Free Medial Femoral Condyle Flap for Reconstruction of Scaphoid Nonunion: A Systematic Review

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Abstract

Background The free medial femoral condyle (MFC) bone flap is an attractive option for reconstruction of scaphoid nonunion utilizing vascularized bone to augment bony healing, especially in cases of failed prior treatment or osteonecrosis. This review aims to determine the role and reliability of the free MFC flap for treatment of scaphoid nonunion.

Methods A search of electronic databases was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Articles examining free MFC bone flaps for treatment of scaphoid nonunion were included for analysis. Outcomes of interest included flap failure, postoperative union rate, time to union, carpal indices, functional outcomes, and complications.

Results Twelve articles met the inclusion criteria. A total of 262 patients underwent free MFC flaps for treatment of scaphoid nonunion. The most common site of nonunion was the proximal pole of the scaphoid with 47% of patients receiving prior attempts at operative management. Overall bony union rate was 93.4% with a mean time to union of 15.6 weeks. There were no flap failures reported. Improvements in carpal indices including scapholunate ($p < 0.0004$), radiolunate ($p < 0.004$), lateral interscaphoid angles ($p < 0.035$), and revised carpal ratio height ($p < 0.024$) were seen postoperatively. Visual analog scale improved postoperatively from 6.5 to 2.3 ($p < 0.015$). Postoperative complications were observed in 69 cases (26.3%), with 27 patients (10.3%) requiring further operative intervention. However, no major donor or recipient site morbidity was appreciated.

Conclusion MFC flaps provide a highly versatile and reliable option for reconstruction of scaphoid nonunion with excellent bony union rates and acceptable complication rates. The present literature suggests that MFC reconstruction of scaphoid nonunion restores radiocarpal anatomy and improves wrist function without causing significant donor or recipient site morbidity.

Keywords
- ► free flap
- ► medial femoral condyle
- ► vascularized bone graft
- ► scaphoid nonunion
- ► microvascular surgery
- ► hand surgery

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Scaphoid nonunion poses a significant therapeutic challenge, particularly in the setting of associated avascular necrosis (AVN) and the potential for carpal collapse and scaphoid nonunion advanced collapse (SNAC) wrist arthritis. Failed prior surgery can further complicate the scenario resulting in bone loss, and an unfavorable environment for future bony healing.

Surgical intervention in scaphoid nonunion is indicated to prevent progressive degenerative changes, including humpback deformity, carpal collapse, and the eventual development of SNAC wrist.[1,2] The goals of surgery include restoration of vascularity to the proximal pole (if required), recovering scaphoid length and alignment, and managing carpal instability.[3,4]

The free medial femoral condyle (MFC) flap is a vascularized osseous segment harvested from the transverse branch of the descending genicular artery, or, less commonly, the superomedial genicular artery.[5] This flap has been utilized in the treatment of scaphoid nonunion with proximal pole osteonecrosis, conferring a number of advantages over the conventional pedicled osseous flaps including excellent union rates. The MFC flap utilizes corticoperiosteal and corticocancellous components to provide a structural augment that restores scaphoid length and prevents carpal collapse. Moreover, the independent and reliable vascular inflow aims to address the poor blood supply in cases of AVN. The MFC provides a thin, pliable flap that can be harvested in several configurations to allow for precise tailoring according to the specific defect and can be utilized for reconstruction of intercalary defects across the entire length of the scaphoid.

In cases of highly proximal scaphoid nonunion resulting in a proximal fragment that is too small to reconstruct with the conventional MFC flap or has significant cartilaginous loss, the medial femoral trochlea (MFT) flap has been described.[6,7] Harvested as an osseocartilaginous construct, the MFT flap can be used to accurately reconstruct the convex cartilaginous surface of the proximal scaphoid while also providing the osteogenic benefits of a vascularized bone flap. Although the MFT flap provides a useful reconstructive option in highly proximal scaphoid pole nonunion, it is beyond the scope and focus of this article.

The purpose of this article was to review the outcomes of the free MFC flap and to clarify its utility in reconstruction of scaphoid nonunion. While promising results have been demonstrated in the literature, the results of the MFC flap have not been summarized to date. Thus, the aim of this systematic review was to evaluate the clinical and radiological outcomes of the free MFC flap for management of scaphoid nonunion.

Methods

A systematic review of the available literature was performed in October 2020 according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. An electronic search of PubMed, MEDLINE, EMBASE, and the Cochrane Controlled Register of Trials (CENTRAL) databases was performed from 2000 (the first description of the free MFC flap for management of scaphoid nonunion[8]) to October 2020. Key search phrases such as “medial femoral condyle flap,” “free vascularized bone graft,” “scaphoid nonunion,” and “scaphoid pseudarthrosis” were used in various combinations with Boolean logical operators and MeSH search terms to maximize search sensitivity.

Studies were eligible for inclusion if they described the use of a free MFC flap for management of scaphoid nonunion. Further inclusion criteria were human only studies, a series of five or more MFC flaps, transfers for radiographically established scaphoid nonunions, and extractable postoperative outcomes. Exclusion criteria included: (1) studies not reporting outcome measures, (2) studies reporting flap recipient sites other than the scaphoid, (3) studies reporting the use of the MFT flap for scaphoid reconstruction, (4) animal studies, and (5) abstracts, review articles, or technique articles. No limitations were placed in terms of language on the search strategy.

Data were extracted by two independent reviewers and any disagreement resolved by consultation with a senior author. All relevant articles were screened for duplicate patients, with studies containing the longest follow-up data included for analysis. The primary outcomes were time to radiographic union, overall union rate, and flap failure rate. Secondary outcomes were grouped into carpal indices (including scapholunate, radiolunate, and lateral interscaphoid angles, as well as scaphoid height-to-length and revised carpal height ratios), functional outcomes (wrist range of motion [ROM], grip strength, and patient-reported outcome measures), and complications.

Data were extracted from the text, tables, and figures of the included studies and displayed in tables where appropriate. Extracted data included baseline patient demographics (age and sex), previous operative management, anatomical location of scaphoid nonunion, and duration of nonunion. Additionally, flap fixation techniques and any further ancillary procedures were recorded in conjunction with follow-up duration. Major complications included flap failure, donor site fracture, and progression to SNAC wrist requiring further operative management. Minor complications included infection, scarring, or persisting donor site discomfort.

Two researchers independently assessed the risk of bias for each included study using the Joanna Briggs Institute Critical Appraisal Checklist for bias in case series.[9] The quality of evidence was examined using the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) framework.[10] The GRADE standardized approach rates evidence for an outcome of interest by upgrading or downgrading evidence based on various factors. Factors for upgrading evidence include having large effect sizes and dose–response gradients. Indications for downgrading quality of evidence include serious risk of bias, inconsistencies between studies, indirectness, imprecision, and publication bias.

Statistical analysis was performed via pooled means for outcomes of interest when data permitted. A paired Student's *t*-test was used to evaluate differences between pre-

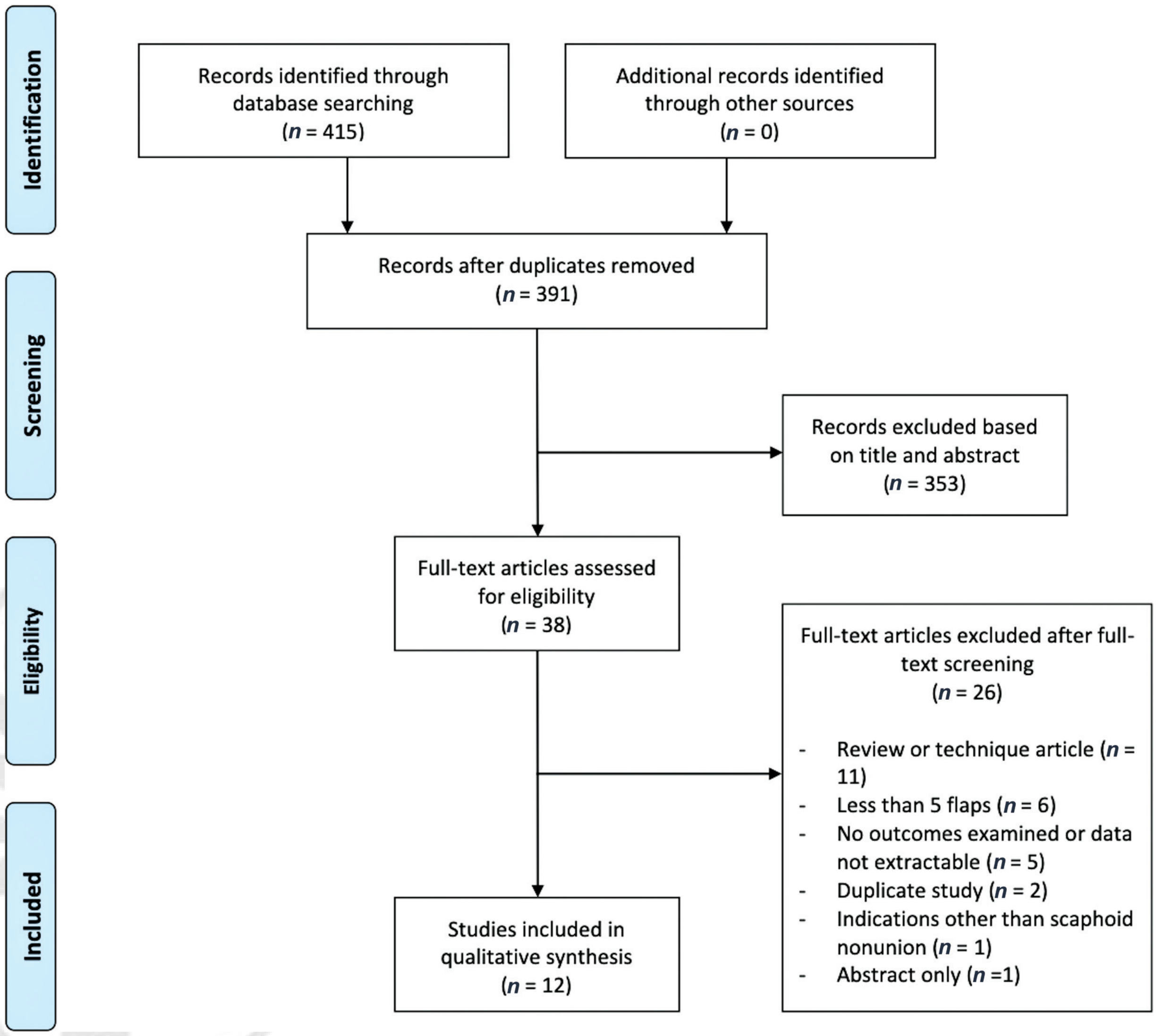

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of study selection.

and postoperative pooled mean values for outcome variables of interest. All *p*-values less than 0.05 were considered statistically significant.

Results

The initial electronic database search yielded 415 articles for screening. After application of exclusion criteria and removal of duplicate studies, a total of 12 studies were identified for analysis (►**Fig. 1**). All 12 studies were retrospectively designed studies. Study characteristics are reviewed in ►**Table 1**.

A total of 262 free MFC flaps were performed for treatment of scaphoid nonunion in 262 patients. The mean age of the cohort was 27 years (range: 22.5–33.4 years) with a 91% male predominance. Average follow-up was 1.5 years (range: 0.7–3.5 years). The mean duration of scaphoid nonunion prior to operative intervention with an MFC flap was 24.8 months (range: 19–41 months). For studies describing anatomical location of the nonunion, the proximal pole was the most common site, followed by the waist and distal pole respectively. Studies described a combination of flap fixation techniques including the use of Kirschner (K) wire or cannulated compression screw fixation as a mainstay, and less commonly, volar locking mini-plates. There were 47 further planned operative cases: 43 patients underwent removal of K-wires, while another 4 had extraction of the compression screws (►**Table 1**).

Radiological Outcomes

There were no reported microvascular complications resulting in flap failure for studies that utilized an osteocutaneous MFC free flap. All studies reported bony union as determined by evidence of bridging trabeculae across the proximal and distal interfaces on radiographic imaging. Of the 262 flaps, 237 achieved successful bony union, yielding a union rate of 93.3%. Mean time to union was 15.6 weeks (range: 12–30 weeks; ►**Table 2**).

Prognostic Factors

Prognostic factors including presence of AVN, preoperative carpal collapse, or previous failed operative management

Table 1 Study characteristics and operative techniques

Study	Age (y)	Sex	Number of patients	Site of nonunion	Duration of nonunion (mo)	Fixation techniques	Additional procedures	Follow-up (y)	Level of evidence
Doi (2000)[8]	33.4	9 M, 1 F	10	8 waist, 4 proximal pole	19	10 K-wire	10 K-wire removal	3.5	Retrospective
Jones (2008)[3]	23	12 M	12	12 proximal pole	31	7 screw fixation, 4 K-wire, 1 K-wire + screw	–	1	Retrospective
Burger (2009)[41]	28.5	14 M, 1 F	15	15 waist	29.5	15 cannulated screw	–	2.6	Retrospective
Jones (2010)[42]	25.3	12 M	12	12 proximal pole	20	8 cannulated screw fixation, 3 K-wire, 1 K-wire and screw	4 K-wire removal	0.7	Retrospective
Elgammal (2014)[29]	28	29 M, 1 F	30	30 proximal pole	NR	21 compression screw, 5 K-wire, 4 locking plate	–	1.2	Retrospective
Chaudhry (2016)[43]	25.3	19 M	19[a]	11 proximal pole, 7 waist, 1 distal pole	40.8	NR	4 screw removal	NR	Retrospective
Kumta (2017)[27]	22.5	11 M	11	11 proximal pole	27.2	2 cannulated screw, 9 K-wire	–	1	Retrospective
Aibinder (2017)[44]	22.8	40 M, 5 F	45	38 waist, 7 proximal pole	15.6	NR	8 K-wire removal	1	Retrospective
Kazmers (2018)[45]	26.8	8 M, 4 F	12	NR	NR	9 K-wire, 1 Herbert screw, 2 no fixation (press fit)	–	0.95	Retrospective
Pulos (2018)[46]	23	44 M, 5 F	49	49 proximal pole	24	21 cannulated screw, 22 K-wire, 6 using both	21 K-wire removal	2.9	Retrospective
Guzzini (2019)[47]	33	11 M, 4 F	15	NR	NR	NR	–	1.1	Retrospective
Kollitz (2019)[28]	32	28 M, 4 F	32	8 proximal pole, 24 waist	16	28 cannulated screw, 4 K-wire	–	1	Retrospective
Totals	**27.0**		**262**		**24.8**			**1.5**	

Abbreviations: F, female; M, male; NR, not reported; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.
[a]One patient excluded by authors due to loss to follow-up.

Table 2 Union rates and prognostic factors

Study	Flaps performed	Number of successful unions	Union rate (%)	Time to union (wk)	Prognostic factors			
					AVN	AVN union rate (%)	Preoperative carpal collapse	Previous failed operative management
Doi (2000)[8]	10	10	100.0%	12	10 of 10	100.0	No	8
Jones (2008)[3]	12	12	100.0%	13	12 of 12	100.0	Yes	6
Burger (2009)[41]	15	15	100.0%	NR	15 of 15	100.0	No	5
Jones (2010)[42]	12	12	100.0%	13	12 of 12	100.0	Yes	9
Elgammal (2014)[29]	30	24	80.0%	NR	10 of 14	71.4	Yes	15
Chaudhry (2016)[43]	19	17	89.5%	30.4	11 of 13	84.6	No	4
Kumta (2017)[27]	11	11	100.0%	12	8 of 8	100.0	No	7
Aibinder (2017)[44]	45	40	88.9%	15.5	36 of 41	87.8	Yes	29
Kazmers (2018)[45]	12	10	83.3%	17.9	10 of 12	83.3	No	8
Pulos (2018)[46]	49	41	83.7%	16	41 of 49	83.7	No	36
Guzzini (2019)[47]	15	15	100.0%	13.9	15 of 15	100.0	No	0
Kollitz (2019)[28]	32	30	93.8%	12	30 of 32	93.8	Yes	0
Totals	**262**	**237**	**93.3%**	**15.6**		**92.05**	**41.7%**	**127**

Abbreviations: AVN, avascular necrosis, NR, not reported.

were collated. AVN was defined as absence of punctate bleeding of the scaphoid on tourniquet deflation and was noted in 210 cases. No significant differences in union rates were found in patients receiving an MFC flap with AVN alone compared to scaphoids without evidence of AVN (92.1%, $p = 0.738$). Preoperative carpal collapse was reported in 5 out of 12 studies (41.7%). A total of 127 patients received prior attempts at operative intervention of their nonunion without success, giving a preoperative failure rate of 48.5% (127/262 patients; ►**Table 2**). The individual reasons for prior operative failures were not recorded due to incomplete or absent documentation between studies.

Carpal Indices

Eight studies reported pre- and postoperative changes in carpal indices. Carpal alignment and scaphoid length were found to have improved significantly following utilization of MFC flaps. The mean preoperative to postoperative improvement for the scapholunate angle was 65.7–55.3 degrees ($p < 0.0004$), from 18.3 to 9.2 degrees for the radiolunate angle ($p < 0.004$), from 52 to 30.5 degrees for the lateral interscaphoid angle ($p < 0.035$), and from 1.46 to 1.5 for the revised carpal height ratio ($p < 0.024$). Although the scaphoid height-to-length ratio decreased from 0.71 to 0.63, this was not statistically significant ($p = 0.134$; ►**Table 3**).

Functional Outcomes

There was significant heterogeneity in reporting of postoperative functional wrist outcomes, including ROM measurements between studies. Although a moderate number of studies reported postoperative results, only two described preoperative baseline measurements to allow for statistical analyses. There were no significant differences appreciated between pre- and postoperative wrist flexion (48–43 degrees, $p < 0.087$) and extension (44.7–44.6 degrees, $p < 0.477$). Postoperative radial deviation was measured at 14.2 degrees and ulnar deviation at 24.8 degrees (►**Table 4**).

For studies that reported functional wrist outcomes, average postoperative grip strength was 38.5 kg. The visual analog scale improved from 6.5 to 2.3 ($p < 0.015$); however, only two studies provided preoperative measurements, rendering comparison limited. While patients with recorded Mayo Wrist scores improved from 47.9 to 84.5 ($p < 0.188$), this did not reach statistical significance. For studies that recorded Disabilities of the Arm (DASH) and Patient-Rated Wrist Evaluation (PRWE) scores, these were 14.1 (40 preoperatively) and 12.5, respectively (►**Table 5**). Lack of data precluded statistical analysis between pre- and postoperative DASH and PRWE scores.

Complications

Postoperative complications were seen in 69 cases (26.3%) with 27 (10.3%) requiring an unplanned return to theatre (►**Table 6**). The most common complication was persistent nonunion, which was seen in 27 cases. Of these, 15 patients underwent further operative management. Nine patients underwent scaphoidectomy and four-corner fusion; two

Table 3 Carpal indices

Study	Scapholunate angle (degrees)		Radiolunate angle (degrees)		Lateral interscaphoid angle (degrees)		Scaphoid height-to-length ratio		Revised carpal height ratio	
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
Doi (2000)[8]	58	52					0.54	0.55		
Jones (2008)[3]	70	57	15	10	57	32			1.49	1.51
Burger (2009)[41]	63	52.3							1.42	1.49
Jones (2010)[42]	63	49	15	6	66	28	0.78	0.65	1.49	1.51
Elgammal (2014)[29]	73	61			41	28			1.4	1.5
Chaudhry (2016)[43]										
Kumta (2017)[27]										
Aibinder (2017)[44]	62.4	57.7	21.3	15	64	48.5	0.77	0.69	1.49	1.53
Kazmers (2018)[45]										
Pulos (2018)[46]	66	58	20	10			0.7	0.61	1.46	1.49
Guzzini (2019)[47]										
Kollitz (2019)[28]	70	55	20	5	32	16	0.76	0.63	1.49	1.49
Totals	**65.7**	**55.3**	**18.3**	**9.2**	**52.0**	**30.5**	**0.71**	**0.63**	**1.46**	**1.50**
	$p = 0.0004$		$p = 0.004$		$p = 0.035$		$p = 0.134$		$p = 0.024$	

received radioscapholunate arthrodesis; a single patient underwent scaphotrapeziotrapezoid arthrodesis; and three received a salvage pedicled 1,2-intercompartmental supraretinacular artery flap. All three patients receiving further pedicled bone flaps went on to achieve bony union.

No major donor or recipient site morbidity was recorded. The most frequently reported donor site complications included four cases of superficial infection, three patients with hypertrophic scarring not requiring operative intervention, and four cases of persisting knee pain or discomfort. Common recipient site complications included hypertrophic scarring, hardware loosening with local irritation, and persisting postoperative wrist pain (►**Table 6**). Three patients were lost to follow-up.

Discussion

This systematic review provides a comprehensive summary of both radiological and clinical outcomes following management of scaphoid nonunion using the MFC free flap. Overall, our results support the consensus that the MFC free flap provides reliable and well-vascularized bone that is particularly advantageous in the treatment of recalcitrant scaphoid nonunion. The free MFC flap has excellent union rates, restores radiocarpal anatomy, and carries limited donor site morbidity.

Several studies have demonstrated the increasing role and reliability of the MFC flap in the treatment of scaphoid nonunion. The results of our systematic review are directly in keeping with those in the published literature. A recent comparative review examining outcomes of vascularized bone grafting (VBG) for treatment of scaphoid nonunion and Kienböck disease have shown favorable outcomes for VBG.[11] In a subset of their data examining 143 patients, the authors reviewed the use of the MFC for treatment of scaphoid nonunion and demonstrated overall bony union in 127/143 patients (88.8%) with a mean time to union of 12 weeks.[11] The results of our current review demonstrated a higher bony union rate (93.4%) and similar time-to-union rate (15.6 weeks). The authors also demonstrated no significant differences in bony union rates when comparing the presence of AVN, which is also consistent with our present findings. Inherent limitations of the previous review by Tsantes et al[11] include a lack of carpal indices, functional outcome data and assessment of complications, which our review intended to address.

The goals of treatment following scaphoid nonunion are achieving bony union, correcting carpal deformity, reducing pain, and preventing degenerative wrist changes.[12] In subjects with normal scaphoid alignment, preserved carpal stability, and intact proximal pole vascularity (evidenced by intraoperative bleeding after tourniquet deflation[13]), rigid fixation may be used as a standalone procedure to achieve bony union.[12,14] However, in the context of significant foreshortening, rotation, or flexion of the scaphoid, the addition of structural bone is indicated to correct carpal and scaphoid alignment.[15] The ideal type of bone graft or flap required to restore scaphoid anatomy remains a topic of conjecture, and

Table 4 Range of motion outcomes

	Range of motion (degrees)							
	Flexion		Extension		Radial deviation		Ulnar deviation	
Study	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
Doi (2000)[8]		61		59		11		19
Jones (2008)[3]		42		40				
Burger (2009)[41]								
Jones (2010)[42]	44	35	38	45				
Elgammal (2014)[29]		40		45		15		25
Chaudhry (2016)[43]		36		29				
Kumta (2017)[27]								
Aibinder (2017)[44]		50.8		42.9		16.7		30.3
Kazmers (2018)[45]								
Pulos (2018)[46]	51	37	46	46				
Guzzini (2019)[47]								
Kollitz (2019)[28]								
Totals	**47.5**	**43.1**	**42.0**	**43.8**		**14.2**		**24.8**
	$p = 0.087$		$p = 0.477$					

Table 5 Functional outcome measures

Study	Grip strength (kg)		VAS		DASH score		PRWE score		Mayo Wrist Score	
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
Doi (2000)[8]		33								84
Jones (2008)[3]		44								
Burger (2009)[41]									65.7	79
Jones (2010)[42]										
Elgammal (2014)[29]		38	6	2	40	20				
Chaudhry (2016)[43]										
Kumta (2017)[27]										
Aibinder (2017)[44]		38.9								
Kazmers (2018)[45]										
Pulos (2018)[46]				0.8		8.2		12.5		
Guzzini (2019)[47]			7.05	1.5					30	90.5
Kollitz (2019)[28]										
Totals		**38.5**	**6.5**	**1.4**	**40.0**	**14.1**		**12.5**	**47.9**	**84.5**
			$p = 0.015$						$p = 0.188$	

Abbreviations: DASH, Disabilities of the Arm, Shoulder and Hand; PRWE, Patient-Rated Wrist Evaluation; VAS, visual analog scale

Table 6 Complications

Complications	Number
Flap-related complications	
Nonunion	27
Scaphoidectomy and four-corner fusion	9
1,2-ICSRA graft	3
Radioscapholunate arthrodesis	2
Scaphotrapeziotrapezoid arthrodesis	1
SLAC	5
Prolonged time to union	2
Heterotopic bone excision	3
Radial styloidectomy	3
Donor site complications	
Superficial donor site infection	4
Knee pain or discomfort	4
Hypertrophic scar	3
Hematoma	1
Deep donor site infection	1
Paresthesia	1
Recipient site complications	
Hypertrophic scar	4
Wrist pain	3
Removal of prominent screw	2
Additional K-wire or plate placement	2
Surgical site infection	1
Other complications	
Loss to follow-up	3
Total	**69**

Abbreviations: ICSRA, intercompartmental supraretinacular artery; SLAC, scapholunate advanced collapse.

no formalized treatment algorithm currently exists. In the context of proximal pole osteonecrosis, nonvascularized bone grafting (NVBG) has had limited success. A meta-analysis comparing vascularized flaps versus NVBG for scaphoid nonunion with AVN demonstrated complete union in only 47% of patients using NVBG compared to 88% when bone with an independent blood supply was used.[4]

Alluri et al[16] evaluated the role of the VBG for scaphoid nonunion. This systematic review examined 1,009 patients undergoing VBG for scaphoid nonunion. VBG demonstrated an 85% radiographic union rate by 13 weeks and showed significant improvements in postoperative ROM scores, reduction in time until return to work, and excellent overall patient satisfaction scores. In a subgroup analysis of 157 patients receiving free VBG reconstruction (including the free MFC flap), there was a 93% union rate over 14 weeks consistent with the present findings. The free VBG demonstrated slightly worse postoperative ROM outcomes compared with pedicled VBG techniques; however, the free VBG demonstrated an 11% higher union rate, which was not deemed statistically significant. All other clinical parameters including radiographic and patient-centered outcomes remained the same between VBG groups.

Osseous flaps offer numerous benefits over their nonvascularized graft counterparts. Although regarded as more technically demanding, osseous flaps allow preservation of osteocytes following transfer, thus creating a favorable environment for bony healing.[17] The intrinsic vascularity of the flap delivers an influx of both osteogenic and angiogenic factors that are fundamental to increasing bony perfusion over time.[18,19] Secondly, the utilization of an osseous flap results in primary bone healing, as opposed to creeping substitution, which is seen with nonvascularized bone grafts, thereby leading to more rapid bone incorporation and, theoretically, an earlier time to union.[20,21] Evidence for quicker revascularization of previously avascular segments of bone has been described in canine models comparing osseous flaps to NVBG for scaphoid nonunion.[22]

Initially described by Sakai et al[5] in 1991 for treatment of nonunion of fractures in the upper extremity, the free MFC flap provides an excellent source of vascularized bone to reconstruct small- to medium-sized osseous defects. The free MFC flap was later adapted by Doi et al[8] as a volar onlay graft for treatment of scaphoid nonunion, and has since seen early success. In our review, reconstruction of scaphoid nonunion using the free MFC flap conveyed a union rate of 93.4%, with a mean time to union of 15.6 weeks.

The MFC flap has several qualities that may be responsible for its success. Firstly, the consistent anatomy of the flap lends itself to a relatively straightforward harvest. The MFC is highly vascularized with a strong periosteal layer that tends to retain its vascularity more reliably after contouring for flap inset, as opposed to the more fragile pedicled grafts that are more readily rendered avascular in graft preparation.[23,24] Numerous anatomical studies have demonstrated both the reliability and robustness of the MFC vasculature.[25,26] A cadaveric study by Yamamoto et al[26] identified the vascular anatomy and supply of the MFC flap. The authors identified the presence of the descending genicular artery in 89% of specimens with a consistent origin on average 13.7 cm proximal to the articular surface of the knee. Moreover, the greatest density of perforators was found to be in the posterior distal quadrant of the condyle, which is incorporated during graft harvest.[26] The superficial location of the medial condyle offers a broad area of graft available for harvest, without altering the articulation of the tibiofemoral joint, or the strength of the femoral shaft.[27] Owing to its versatility, the MFC flap can also be harvested in a number of configurations. When harvested as a corticoperiosteal flap, periosteum incorporating the cambial layer in addition to a thin layer of outer cortical bone is included, delivering robust osteogenic capacity through transfer of osteoblastic cells.[6,8] The corticoperiosteal flap allows for a thin harvest, resulting in a highly pliable graft that readily conforms to the recipient bed. In cases with proximal pole fragmentation or disruption of the articular scaphoid cartilage, an osseocartilaginous MFT flap has been described to effectively reconstruct the proximal pole.[6,7]

Another advantage of the MFC flap is the structural integrity afforded by the bone stock, which can be inset as either an inlay or wedge graft. Patients with both carpal collapse and AVN of the proximal pole of the scaphoid require restoration of normal scaphoid geometry to optimize union.[28] For these cases, harvest of a corticocancellous MFC flap provides the ability to correct any preexisting scaphoid deformity, thus restoring carpal alignment and biomechanics. This review demonstrates that key carpal indices including the scapholunate, radiolunate, lateral interscaphoid angles, and revised carpal height ratio were significantly improved following utilization of the MFC flap for scaphoid nonunion. Furthermore, despite a subset of patients with poor prognostic factors (including carpal collapse, AVN, or previous failed nonunion surgery), the MFC flap achieved excellent union rates. Restoring vascular supply in the setting of AVN and the importance of correcting scaphoid humpback deformity have been well established in the literature.[3,29] Our study demonstrates that the MFC flap achieves both tasks by providing structural support to correct deformity and ample blood supply to promote union in a difficult subset of scaphoid nonunion patients.

A systematic review of MFC donor site morbidity by Giladi et al[30] has shown the postoperative morbidity of the MFC harvest to be excellent. The results of our study support these findings, with minimal donor and recipient site morbidity reported within the included studies. The most common donor site complaints included superficial wound infection, persisting knee pain or discomfort, and paresthesias, none of which required further operative intervention. No major donor site complications including femoral fracture, knee stiffness, instability, loss of motion, or development of osteoarthritis were described in the series. To date, there have been three reports in the literature of iatrogenic femoral fracture following MFC harvest.[31–33] Although a bone harvest greater than 7 cm in length has been shown to affect torsional strength of the femur in a cadaveric model,[34] the clinical relevance of this finding is unclear. Other biomechanical models have demonstrated the femur retains axial stability (parameters including both deformation and stiffness) when subjected to a supraphysiological load despite harvest of large corticocancellous flaps of up to 15 cm in length.[35] In an attempt to avoid the high morbidity associated with iatrogenic femur fracture, several principles during harvest should be adhered to. The MFC harvest should be limited to the medial cortex without disrupting the anterior or posterior surfaces.[30,31] Giladi et al[30] also advocates for limiting the proximal dissection to the metaphysis, without inclusion of the thicker diaphyseal bone. Limiting depth of harvest must be taken into account as excess of cancellous bone may undermine subchondral stability.[32] Furthermore, consideration of patient factors including osteoporosis, obesity, or prior surgery to the harvest site should influence operative decision-making. In reconstructive cases requiring significantly large amounts of bone stock, use of other conventional vascularized bone flaps such as the fibula[36] and iliac crest[37] may be more appropriate.

There exist several limitations to the indications for a free MFC flap. Previous studies have cautioned the use of the MFC flap only in the context of intact proximal pole of the scaphoid integrity. Authors advocate that the MFC flap should only be used when the proximal pole of the scaphoid is of adequate size for bony fixation (either by headless compression screw or K-wire fixation), possesses an intact cartilaginous shell, and is free from fragmentation.[3,38] It is evident that one of the limitations of the MFC flap is its inherent structural limitations in precisely replacing the articular surface of highly proximal pole scaphoid fractures. If the characteristics of the proximal pole of the scaphoid are beyond the previous indications, a free MFT flap should be considered. Although most studies included for analysis in this review examined reconstruction of proximal pole scaphoid nonunion, no articles described replacement of the entire proximal pole of the scaphoid with an MFT flap. An explanation for this is likely due to authors utilizing the MFC flap for reconstruction of an intercalary bone defect in the proximal scaphoid with adequate bone and cartilaginous integrity.

While no microvascular failures were reported, clinical assessment of microvascular success throughout the included studies was variable and, in some instances, unclear. Doi et al[8] utilized harvest of an osteofasciocutaneous MFC flap with inclusion of a skin paddle for postoperative flap monitoring. Although four out of six skin island flaps survived (the two failures were debrided), osseous take and subsequent union remained at 100%. Thus, it is uncertain as to the utility of harvesting a separate skin paddle for monitoring, and whether this improves overall outcomes. Inclusion of a separate monitoring skin flap may unnecessarily add operating time, especially in cases of a tedious dissection. Thus, it is uncertain whether the vascularity is indeed maintained, and rather the structural benefits of the MFC flap and debridement of the nonunion site, coupled with adequate internal fixation, may be sufficient to provide union in these challenging cases. The more likely scenario is that the MFC flap undergoes bony union despite microvascular failure.

This review is constrained by several limitations. The studies included for analyses were entirely retrospective in nature with comparatively small patient cohorts, limiting both power and generalizability of our results. Studies were further limited by an incompleteness or paucity of data with regard to function wrist outcomes and ROM outcomes. While most articles reported postoperative functional outcomes, very few included preoperative baseline measurements, precluding meaningful comparison and analyses. Additionally, while reporting of complications was largely complete, a small number of studies had unextractable complication data preventing complete documentation of postoperative complications. It is also important to highlight that the mean follow-up duration in our review was only 1.5 years, and a longer period would be recommended to identify critical degenerative or arthritic changes.[39] Further studies examining MFC graft outcomes should take into consideration the importance of donor site morbidity. Applying validated knee-specific patient-reported outcome tools, such as the International Knee Documentation Committee subjective knee evaluation form,[40] should be considered in future studies to ensure standardization of measurement.

Conclusion

This study confirms that the MFC flap provides a reliable and versatile option for reconstruction of scaphoid nonunions, restoring scaphoid vascularity and carpal alignment. Furthermore, the MFC flap has shown consistency in promoting successful healing for difficult cases of proximal pole AVN, carpal collapse, and prior failed operative surgery. Although donor site morbidity is low, as with all reconstructive surgical options, careful consideration of both the risks and benefits of the procedure must be discussed with the patient to ensure suitable expectations. While the results of this review are encouraging, longer-term follow-up with larger, prospectively designed studies are needed to assess the lasting efficacy of the MFC graft for scaphoid nonunion.

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