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TRAUMA SURGERY

Clinical results of using minimally invasive long plate osteosynthesis versus conventional approach for extensive comminuted metadiaphyseal fractures of the radius

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Abstract
Introduction The minimally invasive plate osteosynthesis (MIPO) technique has been introduced recently. The extensive comminuted fractures of the distal radial metaphysis with diaphyseal involvement are probably good indications for MIPO technique because of less extensive dissection and soft-tissue stripping. The purpose of this retrospective study was to compare the clinical results of MIPO technique to those of conventional open reduction in extensive metadiaphyseal fractures of distal radius.
Materials and methods Of 34 patients treated for comminuted metadiaphyseal fractures of the distal radius between June 2006 and May 2012, all the patients had extra-articular fractures. Twenty-one patients underwent MIPO technique and 13 underwent conventional open reduction with long periarticular locking plates system (Zimmer). Six patients in the MIPO group and three in the conventional group who had concomitant distal ulnar fractures or distal radioulnar joint (DRUJ) injury underwent plate osteosynthesis or Kirschner-wire fixation before radial fixation. Perioperative parameters and union time were recorded. Radiologic assessment, Mayo Wrist Score, and satisfaction scale were evaluated at the final follow-up.
Results All fractures united without secondary procedures. Radiologic assessment, Mayo wrist score, and time to union showed no significant difference between the two groups, but the MIPO group had significantly smaller incision wound, higher satisfaction scale, and shorter operative time than did the conventional group.
Conclusions MIPO is capable of achieving functional results as good as those of conventional open reduction, with a higher satisfaction scale, smaller incision, and shorter operative time. When MIPO intervention is planned, concurrent distal ulnar fracture or DRUJ injury should be repaired first, thus facilitating subsequent indirect reduction. For treating intra-articular fractures, anatomical reduction of the articular surface is more important, and the MIPO technique described here is not recommended.

Keywords Distal radial fracture · Metadiaphyseal fracture · Minimally invasive plate osteosynthesis (MIPO)

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Introduction

Fracture of the distal radius is a common injury. Because of pre-existing osteopenia, elderly patients frequently present with extensively comminuted fractures in the absence of high-energy trauma; young patients who have normal bone quality typically suffer comminuted fractures only as a result of a high-energy impact. The use of a volar locking plate to treat fractures of the distal radius has gained favor because it can facilitate earlier return to work and normal daily activities [1–3]. Previously, orthopedic surgeons often achieved primary stability with osteosynthesis, which usually required extensive surgical dissection and soft-tissue stripping. Currently, a more ''biological'' approach to limit dissection has received increasing attention [4]. To this end, treatment with indirect reduction and the minimally invasive plate osteosynthesis (MIPO) technique has been introduced in recent years. This technique was first applied to fractures of the lower extremity [5, 6]; however, it is also used for fractures of the upper limb, especially those of the humerus [7–9] and distal radius [10–13].

Some surgeons [10] have used MIPO technique to treat comminuted and displaced fractures of the distal radial metaphysis, for which the plates are inserted through small distal longitudinal incisions and a communicating epiperiosteal tunnel to achieve indirect reduction and to maintain an intact pronator quadratus (PQ). Good-to-excellent clinical outcomes have been reported from the use of MIPO techniques, which can avoid wide exposure of the fracture site and minimize soft-tissue damage. Other surgeons [14] found no significant difference in outcomes between two groups using MIPO technique and the conventional Henry's approach.

In the past, there have been few reports on MIPO technique for fractures of the distal radius [10–12, 14], and MIPO technique was not considered to be more advantageous than the conventional approach [14]; however, the aforementioned reports did not describe extensive fractures. In contrast, we have observed that MIPO is advantageous for extensive comminuted fractures of the distal radius metaphysis with diaphyseal involvement, and this kind of injury possibly is suitable for the use of MIPO in place of conventional plate osteosynthesis. We hypothesized that using the MIPO technique for extensive comminuted metadiaphyseal fractures of the distal radius would achieve better clinical results. We present the results of 34 patients who had metadiaphyseal fractures of the distal radius, 21 of whom were treated using MIPO technique. The other 13 patients were treated with conventional open reduction. All of the procedures were performed with one periarticular long locking volar plate. The purpose of this current study was to review retrospectively and compare the clinical outcomes of these two different surgical methods, and the study design was approved by the appropriate ethics review boards.

Materials and methods

This retrospective study excluded patients who had open fractures, intra-articular fracture, previous surgery involving the distal radius, concurrent injury involving the ipsilateral upper limb, and wrist pain predating this injury. Thirty-four consecutive patients who suffered extensive comminuted metadiaphyseal fractures of the radius between June 2006 and May 2012 were included. We defined metadiaphyseal fracture as a fracture that exceeded the square box area formed by the distal radius and ulna at the widest distance (Fig. 1). The AO/OTA fracture classification was 22 with 23. A long periarticular locking plates system (Zimmer, Warsaw, IN, USA) was used to treat all patients (Fig. 2). The patients were divided into two groups according to whether they underwent MIPO or conventional open reduction. The MIPO group consisted of 21

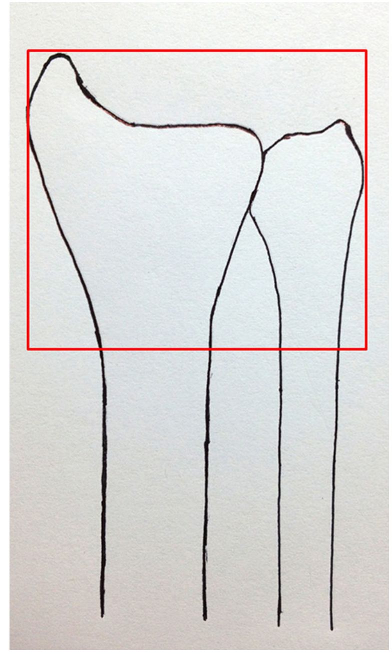

Fig. 1 Metadiaphyseal fracture was defined as a fracture exceeding the *square box* area formed by the distal radius and ulna at the widest distance

patients (seven men and 14 women), with a mean age at surgery of 48.71 ± 14.53 years (range 17–72 years). The conventional group consisted of 13 patients (7 men and 6 women), with a mean age at surgery of 45.15 ± 16.0 years (range 18–67 years). In addition, six patients in the MIPO group and three patients in the conventional group who had either concomitant distal ulnar fractures or distal radioulnar joint (DRUJ) injury underwent plate osteosynthesis or Kirschner-wire fixation before radial fixation in MIPO group and conventional group separately (Table 1).

Operative technique for minimally invasive plate osteosynthesis (MIPO)

Under general anesthesia, the affected extremity was sterilely prepared and draped. As a guide, a plate of appropriate length would allow at least three screw holes beyond the comminution. Desirable plating position was marked on the forearm skin under an image intensifier (Fig. 3a). An approximately 2-cm crescent-shaped skin incision was made along the wrist crease from the palmaris longus (PL) tendon to the flexor carpi radialis (FCR) tendon. It was then curved proximally and longitudinally in a straight line approximately 1 cm along the FCR tendon, and the antebrachial fascia was incised longitudinally along the FCR tendon. Next, the main trunk of the median nerve was traced, and the PL tendon and median nerve were retracted to the ulnar side (Fig. 3b). Similarly, the FCR tendon was retracted to the radial side. The distal edge of the PQ

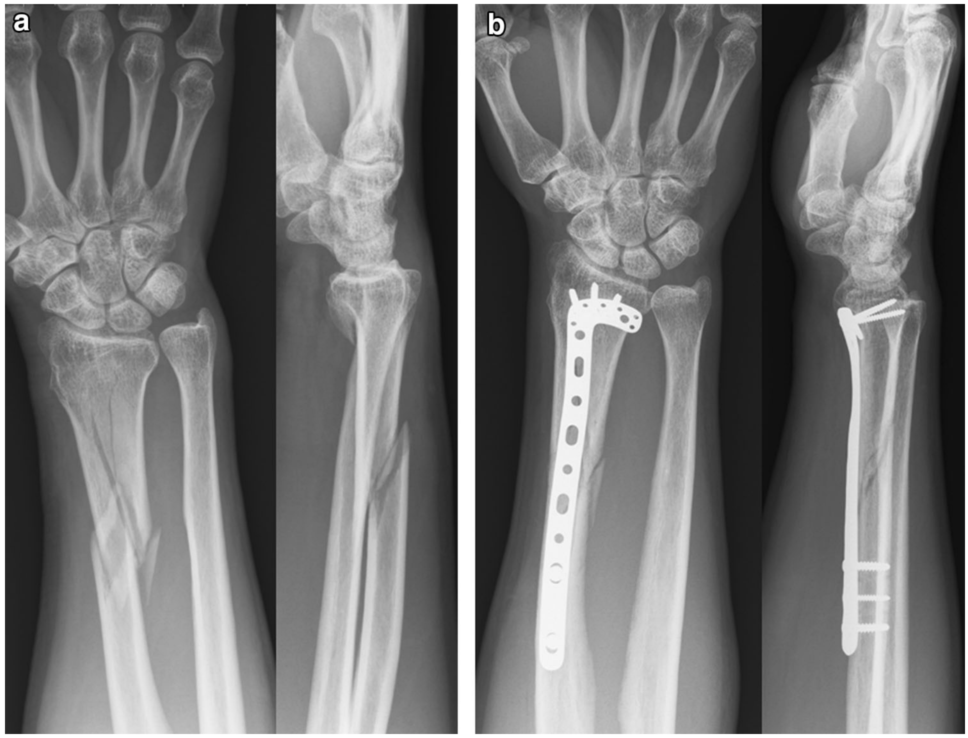

Fig. 2 **a** Anteroposterior and lateral radiograph of 47-year-old female patient with extensive comminuted metadiaphyseal fractures of the distal radius treated. **b** Complete bone union at 4 months, after MIPO technique with long locking plate fixation

Table 1 Concomitant injury and treatment

	Number of patients (%)	Details
MIPO group	6 (28.57)	3 DRUJ injury received K-wire fixation
		2 Distal ulnar fractures received plate fixation
		1 Distal ulnar fracture received K-wire fixation
Conventioal group	3 (23.08)	2 DRUJ injury received K-wire fixation
		1 Distal ulnar fracture received plate fixation
P value	0.724[a]	

[a] Chi-square test

muscle was exposed between the FCR and the PL. We then selected an adequate periosteal elevator, slightly wider than the plate (approximately 1 cm), which was then passed underneath the PQ muscle belly from the distal edge, in order to maintain intact radial and ulnar attachments. A submuscular space was created, and the periarticular locking plate of appropriate length was inserted from the distal skin incision and was placed beneath the PQ muscle (Fig. 3c). The 3-cm proximal and longitudinal skin incision was over the most proximal three holes of the plate. The drill guide sleeve was threaded into one of the distal locking holes, and the 1.8-mm drill bit or 1.6-mm Kirschner wire was inserted just beneath the subchondral bone of the articular surface to provide distal temporary fixation. All procedures were performed under fluoroscopic observation. The FPL muscle belly was retracted toward the ulnar side to view and ensure that the plate was located on the radial shaft in the proximal skin incision. Indirect reduction was achieved using a gentle traction maneuver, and then a 1.8-mm drill bit or 1.6-mm Kirschner wire was used proximally to stabilize the fracture temporarily (Fig. 3d). The alignment, length, and rotation of the fracture site were confirmed and verified under image intensification, and the proper locking screws were inserted into the proximal and distal sides of the plate. In the six cases with concurrent distal ulnar fracture or DRUJ injury in the MIPO group, we used plate osteosynthesis or Kirschner-wire fixation before radial reduction. Finally, it was important to ensure that soft tissue was not trapped between the bone and the plate before wound closure.

Operative technique for conventional open reduction (Henry's approach)

Under general anesthesia, the affected extremity was sterilely prepared and draped. A longitudinal incision was made along the FCR tendon. Dissection was carried down carefully between the radial artery and the FCR tendon.

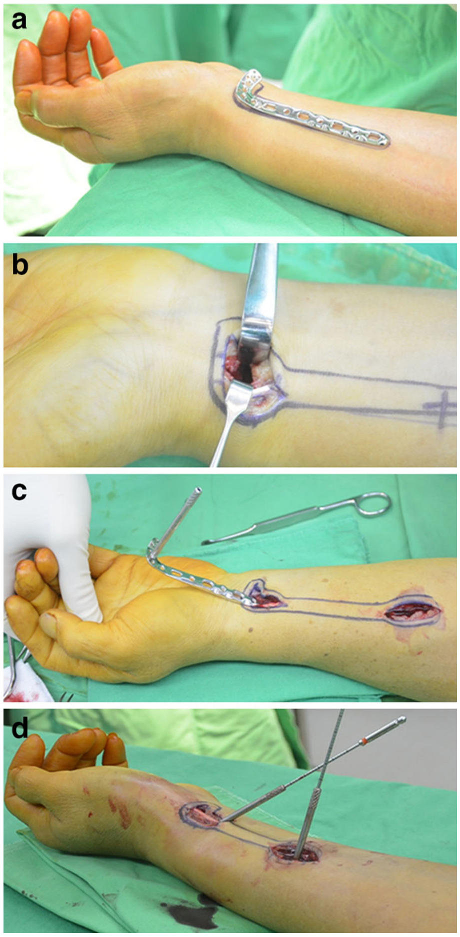

Fig. 3 **a** A plate of appropriate length was selected and a desirable position was marked under an image intensifier. **b** A 3-cm crescent-shaped skin incision was made, and the flexor carpi radialis was retracted radially. **c** The plate was inserted through a distal incision and was passed underneath the pronator quadratus muscle. **d** Two drill bits were used for temporary fixation after reduction under fluoroscopy

Then, the PQ was incised and detached to expose the fracture site. The incision length was determined by the fracture area and plate length of at least three screw holes beyond the comminution. The fracture was reduced under direct visualization. Then, the contour periarticular locking plate was located carefully on the volar aspect beneath the watershed line. Proper locking screws were inserted, and reduction and prominent screw tips on the dorsal cortex were rechecked under fluoroscopic assistance. In three cases with concurrent distal ulnar fracture or DRUJ injury in the conventional group, we used plate osteosynthesis or Kirschner-wire fixation before radial reduction.

Postoperative care and follow-up

The wrist was immobilized postoperatively with a short arm splint until the soft-tissue swelling subsided and the patient was pain-free. Wrist mobilization usually started approximately 5–7 days after surgery. After discharge from the hospital, routine follow-up was scheduled monthly. Bone union was defined as the presence of complete bridging bone and obliteration of the fracture gap as seen on plain radiographs with no tenderness or pain at the fracture site. The radiologic assessments (including volar tilt, radial inclination, and ulnar variance), postoperative Mayo wrist score [15], and non-validated satisfaction scale (0–10) were evaluated at the last outpatient visit. The wound size (cm), operative time (min), blood loss (c.c.), complications, time to fracture union (weeks), and the time to to resumption of work were all recorded.

Statistical analysis

Results are expressed as mean ± standard deviation. Mann–Whitney *U* test was used to determine the statistical significance of age, operative time, follow-up period, union time, Mayo wrist score, and satisfaction scale between the two groups. Chi-square test was used for enumeration data between the two groups. All statistical analyses were performed using SPSS version 17.0 software (SPSS, Chicago, IL, USA). The level of statistical significance was set at $P < 0.05$ for each test.

Results

Twenty-one patients in the MIPO group were followed for a mean period of 14.44 months (range 12–18 months) after surgery, and the average time to fracture union was 20.22 weeks (range 12–32) without secondary operative procedures. Thirteen patients in the conventional group were followed for a mean period of 14.0 months (range 12–18 months) after surgery, and the average time to fracture union was 21.54 weeks (range 16–32 weeks) without a secondary operative procedure. No patient had a wound infection, loss of reduction, fracture nonunion, tendon irritation, or neurovascular injury. The mean operative time was 60.0 min in the MIPO group and 86.54 min in the conventional group, and the mean wound size was 6.62 cm in MIPO group and 13.46 cm in the conventional group (Table 2). Both the operative time and wound size were significantly different between two groups. Moreover, the satisfaction scale was higher in the MIPO group than in the conventional group; however, the mean Mayo wrist score was 95.0 (range 85–100) in the MIPO group and 93.85 (range 80–100) in the conventional group, which assessed pain intensity (maximum 25 points), functional status (maximum 25 points), range of motion (maximum 25 points), and grip strength (maximum 25 points). Based on this score, the clinical results were

Table 2 The Patient's demographics, perioperative measurements, and clinical results

	MIPO group	Conventioal group	P value
Number of patients	21	13	
Gender (M/F)	7/14	7/6	0.238[b]
Age (years)	48.71 ± 14.53	45.15 ± 16.0	0.748[a]
Follow-up period (months)	14.44 ± 2.36	14.0 ± 2.71	0.548[a]
Time to union (weeks)	20.22 ± 5.22	21.54 ± 5.30	0.497[a]
Operation time (min)	60.0 ± 13.23	86.54 ± 16.38	<0.01[a]
Wound size (cm)	6.62 ± 0.80	13.46 ± 1.98	<0.01[a]
Mayo wrist score	95.0 ± 5.94	93.85 ± 5.83	0.595[a]
Satisfaction scale (0–10)	9.26 ± 0.65	8.61 ± 0.87	0.022[a]

[a] Mann–Whitney U test

[b] Chi-square test

Table 3 Radiologic parameters

	MIPO group	Conventional group	P value[a]
Volar tilt (°)	9.86 ± 3.86	10.31 ± 3.35	0.731
Radial inclination (°)	22.43 ± 3.20	22.00 ± 3.16	0.706
Ulnar variance (mm)	0.29 ± 1.31	0.15 ± 1.57	0.793

[a] Mann–Whitney U test

stratified as excellent (90–100 points), good (80–90 points), satisfactory (60–80 points), or poor (<60 points). We found that the difference in Mayo wrist score was not significant. In addition, radiologic assessment (Table 3) revealed that the mean volar tilt angle was 9.86° ± 3.86° (range 0°–17°) in the MIPO group. The respective value for the conventional group was 10.31° ± 3.35° (range 3°–17°). The mean radial inclination angle was 22.43° ± 3.20° (range 17°–28°) in the MIPO group. The respective value for the conventional group was 22.00° ± 3.16° (range, 17°–26°). The mean length of ulnar variance was 0.29 ± 1.31 (range −2 to 2) in the MIPO group. The respective value for the conventional group was 0.15 ± 1.57 (range −3 to 2). No significant difference was noted in radiologic observations between the two groups. All patients resumed work within approximately 3–5 months.

Discussion

In this present study, we adopted a crescent-shaped skin incision and used MIPO technique for extensive metadiaphyseal fractures with periarticular long locking plate.

We found that the MIPO technique had better wound size, operative time, and patient satisfaction than conventional technique. However, no statistically significant differences were apparent in time to fracture union, radiologic observations, or postoperative functional recovery.

Recent reports have introduced various MIPO procedures applied to distal femur or humeral shaft [7–9], however, few reports on distal radius fixation using MIPO [10–12, 14]. Imatani et al. [10] reported good-to-excellent clinical outcomes in five patients with comminuted fractures of the distal radial metaphysis treated with the MIPO technique. Milan et al. [12] recommended the same MIPO technique as a better option for extra-articular fractures or selected intra-articular fractures. They believed that the traditional Henry's approach, which requires PQ muscle incision and extensive soft-tissue stripping over the metaphysis, may increase the risk of damaging the blood supply and result in nonunion or delayed healing. Other authors [13, 16] have emphasized that maintaining an intact PQ muscle or repairing the PQ muscle is important after implant placement. Conversely, Hershman et al. [17] reported that union time and functional outcome did not differ significantly in patients with or without PQ muscle repair. Moreover, Zenke et al. [14] compared the postoperative results of MIPO and conventional Henry's approach and found no significant differences in postoperative radiological observation, fracture-healing rate, range of motion, grip strength, DASH scores, or VAS scores. We agree that postoperative functional recovery for distal radius fracture depends mainly on accurate anatomical reduction of the articular surface [18], rather than on whether the MIPO technique is employed or the PQ muscle remains intact. A cadaveric study [19] showed that the palmar arch of vessels supplying the PQ muscle and the anterior branch pierce the periosteum of the radial metaphysis and diaphysis. Theoretically, keeping the PQ muscle intact could be important for bone healing. Most fractures of the distal radius are metaphyseal fractures, and in our opinion, an intact PQ muscle does not play an important role in fracture healing because the metaphyseal bone has good healing capability. Moreover, the MIPO technique does not substantially reduce wound size in metaphyseal fractures, and small surgical wounds may be associated with complications of soft-tissue traction injury and tendon irritation.

Michele et al. [20] treated 21 patients with distal radius fractures involving the diaphyseal region using an extended volar Henry's approach. Two patients had major complications; one had radioulnar synostosis and the other had nonunion. Both required secondary surgical intervention. Using conventional open reduction to treat extended metadiaphyseal fractures usually requires a large incision and extensive dissection. In accordance with the AO principles for internal fixation, we count on secondary bone healing of a comminuted fracture. We believe that the MIPO technique is more beneficial for extensive metadiaphyseal fractures than for limited metaphyseal fractures because in extensive metadiaphyseal fractures, conventional open reduction and internal fixation presents greater disruption of blood supply, more soft-tissue dissection, and more complications.

In the current study, all patients had an extra-articular fracture with an extensive comminuted metadiaphyseal fracture beneath the PQ muscle. Therefore, we had to focus on anatomical reduction of the articular surface but rather on maintaining an intact PQ muscle. We demonstrate that the MIPO technique is beneficial for metadiaphyseal fractures; wound size, operative time, and patient satisfaction were significantly better than with conventional technique. However, no statistically significant differences were apparent in time to fracture union, radiologic observations, or Mayo wrist score. Whether using the MIPO technique or the conventional approach to open reduction and internal fixation, surgeons adhered to modern principles of fracture fixation and were careful to avoid extensive dissection and periosteal stripping, and thus, the time to fracture union was not significantly different between the two groups. The observation that both groups had similar functional outcomes was likely due to the fact that all cases were extra-articular fracture, and the volar tilt and radial inclination were intact. Some patients with distal ulnar fracture or DRUJ injury underwent ulnar reduction and fixation before radius fixation to help restore radial length. Therefore, there was no significant difference in ulnar variance. The smaller skin incisions may help to reduce wound pain, ease early rehabilitation, and early return to daily activities as well as improved cosmesis. Patients in the MIPO group reported significantly higher satisfaction scores.

With regard to skin incisions, Imatani et al. [10] recommended a distal longitudinal skin incision, whereas Zenke et al. [14] recommended a distal transverse skin incision along the wrist skin crease. Unlike the single longitudinal or transverse skin incision, we adopted a crescent-shaped skin incision, so the distal end of the plate was clearly visible, and the ulnar corner screw could be applied without hard retraction of FCR and PL. The applied periarticular long locking plate is well suited to the MIPO technique in these fractures. The tapered plate shaft design allows easy submuscular passage, and the low profile and hockey-stick-shaped distal end of the plate is easier to insert under a crescent incision and facilitates fixation without soft-tissue impingement.

A radial and ulnar fracture is usually considered to be an intra-articular fracture because it involves structures of the forearm that include the DRUJ, interosseous membrane, and PRUJ. Most orthopedic surgeons regard direct anatomical reduction and primary bone healing as standard procedures and may regard indirect reduction with the MIPO technique as difficult and unreliable. Furthermore, the ulnar length and DRUJ restoration are extremely important before indirect reduction in radius fractures. Fortunately, in our series, most patients had an intact distal ulna and DRUJ, and six patients with distal ulnar fracture or DRUJ disruption underwent distal ulnar anatomical reduction with plate fixation or DRUJ restoration before MIPO technique. In our experience, reduction of an extensive comminuted fracture of the distal radius is easier to perform after distal ulnar anatomical fixation or DRUJ restoration.

This study has several limitations. First, this was a retrospective study. Second, several surgeons performed the procedures, and each surgeon's experience may have influenced the outcomes. Third, the number of cases was small because metadiaphyseal fractures are relatively rare. Fourth, we only described extra-articular fracture in the present study because we believe that intra-articular fractrues should be treated by ORIF rather than by MIPO.

Conclusion

MIPO is capable of achieving functional results as good as those of conventional open reduction, with a higher satisfaction scale, smaller incision, and shorter operative time. When MIPO intervention is planned, concurrent distal ulnar fracture or DRUJ injury should be repaired first, thus facilitating subsequent indirect reduction.

Conflict of interest No financial or material support has been received or will be received from any commercial party related directly or indirectly to this research. None of the authors have any potential conflicts of interest.

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