c) postoperatively (arrow 3).

Figure 2. Operative procedures. (a) A longitudinal incision is made in the medial aspect of the first metatarsal. (b) The medial capsule is opened with 10-mm-wide and 40-mm-long flap. (c) The osteotomy is parallel to the sole of the foot, and both distal and proximal bone fragments are partially

shifted laterally, then fixed with AcuTwist® Acutrak® 2.0-mm headless compression screws. Figure 3. Operative procedures. (a) The adductor hallucis tendon is dissected from the base of the hallux proximal phalanx, and marked by 3-0 PDS suture. (b) A capsule hole is made in the lateral side of the hallux metatarsophalangeal (MTP) joint. (c) A medial capsule flap is interposed into the hallux MTP joint (d) and sutured to the adductor hallucis tendon that was dissected from the hallux proximal phalanx. Figure 4. Representative sequential radiographs of both modified scarf osteotomy groups. (a) Without interposition. (b) Combined with interposition. Figure 5. Mean pre-operative and postoperative (a) hallux metatarsophalangeal (MTP) joint gaps (mm), (b) changes of JSSF function scores (full score 45 points), and (c) changes of total JSSF scores. Bars indicate standard deviations. JSSF, Japanese Society of Surgery of the Foot; N.S., not significant. ** P < 0.01, *** P < 0.001, without interposition vs. interposition group.

resected based on measurements on the pre-operative radiographs. (d) The distal bone fragment is

272 function score and (b) total JSSF score at final follow-up.

JSSF, Japanese Society of Surgery of the Foot; IP, interposition; MTP, metatarsophalangeal.

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Figure 6. Scatter plots for the hallux metatarsophalangeal (MTP) joint gap (mm) and (a) JSSF

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reliability and validity of the newly established standard rating scales and Japanese Orthopaedic Association

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Figure 4







Variable		Without interposition	Interposition	D .1
variable		(n=33)	(n=31)	P value
	Hallux	Modified Scarf (n=33)	Modified Scarf (n=31)	
Operation			Akin osteotomy (n=1)	
methods (n)	Lesser toes	Off-set osteotomy (n=16)	Off-set osteotomy (n=20)	0.20
Age, (years)		65.5±12.0 (40-87)	72.3±9.4 (48-93)	0.014
Gender, Females (%)		93.9	87.1	0.63
Body mass index (kg/m ²)		22.5±3.1 (18.1-30.1)	23.1±2.4 (19.0-28.5)	0.39
Clinical scores				
Total JSSF score (100 points)		41.5±1.9 (15-65)	38.5±1.9 (14-65)	0.27
Pain score (40 points)		19.4±7.0 (0-30)	18.4±6.9 (0-30)	0.57
Function score (45 points)		20.8±5.4 (14-35)	18.3±5.4 (10-32)	0.063
Alignment score (15 points)		1.2±2.9 (0-8)	1.8±3.4 (0-8)	0.46
Radiographic assessment				
HV angle (°)		45.4±7.7 (30-65)	41.9±8.3 (28-57)	0.084
M1M2 angle (°)		16.0±3.9 (2-22)	16.3±4.3 (10-29)	0.83
M1M5 angle (°)		36.2±5.3 (26-50)	37.3±5.9 (21-47)	0.43
Sesamoid Hardy grade (1-7)		6.5±0.8 (4-7)	6.6±0.7 (5-7)	0.86
Hallux MTP joint gap (mm)		1.4±0.4 (1.0-2.1)	1.6±0.7 (0.9-3.2)	0.092

1 Table 1. Baseline clinical characteristics by group

2 Mean ± Standard Deviation (range). JSSF, Japanese Society of Surgery of the Foot; HV, Hallux valgus;

3 M1M2, first metatarsal and second metatarsal; M1M5, first metatarsal and fifth metatarsal; MTP,

4 metatarsophalangeal. Differences between the groups were determined by the Mann-Whitney U test or

5 the chi-squared test.

6

Table 1

Table 2

	Without interposition	Interposition	Daughu	
Variable	(n=33)	(n=31)	<i>P</i> value	
Follow-up duration (months)	25.7±2.0 (13-50)	27.5±1.7 (13-45)	0.49	
Clinical scores of final follow-up				
Total JSSF score (100 points)	81.8±7.7 (65-100)	88.5±7.6 (77-100)	< 0.001	
Change of total JSSF score	40.3±12.4 (20-75)	50.0±12.7 (22-81)	0.0029	
Pain score (40 points)	34.2±5.0 (30-40)	37.1±4.6 (30-40)	0.021	
Change of pain score	14.8±8.3 (0-40)	18.7±8.8 (10-40)	0.078	
Function score (45 points)	33.6±3.2 (27-45)	36.6±4.8 (29-40)	0.0045	
Change of function score	12.7±4.2 (0-20)	18.4±6.0 (5-30)	< 0.001	
Alignment score (15 points)	13.9±2.5 (8-15)	14.8±1.3 (8-15)	0.10	
Change of alignment score	12.7±3.5 (7-15)	13.0±3.5 (7-15)	0.79	
Radiographic assessment				
Post-op 1 week				
HV angle (°)	6.3±6.6 (-4-19)	6.8±6.1 (-12-18)	0.79	
M1M2 angle (°)	4.2±3.1 (-5-10)	5.1±2.4 (1-9)	0.16	
M1M5 angle (°)	18.4±4.9 (9-29)	19.0±5.1 (7-27)	0.62	
Sesamoid Hardy grade (1-7)	2.9±1.3 (1-6)	2.5±0.9 (1-4)	0.17	
Hallux MTP joint gap (mm)	1.8±0.5 (0.6-3.1)	3.8±1.5 (1.0-8.1)	< 0.001	
Change of hallux MTP joint gap	0.4±0.5 (-0.2-1.7)	2.1±1.5 (0-6.8)	< 0.001	
Final follow-up				
HV angle (°)	13.7±6.4 (2-26)	10.7±8.8 (-10-26)	0.13	
M1M2 angle (°)	6.8±2.7 (2-14)	7.6±3.3 (1-14)	0.29	
M1M5 angle (°)	24.6±4.8 (17-36)	25.6±5.1 (12-41)	0.42	
Sesamoid Hardy grade (1-7)	3.2±1.4 (1-6)	3.1±1.0 (1-5)	0.79	
Hallux MTP joint gap (mm)	1.5±0.3 (0.8-2.1)	2.6±1.1 (1.0-5.4)	< 0.001	
Change of hallux MTP joint gap	0.2±0.4 (-0.9-1.2)	1.0±1.1 (-0.3-4.1)	< 0.001	

1 Table 2. Operation-related outcomes by group

2 Mean ± Standard Deviation (range). JSSF, Japanese Society of Surgery of the Foot; Post-op,

3 postoperation; HV, Hallux valgus; M1M2, first metatarsal and second metatarsal; M1M5, first metatarsal

4 and fifth metatarsal; MTP, metatarsophalangeal. Differences between the groups were determined by the

5 Mann-Whitney U test.