Biomechanical considerations for strategies to improve outcomes following volar plating of distal radius fractures

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ABSTRACT

This article is a systematic review of the recent published literature on the biomechanics of volar locking plate fixation of distal radius fractures.

PUBMED/MEDLINE and EMBASE databases were searched on 13th Sep 2018. Biomechanical papers on volar locking plate fixation of distal radius fractures since 2010 were included. Papers were analysed and included studies were appraised by the author using the validated quality assessment GRADE tool.

The search revealed 456 papers between January 2010 and the present day whose abstracts were reviewed for relevance and 21 papers were included for full paper review.

The aim of this systematic review was to evaluate the evidence to determine the surgical techniques and strategies that are associated with the best biomechanical outcomes of volar plating for distal radius fractures. Review of the literature revealed that it was not necessary to fill all available distal locking screws, there was little evidence to support the use of 2 rows of screws distally over 1 row. Screws of 75% length of the distal cortex are sufficient to withstand standard postoperative regimes in extrarticular fractures. The was a paucity of evidence to conclude multidirectional locking plates were superior to fixed angle plates or that one brand of plate was superior to another.

1. Introduction

Distal radius fractures are extremely common accounting for up to 15% of extremity fractures.[16] A variety of treatment options are available in the treatment of this common injury including closed reduction and casting, percutaneous k wiring, external fixation and open reduction and internal fixation. Satisfactory outcomes have been reported despite poor radiological results in lower demand patients over 60[35] however the aim of all treatments is to achieve anatomical reduction and stability of the fracture to enable rehabilitation and been shown to produce good outcomes.[6] Locking plates are considered to provide a strong fixation to facilitate early mobilisation and aid rehabilitation with multiple papers showing good outcomes.[7]

The popularity of volar locking plates in the treatment of these fractures has grown enormously since their introduction over a decade ago.1st generation plates resembled a blade plate. Their design gave no capacity to adjust the angle or length of blade component and were technically challenging to use. Second generation plates improved the plate - screw locking interface but had symmetrical distal screw angulation. 3rd and subsequently 4th generation plates introduced the concept of variable angled screws allowing adaptation of plate position for subchondral placement of screws whilst theoretically minimizing the risk of screw perforation into the radio-carpal joint. They also aided the capture of variable fracture fragments.[29]

We performed a systematic review of recent literature to summarise biomechnical evidence on volar plate fixation of distal radius fractures using modern implants. The aim of this was to evaluate the evidence to determine the surgical techniques and strategies that are associated with the best biomechanical outcomes of volar plating for distal radius fractures.

2. Methods

A systematic review of the literature was conducted according to PRISMA guidelines. PubMed and EMBASE databases were searched using the terms 'volar plate fixation' or 'volar plating' and 'distal radius fracture' or 'wrist fracture.' The searches were performed independently by each author in January 2016 and repeated in March 2016.

All original biomechanical papers on volar plate fixation of adult distal radius fractures in English from 1st Jan 2010 were considered.

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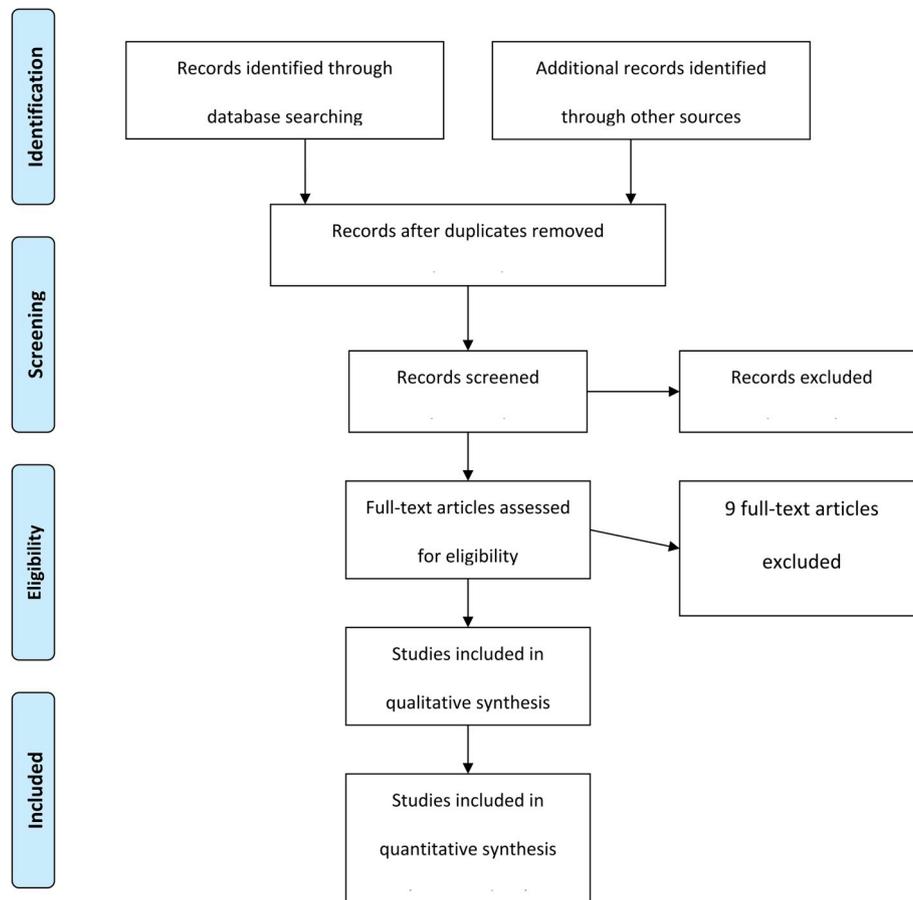*E-mail address:* alramavath@gmail.com (A. Ramavath).

Fig. 1. Grade table.

Abstracts and titles were analysed for relevance independently by 2 authors. All types of distal radius fractures were included (intra and extra-articular fracture models) in both cadaveric and sawbone models. Construct stability was assessed using biomechanical models to assess fixation stiffness and load to failure (loss of articular congruity) when this was included. All implants and plates were included for analysis as many papers compared modern and older previously used implants. The included publications were checked manually for additional references that potentially met the inclusion criteria. Studies were not blinded for author, affiliation or source. Exclusion criteria were clinical studies, none English language studies.

The studies included were appraised and assessed using the GRADE assessment tool.[11] (see Figs. 1 and 2). Recommendations were then graded as strong or weak and quality of evidence graded as high, moderate or low in accordance with these guidelines. Data on clinical studies and complication rates were extracted from the studies and reported but formal data synthesis was not possible due to the heterogenic nature of the studies.

3. Results

After application of the search strategy 21 papers were eligible for inclusion from the 137 reports initially identified.

Papers were assessed using the GRADE approach. This grading system classifies recommendations as strong (Grade 1) or weak (Grade 2) according to the degree of confidence in estimates of benefits, risks and burden. The system also qualifies the quality of evidence as high (Grade A), moderate (Grade B) or low (Grade C) according to the factors that include precision of estimates, consistency of results and direction of evidence.

Screw Type: Controversy still remains about the use of either pegs or screws in the distal fracture fragment. In theory the lack of thread on smooth pegs reduces the risk of intra-articular penetration with their larger core diameter providing more resistance to bending forces however screws may provide better grip.[7]

3 papers were identified comparing smooth pegs with locking screws or threaded pegs. Yao et al. compared extra articular fractures in 7 cadaveric radii fixed with either smooth or threaded pegs in the distal row and showed no difference in construct stiffness or load to failure between the 2 groups. The specimens were not tested under torsion however and stiffness has been shown to be reduced in sawbone models fixed with only smooth pegs.[12]

Mehling and Weninger compared biomechanical stiffness under both torsional and compression forces.[21,34] Mehling et al. tested 16 extra-articular cadaveric model fractures fixed with either locking pegs or screws. Mehling et al. showed a significant reduction in torsional stiffness after 1000 cycles (99% screws v 76% pegs) and axial compression (99% screws v 0% pegs). They also highlighted different failure mechanisms when tested to failure between the 2 groups with pegs showing a greater failure rate at the peg plate interface. Weninger et al. agreed that torsional stiffness was significantly reduced by 17% using pegs in an extrarticular sawbone model however he showed no difference in axial compression stiffness possibly because of a difference in biomechanical testing and the use of sawbones. Both authors found a significant difference between locking screws and smooth pegs with regard to stiffness under both torsion and compression and advocated the use of screws as opposed to pegs to optimize construct stability.

Screw Length: 2 biomechanical papers looked at the use of shorter distal fragment screws to minimise the risk of extensor tendon irritation and the effect this has on structure stability. Baumbach compared 2 groups of paired cadaveric extra articular wedge osteotomy models fixed with screws traversing 100% v 75% of the distal radius.[3]
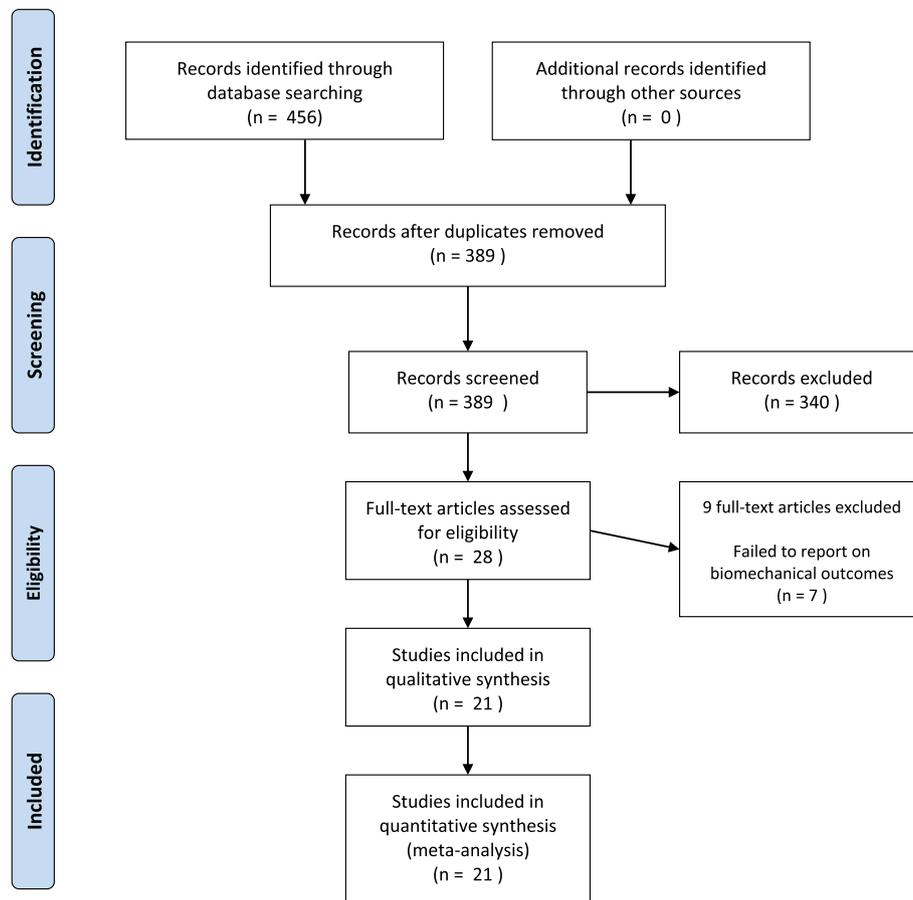
Fig. 2. Prisma flow diagram.

Specimens were tested to failure in axial compression and stability was assessed by stiffness, elastic limit and maximum force. Analysis revealed no differences in construct stability between 75% and 100% in any of the parameters measured. Both specimens exceeded the 250 N of stress well above physiological loads thought to be sufficient to withstand standard post operative rehabilitation. No torsional testing was performed on the specimens.

Wall et al. compared 5 different groups in a sawbone extra-articular wedge osteotomy models;- bicortical, unicorticol locked screws (100%/abutting dorsal cortex, 75% and 50%) and unicorticol pegs (100%).[33] There was no significant difference in any of the groups when comparing volar, and dorsal bending and axial compression during cyclic loading. However force needed to displace fracture fragments by 2 mm was significantly less for the 50% unicorticol screws (311 N) in comparison to the other groups (mean 420 N). Forces for catastrophic failure (closure of 1 cm osteotomy site) were also lower in both 50% unicortical screws (702 N) and pegs (749 N) than full length unicorticol (860 N) and 75% unicorticol (894 N) constructs. Again no torsional forces were applied to the models.

Number of Screws: Additional screws in the distal fracture fragment would logically lead to a more stable construct however this has to be balanced with the associated costs and clinical risks. 3 papers were identified looking at the number of screws used to assess construct stability. They compared the number of screws needed in the distal fragment to obtain satisfactory stability and whether 1 or 2 rows of screws is preferential.

Mehling et al. compared 4 different screw placement options in the distal fragment fixation (4 locking screws, 4 locking screws alternately in distal and proximal rows, 3 locking screws in proximal row and 7 locking screws) of cadaveric segmental extra-articular fractures.[22] They concluded 3 screws in the proximal row offered an unstable fixation

model with a mean stiffness of (83 N/mm). 7 screws offered the highest stiffness under axial compression (429 N) however this was not statistically significant and 4 screws (in distal or alternate proximal and distal) offered sufficient stability (208 N/mm and 177 N/mm) in volar and dorsal bending and axial compression, with plate failure or deformation occurring before cut out of the screws. Weninger et al. also highlighted plate failure before screw cut out when they evaluated 3 screw configurations in an extra-articular fracture model. They compared using 1 distal row v 2 rows of parallel screws v 2 rows of converging screws in multidirectional locking plates. After undergoing axial loading to failure no difference between the groups were found. Indeed more failures were seen as the plate deformed before the screws cut out and therefore the use of 2 distal rows of screws were not recommended.

Moss et al. showed similar results when comparing 4 v 7 distal locking screws in the cadaveric C2-AO fractured wrists.[23] They cyclically loaded the 10 matched pairs of wrists to simulate postoperative stressing and then loaded them to failure, defined as displacement of 2 mm or more. They found no wrists failed during cyclical loading and although the 7 screw construct was stiffer when loaded to failure (139 N v 108 N) although the difference was not statistically significant.

Placement of Distal Screws: 6 papers looked at both the number and position of screws in either proximal or distal rows. Crosby et al. tested 24 synthetic extra articular distal radius fractures with 4 different volar locking plate systems.[9] Each plate was tested using all distal screw holes and half of the distal screws available (most radial and most ulnar holes used). They found that in all plate designs there was less than 0.1 mm difference in mean displacement when comparing all v half distal screws used after none cyclical axial loading, volar and dorsal bending. They also found that mean displacement was less in plates with 2 rows of distal locking screws (0.4 mm) than in plates containing

1 row (0.6 mm) offering a more stable construct although the significance and clinical relevance of this is unproven and specimens were tested a number of times with different screw configurations.

Drobetz et al. also challenged these findings when he compared fixed angle single row plates with variable angle multi row plates in synthetic extra articular fracture models.[10] He not only showed no improvement in construct stability using variable angled multi row plates but even showed a trend in the opposite direction towards fixed angle single row devices after cyclic loading and load to failure testing. This was regardless of whether one or both rows screw rows were used.

In another paper Drobetz did however show a significant increase in load to failure rigidity with increasing total number of screws and screw projection area in the distal row.[11] In a sawbone intra-articular fracture model 5 different volar locking plate models ere cyclically and then loaded to failure. He showed a significant difference in load to failure of a 3 screw model with a surface projection area less than 12 mm (534 N) than other those with 5 or 6 screws and a surface projection area of 12 mm or more (mean 1062 N).

Iba et al. compared the use of radial styloid targeted screws in a cadaveric intra-articular fracture model.[14] After comparing 6 matched specimens with 2 additional locking screws in the radial styloid fragment the additional screw models were found to be stronger and more resistant to articular reduction failure (682 N v 913 N). Loading of these specimens under a physiological cyclical load however was not done which is thought to mimic post operative regimes more closely.

Type of Plate: Plate designs now commonly incorporate the use of variable angled locking screws to accommodate screw placement into a variety of fracture configurations and offer possible improved construct stability.

Stanbury investigated this in a paper comparing variable angle and fixed angle plates used to fix AO-C3 synthetic fractures.[32] 2 fracture types were investigated with a distal radial styloid fracture fragment model and a more proximal osteotomy with central coronal fracture line. No failures were seen in cyclical loading representing post-operative treatment regime however when loading to failure the variable angle plate showed significant mechanical advantage over the fixed angle construct in fractures with a radial styloid fragment with no articular failure recorded.

Rausch agreed that polyaxial two column plates produced a more stable construct with significantly lower loss of reduction than the fixed angle device in cadaveric intra-articular fracture models.[27] This improved stability in axial compression was also replicated by Martineau in extra articular fractures, but not in bending forces.[20]

Hart et al. then looked to see if the use of variable angled plates could compensate for suboptimal position by moving the plates 3 mm from its intended ideal placement in sawbone intra-articular fractures.[13] He showed no significant difference in rigidity and load to failure between the groups even in these suboptimal positions and concluded that the variable angle design could compensate for suboptimal plate position. The results however also included the use of a fixed angle device which also showed similar construct stability in a suboptimal position.

Marshall compared titanium and stainless steel plates in a similar fixed angle plate in the fixation of AO-C3 cadaveric fracture models.[19] After undergoing cyclic loading fragments fixed with the stainless steel plate resulted in less displacement and rotation. Finally Dahl et al. compared 8 different modern fixed angle plates in an extrarticular fracture model mimicking postoperative rehabilitation. Each was cyclically loaded at 100 N, 200 N and 300 N for 6000 cycles. All tested plates met anticipated demands and the authors could not recommend the use of one plate over another.

Tendon Rupture: 3 recent papers have looked at tendon ruptures. Selvan et al. showed that plates were significantly more prominent if they were placed 5 mm more proximally of distally form their intended positions.[30] A 5° malreduction also significantly increased implant prominence probably due to more proximal placement of the plate.

Limthongthang even showed prominent profiles of plates at optimum plate placement at the watershed line in relation to the FPL tendon.[17] Perry et al. also highlighted the high risk central screw holes as being most at risk of damaging the EPL tendon.[26]

4. Discussion

No biomechanical or clinical papers have recommended the use of all available distal locking holes. Moss et al. showed that the use of 4-screw distal constructs in AO type C2 fractures exceeded the physiological forces exerted on the distal radius during standard rehabilitation (54 N) by at least 2 fold.[6]

Insignificant biomechanical differences in construct stability have been shown in the comparison of 7 v 4 screw configurations in the distal fragment and the use of more than 4 screws in the distal fragment in the clinical setting has not been shown to be advantageous. Greater stability has been shown with 4 distal screws instead of 3.[5] The implication of the biomechanical studies is it is not necessary to fill all of the screws in an extra-articular distal radius fracture benefitting both operative time and reducing implant cost.[1] Biomechanically 4 screws in the distal fragment seems to offer sufficient stability in the treatment of these fractures however further work is needed to prove this in the clinical setting. Advice on the number of screws needed in more complex intra-articular fractures has not been sufficiently answered. Tornkvist et al. did show that 3 screws were more stable in torsion when compared to 2 in a fracture fragment using synthetic bone foam medium but this would be difficult to obtain in many distal radius fracture configurations.[9]

The additional row of distal screws is designed to provide a 'three dimensional scaffold for optimum subchondral support.' Manufacturers recommend placing the most distal screws parallel to the joint and the second row of screws in the second row at a steeper angle to create a gable construct. The metaphyseal area of bone this second row of screws passes however provides little resistance to loss of reduction and Weninger et al. concluded that using two distal screw rows cannot be recommended.[13]

These findings are supported with a comparative clinical study by Neuhaus who showed no difference in postoperative radiographic alignment of 34 pairs of fractures fixed with either a single row or 2 rows matched for fracture type, dorsal comminution, ulna fracture, mechanism of injury, and age (± 8 y).[24]

Koh et al. evaluated 10 different plate fixation designs (including single and multi row plates) and found that all provided adequate stability for fracture healing and early mobilisation in extra articular cadaveric fractures.

Bicortical distal screws also aid construct stability however risk extensor tendon rupture if the dorsal cortex is penetrated. The trapezoidal shape of the dorsal cortex also makes detection of screw penetration difficult even with the use of fluoroscopy intraoperatively. Joseph et al.'s paper described the use of a novel dorsal horizon or skyline view to detect dorsal penetration and 27% of patients had screws changed intra-operatively with the use of this view.[15] In an observational study the skyline view improved detection rate of 83% when comparing it to more traditional lateral (77%) and oblique (50%) radiographs.[28]

Biomechanical studies have supported the use of unicortical screws demonstrating that 75% distal screw length provides similar primary stability as 100% unicorticol screw length.[10] What studies have not shown is the impact this has on the screw plate interface with the shortened lever arm acting on the plate. The reduction in distal screw length has also not demonstrated a reduction in extensor tendon complications in the clinical setting yet. Obert et al. showed similar complication rates when comparing uniaxial locking screws and none locking screws in one group (31 patients) with polyaxial locking screws (121 patients) in a case series of 152 patients.[25] Unicortical screws or pegs of approximately 75% of the cortex to cortex ratio would seem to

provide adequate construct stability and minimise the risk of extensor tendon irritation with the use of the skyline view to aid dorsal penetration detection rate. Further clinical studies are required however to validate this approach and investigate the reduction of dorsal screw protrusion and subsequent extensor tendon irritation.

Recent biomechanical studies would seem to suggest a stronger construct stability with the use of screws in comparison to pegs as they improve stiffness under both torsional and compressive forces in extra-articular fractures.[4,13] Orbay and Fernandes however recommended the use of smooth pegs to avoid screw penetration into the radiocarpal joint and to avoid carpal damage in the case of fracture collapse.[7]

Most of the published biomechanical work has used an extra-articular fracture models and thus far the increase in construct stability using screws has not been proven in a clinical study. Boretto et al. failed to show any difference in follow up radiographic parameters when comparing 14 v 13 patients with C2 and C3 AO radius fractures fixed with either pegs or screws.[5] Further studies evaluating clinical performance of threaded vs smooth locking pegs and screws are required to make recommendations on screw type comparing the possible improved construct stability of threaded screws against the potentially safer smoother pegs.

The additional costs associated with locking screws has questioned the routine use of locking shaft screws. Bicorticol none locking shaft screws may be sufficient for a stable fixation and the shaft area is also associated with a lower risk of extensor tendon irritation with dorsal cortex penetration. Lutsky et al.'s case series included 51 patients who underwent fixation with the use of none locking shaft screws.[18] They found no instances of hardware failure and all patients fractures healed within acceptable radiographic parameters although these acceptable limits are not outlined. The study didn't comment on complications associated with this and the increased risk of extensor tendon irritation and patients were not randomized. Indeed if a patient was felt to have particularly poor bone stock the operating surgeon could choose to implant locking screws at the time of surgery. Case studies have shown loosening of diaphyseal screws with monocortical none locking screws in osteoporotic patients[3] and bicorticol screw purchase is advantageous in increasing working length and screw anchorage especially when the cortex is thin in osteoporotic patients.[8] Insufficient data is available both biomechanically or in vivo to support the use either bicorticol none locked shaft screws or monocorticol locking screws.

Asadollahi et al. performed a systematic review of tendon injuries following volar plate fixation. After review of 21 studies they concluded that placement of the plate 'proximal,' to the watershed line and removal of the plate in those that are symptomatic can reduce the risk of attritional rupture.[2] Careful placement of the plate is needed to avoid plate 'lift off,' secondary to malposition of the plate or fracture malreduction. Soong et al. compared 2 plate designs with differing volar profiles used at 2 different centres in a comparative clinical series.[31] They did find prominence of hardware over the volar rim on at the watershed line was a risk factor for flexor tendon rupture however couldn't recommend one plate over another with their results due to the rare nature of flexor tendon rupture as a complication.

Zenke et al. investigated 6 EPL rupture cases in a series of 286 patients. Although no obvious cause was found in half the cases, protrusion of screw tips and malreduced dorsal fragments were associated risks of this rare complication.[36]

In conclusion multi-row volar locking distal radius plates do not seem to offer biomechanical advantages over single row fixed angle plates and further biomechanical and clinical studies are necessary to determine the optimal number and position of screws to achieve consistent reproducible good results especially in more complex intrarticular fractures.

The variability in biomechanical papers discussed in this paper has highlighted the difficulty in strong recommendations for the treatment of this spectrum of injuries. Each distal radius fracture is unique and no specific locking screw configuration is appropriate for all fractures.

Conflict of interest

All the authors declare that, none of them have any conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jor.2019.04.006.

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