ORIGINAL PAPER/PŮVODNÍ PRÁCE

Comparative Analysis of First Metatarsophalangeal Arthrodesis: Implant Survival, Failure Modes, and Functional Outcomes across Three Fixation Techniques

Srovnávací analýza artrodézy prvního metatarzofalangeálního kloubu: přežití implantátu, typy selhání a funkční výsledky u tří fixačních technik

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ABSTRACT

Purpose of the study

First metatarsophalangeal (I. MTP) arthrodesis is a well-established surgical procedure for treating hallux rigidus. Despite its widespread use, the optimal fixation method remains debated. This study compares implant survival, failure modes, and functional outcomes across three fixation techniques: two crossed screws, dorsal plate fixation, and dorsal plate fixation with a lag screw.

Material and methos

A retrospective analysis was conducted on 83 patients (89 fusions) who underwent I. MTP arthrodesis between January 2014 and October 2023. Patients were categorized into three groups based on the fixation method: Group A (two crossed screws, n=31), Group B (dorsal plate, n=29), and Group C (dorsal plate with a lag screw, n=29). Implant survival, failure rates, hardware removal, and clinical outcomes were evaluated using radiographic assessment and the American Orthopedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal (AOFAS-HMI) scoring system.

Results

The overall implant survival rate was 96.54% at one year and 93.98% at ten years. No significant differences in implant survival rates were observed among the three groups. Group C had the highest union rate (93.1%). Asymptomatic pseudoarthrosis was most common in Group B (17.24%). The hardware removal rate was higher in the plate groups (10.34%) compared to the two-screw group (3.1%). The mean AOFAS score was 83.30 (±9.29), with no statistically significant differences between groups. Patient satisfaction was highest in Group C (96.6%) and lowest in Group A (87.1%).

Conclusions

The long-term overall implant survival rate was excellent, with similar survival rates observed across all groups. Functional outcomes, assessed using the AOFAS score, were satisfactory and comparable among the fixation techniques. Hardware removal rates were higher in the groups that utilized plate fixation.

Key words: first metatarsophalangeal arthrodesis, first metatarsophalangeal joint fusion, AOFAS score, hallux rigidus.

Acta Chir Orthop Traumatol Cech., 92, 2025, No. 6, p. 311–319

INTRODUCTION

First metatarsophalangeal (I. MTP) arthrodesis is a commonly used procedure in foot surgery, employed for pathologies affecting the first ray of the foot. This procedure is indicated for failed conservative therapy in cases of arthritic involvement of the MTP joint, severe hallux valgus, rheumatoid arthritis, and as a revision surgery (2, 18). The goal of treatment is to alleviate pain and enable the patient to walk. This technique involves preparing the joint surfaces, aligning them in the correct position, and fixation. Several methods can be used for fixation – percutaneous fixation (1), two crossed screws, a plate, or a combination of plate and screw, or other implants – staples (3), Kirschner wires. A clearly defined method that would be the gold standard has not been established. According to a study by Hyer, there is no difference when using a plate, a locking plate, a combination of a locking plate with a lag screw, and a plate with a lag screw (11).

Current literature offers ambiguous answers regarding which fixation method is best. According to Cohen, fixation with two screws is stronger than locking plate fixation (6). Politi et al. determined that the dorsal plate and lag screw biomechanically offer the strongest fixation method for MTP-1 arthrodesis (16). According to an article by Kang, the highest union rate is achieved with the use of staples (12).

Given this background, there is a notable gap in the literature regarding the various types of I. MTP arthrodesis techniques. This study aims to compare implant survival rates, failure modes, and clinical outcomes in patients treated at our institution using three different methods: two crossed screws, dorsal plate arthrodesis with a lag compression screw, and dorsal plate arthrodesis without a lag compression screw.

MATERIAL AND METHODS

This retrospective study included 83 patients (89 fusions) who underwent I. MTP joint fusion between January 2014 and October 2023. Patients were eligible for inclusion if they had undergone arthrodesis of the I. MTP joint for hallux rigidus, classified as grade 3 or 4 according to the Coughlin and Shurnass classification. All patients had no prior surgery and may have had concurrent hallux valgus. The procedure was performed using one of the following techniques: two crossed screws,

Fig. 1. **MTPh joint arthrodesis using 2 crossed screws fixation.**

Table 1. **Demographic characteristics of the cohort: I. MTP joint fusion**

CHARACTERISTIC	CROSSED SCREWS (A)	PLATE (B)	PLATE AND SCREW (C)	OVERALL
Number of fusions	31	29	29	89
Age (years ± SD)	58.74 ± 9.49	59.17 ± 9.03	54.72 ± 7.58	57,57 ± 8,95
Sex, n (%)				
Male	11 (35.48%)	8 (27.59%)	12 (41.38%)	31 (34.83%)
Female	20 (64.52%)	21 (72.41%)	17 (58.62%)	58 (65.17%)
Foot side, n (%)				
Right	18 (58.06%)	19 (65.52%)	16 (55.17%)	53 (59.55%)
Left	13 (41.94%)	10 (34.48%)	13 (44.83%)	36 (40.45%)
Follow up (months± SD)	41.87 ± 23.63	88.52 ± 40.50	60.69 ± 33.79	63.20 ± 38.07
Dominant foot, n (%)				
Yes	18 (58.06%)	17 (58.62%)	16 (55.17%)	51 (57.30%)
No	13 (41.94%)	12 (41.38%)	13 (44.83%)	38 (42.70%)
Smoking, n (%)				
Yes	7 (22.58%)	10 (34.48%)	7 (24.14%)	24 (26.97%)
No	24 (77.42%)	19 (65.52%)	22 (75.86%)	65 (73.03%)

Fig. 2. **a – hallux rigidus stage IV; b – athrodesis of MTPh joint using plate fixation; c – healed bone after plate extraction.**

Acta Chir Orthop Traumatol Cech., 92, 2025, No. 6, p. 311–319

Fig. 3. **Plate and screw fixation for MTPh joint arthrodesis.**

a plate, or a combination of a plate and screw. Surgery was indicated for patients who had failed conservative treatment and continued to experience symptoms. Patients with incomplete follow-up documentation were excluded from the study.

Patients were categorized into three groups based on the surgical technique used (Table 1). Group A consisted of patients who underwent surgery using the two-screw technique (n=31) (Fig. 1). Group B included patients who underwent surgery utilizing a plate (n=29) (Fig. 2). Group C comprised patients who underwent surgery using the plate and tension screw technique (n=29) (Fig. 3).

The age distribution was similar across all three groups, with the youngest patient at the time of surgery being 37 years old and the oldest 79 years old. A female predominance was observed in all three groups. The average follow-up period varied among the groups. In the two-screw group, the follow-up period averaged 41.87 months. It was longer in the plate and tension screw group at 60.69 months and was the longest in the plate group, with an average follow-up of 88.52 months. Smoking was reported in 27% of the total cohort.

Implants

The two-screw technique involved the use of a 3.5 mm headed compression screw and a 2.5 mm headless compression screw. The headless screw featured a differential thread pitch between the proximal and distal threads to facilitate compression. For the plate fixation technique, 2.7 mm fusion plates were used. When a compression screw was applied in combination with the plate, a 3.5 mm titanium-alloy composition screw was utilized.

Evaluation

A follow-up clinical examination was conducted at a minimum of 12 months after the surgical procedure. As part of the retrospective evaluation, perioperative events were analyzed, including the need for reoperation due to hardware failure, extraction of the implanted hardware, the occurrence of infections, and the necessity for rearthrodesis.

In this study, implant failure was defined as the need for revision surgery due to radiologically confirmed implant loosening. This was characterized by a progressive halo around the implant, a change in implant position, or pseudoarthrosis. However, cases in which implant extraction was performed due to subjective patient complaints – such as pressure from footwear or discomfort affecting the extensor tendons – were not classified as implant failure.

Radiographic assessment was conducted to evaluate arthrodesis healing. Union was defined as the absence of pain

reported by patients at follow-up, along with radiographic evidence of osseous bridging across at least three cortices. If a joint line remained visible on radiographs 12 months postoperatively, this was interpreted as a nonunion, representing a postoperative complication. However, nonunion was not classified as failure unless further surgical intervention was required. Cases of nonunion that did not necessitate additional surgery were classified as asymptomatic pseudarthroses and did not require further management (4).

The follow-up examination included a standardized questionnaire-based assessment to evaluate postoperative outcomes. A questionnaire based on the American Orthopedic Foot and Ankle Society-Hallux Metatarsophalangeal Interphalangeal (AOFAS-HMI) scoring system (21) was used. This questionnaire included specific questions regarding regular shoe use, ambulation, level of sports activity, smoking history, side preference, and the patient's willingness to undergo the surgery again in the future. The results of this questionnaire were used to calculate a score according to the modified AOFAS scale. Due to the modification accounting for the absence of movement in the metatarsophalangeal joint of the hallux, the maximum achievable score was 90 points.

The AOFAS score was recorded at the final follow-up examination, with this final assessment being used for patients with longer follow-up periods. A total of five patients were excluded from the AOFAS score evaluation due to predefined failure.

Surgical technique

The operative technique I. MTP joint arthrodesis was consistent for all patients in the study. Patients were placed in a supine position, and a regional block was administered, augmented with general anesthesia, and individualized for each patient. A tourniquet was used during the procedure.

A dorsal longitudinal incision was made to expose the I. MTP joint. Arthrotomy was performed to inspect the joint, and the articulating surfaces, along with osteophytes, were resected using the ball-and-socket principle. The toe was positioned in a plantigrade orientation to maintain contact with the surface, simulated intraoperatively using a flat plate to mimic weight-bearing. However, slight elevation of approximately 5 mm above the flat plate was permitted. At this stage, neutral rotation was also established. Valgus alignment was adjusted to leave the great toe in a physiological position of slight valgus, ensuring proper alignment adjacent to the second toe (10).

For fixation, the lag screw was inserted in a proximal direction from the medial side into the base of the proximal phalanx, in accordance with the fixation method. If bone quality was sufficient and the first screw provided adequate stability, a second screw was inserted in a crosswise manner (Group A). Alternatively, a plate was added in cases requiring additional stabilization (Group C). If the surgeon intended to use a plate, it was implanted first (Group B). However, if intraoperative assessment suggested insufficient stability, a compression screw was added during the procedure. This methodology was previously described by Goucher and Coughlin, where the plate was positioned first and subsequently secured with a screw (9).

Postoperatively, a bandage was applied, and the limb was immobilized in a postoperative boot, providing forefoot offloading for six weeks while allowing full heel weight-bearing without ankle fixation. This approach aimed to reduce the risk of deep vein thrombosis. Perioperative antibiotic prophylaxis was administered with intravenous Cefazolin 2 g in three doses.

Statistical analysis

Standard descriptive statistics were calculated, including means, ranges, frequencies, and percentages. Ordinal data, including limitations, pain, satisfaction, and questionnaire responses, were analyzed using the Mann-Whitney test. To assess the significance of differences between group means, Tukey's Honestly Significant Difference (HSD) test was applied. Statistical significance was defined as $P < 0.05$.

RESULTS

Implant survival

The overall implant survival rate across all groups was 96.54% at one year. At the 10-year follow-up, the survival rate remained high at 93.98%, with eight patients still at risk. (Chart 1).

In Group A, the overall implant survival rate was 96.77% (n=29) at one year, remaining stable at 96.77% (n=22) at two

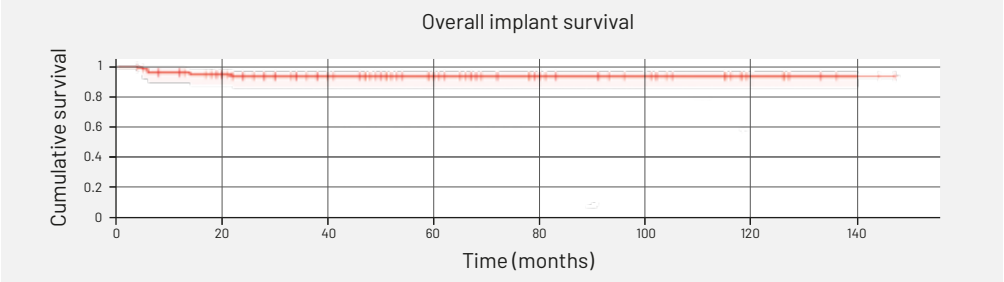

Chart 1. **Overall implant survival curve: I. MTP joint fusion.**

Acta Chir Orthop Traumatol Cech., 92, 2025, No. 6, p. 311–319

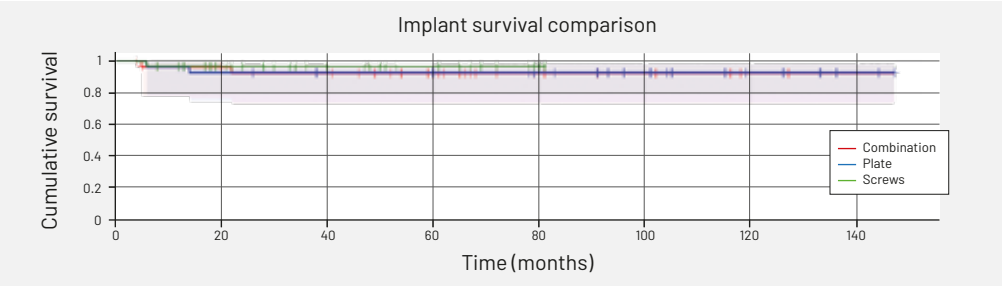

Chart 2. **Comparative analysis of implant survival across fixation groups in I. MTP joint fusion.**

Table 2. **Failure modes across fixation groups in I. MTP joint fusion**

	CROSSED SCREWS (A)	PLATE (B)	PLATE AND SCREW (C)	OVERALL
Infection (n, %)	0 (0.00%)	2 (6.90%)	1 (3.45%)	3 (3.37%)
Nonunion (n, %)	1 (3.33%)	2 (6.90%)	2 (6.90%)	5 (5.62%)
Hardware failure (n, %)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)

Table 3. **Hardware removal and radiological assessment across fixation groups in I. MTP joint fusion**

	CROSSED SCREWS (A)	PLATE (B)	PLATE AND SCREW (C)	OVERALL
Union (n, %)	27 (87.10%)	22 (75.86%)	27 (93.10%)	76 (85.39%)
Asymptomatic pseudoarthrosis (n, %)	3 (9.68%)	5 (17.24%)	0 (0.00%)	8 (8.99%)
Hardware removal	1 (3.1%)	3 (10.34%)	3 (10.34%)	7 (7.87%)

years and 96.77% (n=9) at five years. However, at 81 months (the maximum follow-up period), only one patient remained at risk, with the survival rate still at 96.77%. For Group B, the survival rate was 96.55% (n=28) at one year, decreasing slightly to 92.84% (n=28) at two years. This rate remained consistent at 92.84% (n=23) at five years and 92.84% (n=7) at ten years. In Group C, the survival rate was 96.43% (n=28) at one year, declining to 92.41% (n=24) at two years. The rate remained stable at 92.41% (n=17) at five years and 92.41% (n=2) at ten years. (Chart 2).

Failure mode

No cases of hardware failure, such as plate or screw breakage, were observed in any of the groups. Infections occurred in the plate group (2 patients) and in the plate and screw group (1 patient). No infections were reported in the two-screw group. All infections were successfully managed without the need for implant removal, using a combination of local therapy and systemic antibiotic administration. A total of five cases of nonunion were recorded. At the final follow-up, one patient in Group A experienced nonunion. In Group B, radiological signs of failure were observed in two patients, while in Group C, two patients also experienced failure (Table 2).

Hardware removal and radiological assessment

The necessity for the removal of osteosynthesis material was highest in the groups treated with plate fixation, primarily due to extensor tendon irritation or pressure from footwear. The frequency of hardware removal was 3.1% in Group A (one case) and 10.34% in both Group B and Group C (three cases each).

In Group A, asymptomatic pseudoarthrosis was observed in three patient. In Group A, asymptomatic pseudoarthrosis was observed in five patient; however, these cases were not classified as failures. In contrast, no cases of painless pseudoarthrosis were identified in Group C. Overall, a total of five cases of painless pseudoarthrosis were recorded across all groups. (Table 3).

Functional outcomes

Based on the statistical analysis, the mean overall AOFAS score was 83.30 (± 9.29). The mean score in Group A was 83.47 (± 10.96), in Group B was 82.33 (± 9.1), and in Group C was 84.11 (± 7.55). A statistical analysis was conducted to assess significant differences between the groups. The difference in AOFAS scores between Group A and Group B was −1.1333 [95% CI: −7.0714, 4.8048]; p=0.892. The difference between Group A and Group C was 0.6444 [95% CI: −5.2937, 6.5826]; p=0.9637. The difference between Group B and Group C was 1.7778 [95% CI: −4.3146, 7.8702]; p=0.7661. In all comparisons, the differences in AOFAS scores between the groups were not statistically significant. (Chart 3).

Additionally, patients' overall subjective assessment of surgical outcomes was recorded (Chart 4). In the two-screw group, 87.1% of patients (n=27) reported the outcome as fully satisfactory or satisfactory. In the plate group, 89.7% of

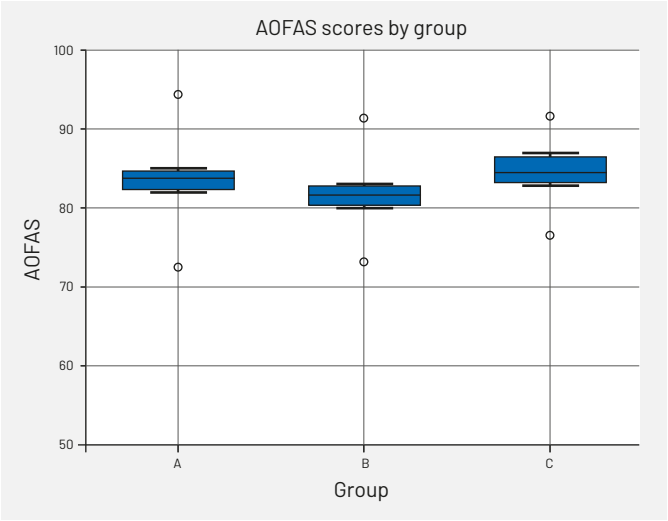

Chart 3. **Functional outcomes: AOFAS scores across fixation groups in I. MTP joint fusion.**

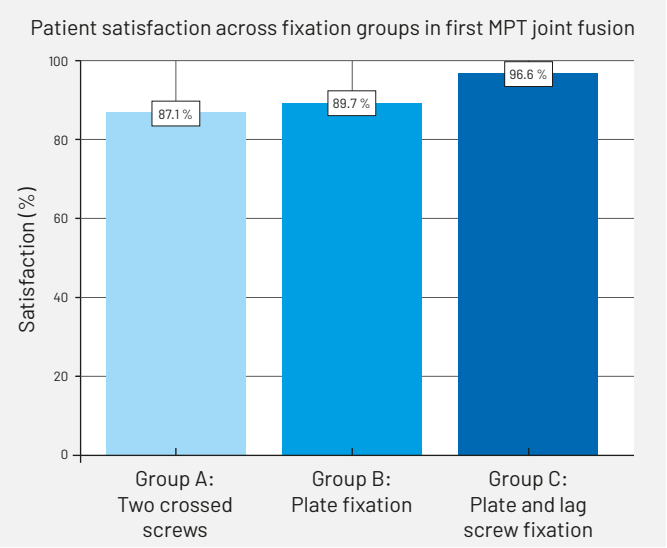

Chart 4. **Patient satisfaction across fixation groups in I. MTP joint fusion.**

patients (n=26) reported satisfaction, while in the plate and lag screw group, 96.6% of patients (n=29) reported satisfaction.

DISCUSSION

Arthrodesis of the I. MTP joint is a well-established surgical solution for managing joint pathologies, particularly in cases of advanced hallux rigidus. Recognized by many as the gold standard treatment, this procedure consistently yields excellent outcomes with minimal complications (13, 17). Our study demonstrated high implant survival rates, with 96.54% at one year and 93.98% at 10 years postoperatively. Patients reported favorable clinical outcomes, achieving AOFAS scores exceeding 82%, regardless of the fixation technique used. Importantly, we observed no significant difference in nonunion rates among the various fixation methods. However, asymptomatic pseudoarthrosis was most frequently associated with plate fixation.

Reported nonunion rates following I. MTP joint arthrodesis vary widely in the literature (19, 20, 22). A prospective study (8) reported a lower complication rate than ours, with only 1 case of nonunion in a cohort of 15 patients. In contrast, another study (5) documented a higher nonunion rate in patients treated with two-screw fixation, where 4 out of 20 cases (20%) failed to achieve fusion. The same study found a lower nonunion rate (5%) in patients treated with a plate and screw combination, with 1 case of nonunion in 20 patients. Similarly, Chraim et al. (4), in their study of 60 patients undergoing I. MTP joint arthrodesis, reported a 93.3% fusion rate, with 6.7% developing painless pseudoarthrosis that did not require additional surgery. Kumar et al. (14) studied 46 patients, with one case of nonunion that remained asymptomatic after metalwork removal—this was the only instance requiring implant removal. Claasen (5) also examined 60 patients, including 20 treated with plate and screw fixation, only1 case of nonunion was observed during a 25-month follow-up period. A comparative study evaluating four fixation techniques across 72 arthrodeses found that dorsal plate fixation alone had a significantly lower nonunion rate than single screw fixation. However, no other significant differences in fusion rates were observed between the techniques (7). Our findings align with Filomeno's study (8), as we did not observe a significant difference in nonunion rates between the groups.

While some studies have reported higher nonunion rates with two-screw fixation in arthrodesis (5, 7), we believe that comparable outcomes can be achieved through meticulous intraoperative assessment and strategic fixation choices. In our practice, we carefully evaluate the stability of the first lag screw after joint surface preparation. If the screw is secure and well-seated, we proceed with crossed placement of the second screw to optimize fixation. However, if there is any uncertainty regarding the initial fixation's stability, we incorporate a locking plate to reinforce construct integrity and enhance overall stability.

The average AOFAS score following arthrodesis of the I. MTP joint generally hovers around 80 in most published studies, irrespective of the follow-up duration. Our findings align with this trend, as we observed an overall AOFAS score of 83.30 ± 9.29, demonstrating consistency with existing literature. Specifically, in Group A, the AOFAS score was 83.47 ± 10.96, reinforcing the similarity to previous reports. Mohammed et al. (15) documented comparable outcomes in a cohort

of 23 patients who underwent arthrodesis with two crossed screws, reporting a mean AOFAS score of 79 at a follow-up of 17 months. Similarly, Chriamanalyzed 60 fusion cases and found a postoperative AOFAS score of 79.3 ± 11.2. Additionally, Kumar (14) reported an average AOFAS score of 82.1, ranging from 72 to 90. No significant difference in AOFAS scores was observed among the various fixation methods utilized in our study. These findings collectively indicate that I. MTP joint arthrodesis yields consistently favorable functional outcomes, irrespective of the fixation technique employed.

Our findings on patient satisfaction partially align with those reported by Filomeno et al. (8) While their study, conducted on a cohort of 30 patients, found no significant difference in satisfaction between two-screw fixation and plate-and-screw fixation (overall satisfaction 93.4%), our results indicate a notable variation between these groups. Interestingly, despite this disparity in subjective satisfaction, there was no corresponding difference in AOFAS scores, suggesting that patient-reported satisfaction may be influenced by factors beyond functional outcomes alone.

This study has several limitations. First, its retrospective design introduces potential biases and limits the available data. Second, the cohort size is relatively small, with an uneven distribution among the groups. Third, the two-screws group had a shorter follow-up period compared to the other groups. Additionally, while the same surgical technique was used, the procedures were performed by different orthopedic surgeons, and implants from various manufacturers were used, as described in the methods section. Despite these limitations, the study achieved adequate results, and functional outcomes were evaluated in a standardized manner.

CONCLUSIONS

This study evaluated and compared implant survival rates, failure modes, and clinical outcomes among three different fixation methods. The long-term overall implant survival rate was excellent, with similar survival rates observed across all groups. Functional outcomes, assessed using the AOFAS score, were satisfactory and comparable among the fixation techniques. Hardware removal rates were higher in the groups that utilized plate fixation. Notably, no infectious complications were encountered in the two-crossed-screws group during the shorter follow-up period. To determine the optimal fixation method with greater certainty, larger randomized prospective studies are warranted.

Institutional review board statement

This study was conducted according to the guidelines of the Declaration of Helsinki. Consent was not deemed necessary by the ethics committee due to study design, which was based on routine clinical data.

Informed consent statement

Informed consent was obtained from all subjects involved in the study. ■

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