JOURNAL OF PLASTIC SURGERY AND HAND SURGERY
2024, VOL. 59, 24–31
https://doi.org/10.2340/jphs.v59.12435

REVIEW ARTICLE

The first dorsal metacarpal artery flaps versus reverse homodigital dorsal flaps for thumb reconstruction: a systematic review and meta-analysis

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ABSTRACT

Purpose: This review was performed to systematically compare the effectiveness and safety of the first dorsal metacarpal artery flaps (FDMAF) and reverse homodigital dorsal flaps (RHDF) for thumb reconstruction.

Methods: All literatures, which compared FDMAF versus RHDF for thumb reconstruction, were acquired through a comprehensive search in multiple databases from inception until 31st August 2022. A meta-analysis was performed using the Cochrane Collaboration's RevMan 5.4 software.

Results: A total of 19 articles were retrieved, comprising 396 patients in the FDMAF group and 423 patients in the RHDF group. The pooled estimates suggested that there were no significant differences in venous congestion, complications about flap necrosis and reduced range of motion (ROM) of thumb, static 2-point discrimination (S-2PD) between the two groups. On the other hand, patients in the RHDF group had less vascular crisis (odds ratio [OR] = 3.15, 95%CI, 1.31–7.56), complications about poor cortical reorientation (OR = 440.02, 95%CI, 91.97–2105.27) and higher satisfaction rate (OR = 0.56, 95% CI, 0.33–0.96) than those in the FDMAF group.

Conclusions: The two surgical procedures were both safe and reliable since no significant differences were found in flap necrosis between the two groups. However, the patients in the RHDF group had less complications about vascular crisis, poor cortical reorientation and higher satisfaction rate. Accordingly, we thought RHDF may be more superior for thumb reconstruction than FDMAF.

ARTICLE HISTORY
Received 3 May 2023
Accepted 21 January 2024

KEYWORDS
Thumb defects; thumb reconstruction; the first dorsal metacarpal artery flaps; reverse homodigital dorsal flaps; meta-analysis

Introduction

Traumatic soft tissue defects of the thumb with exposure of tendons, nerves, or bone are commonly encountered in modern industrial society. It significantly affects the work and life of these patients. Ideal reconstruction for thumb should not only preserve digit length but also provide an esthetically acceptable appearance as well as sensate coverage [1,2]. Several surgical options, including skin grafting, local, regional or free flaps are available. Procedure of skin grafting is easy but grafting over exposed bone commonly results in an unstable closure and is prone to be worn down [3]. Local flaps offer superior esthetic results due to replacement 'like with like' tissue. However, it is only suitable for small defects and the arc of rotation is limited [4]. Abdominal, cross-finger, and cross-arm flaps were commonly used in the past but require two-stage procedures [5–7]. Littler's neurovascular island flaps, harvested from the distal ulnar aspect of the middle or ring finger, represent a classic and reliable solution for thumb reconstruction. However, the sacrifice of one main digital artery of the donor finger and postoperative incomplete cortical reorientation are often unavoidable [8,9]. The application of free sensate flaps from the toe can provide both good sensation and appearance for thumb reconstruction. Nevertheless, the major disadvantages are that the technique requires ultramicrosurgical experiences and facilities, prolonged operation, and has a high risk of total flap loss [10–12].

Currently, the first dorsal metacarpal artery flaps (FDMAF) are widely performed for thumb reconstruction. Hilgenfeldt [13] firstly described the FDMAF in 1961 and Hollevich [14] refined it as a peninsular flap with preservation of the skin over the pedicle in 1963. Subsequently, Foucher and Braun [15] modified a sensate skin island flap harvested from the dorsum of the index finger based on the first dorsal metacarpal artery in 1979. Reverse homodigital dorsal flaps (RHDF), including radial or ulnar flaps, are another new option for thumb reconstruction, which have a distal pedicle with reversed blood flow supplied by the dorsal artery of thumb [16–18]. RHDF was firstly described by Moschella [19]. Then, Brunelli first reported the anatomic study of the dorsoulnar flap of the thumb in 1991 [20] and carried out the flaps for clinical application in 1993 [21]. Although some scholars had compared the effectiveness and safety of FDMAF versus RHDF for thumb reconstruction, it remains unclear which surgical technique is better. Therefore, this meta-analysis was the firstly performed to integrate more reliable evidence to comprehensively compare the two different surgical techniques.

Materials and methods

This study is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [22] and Assessing the methodological quality of systematic reviews (AMSTAR) guidelines [23].

Search strategy

All studies that compared FDMAF versus RHDF to treat thumb defects published in English or Chinese were electronically retrieved from PubMed, Cochrane databases, Web of Science, MEDLINE, BIOSIS, Wan

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Fang and CNKI EMBASE. The reference lists in the selected studies were manually screened by the authors. The combinations of the following keywords were used during retrieval: ('thumb tip defects' OR 'thumb pulp defects') and ('first dorsal metacarpal artery flaps' OR 'Foucher flaps' OR 'kite flaps' OR 'index finger dorsal island flaps') and ('reverse dorsal homodigital island flaps' OR 'reverse homodigital dorsoradial flaps' OR 'reverse homodigital dorsoulnar flaps' OR 'Brunelli flaps').

Inclusion criteria

Articles were included based on the following criteria: (1) patients with thumb tip or pulp defects; (2) studies that compared FDMAF versus RHDF for thumb reconstruction; (3) randomized or non-randomized controlled clinical studies; (4) minimum sample size of five cases and a follow-up period of 6 months.

Exclusion criteria

Studies were excluded if they met one of the following criteria: (1) patients less than 16 years old or over 60 years old; (2) injured thumb with history of trauma, chronic dermal lesions, or combined with infection, tumour, deformity, osteoporosis or rheumatoid arthritis; (3) studies without valid data; (4) duplicate studies, conference abstracts, review articles, case reports, biomechanical and cadaveric studies.

Data extraction and management

The following data were collected from each study using a standardized form by YJ Huang and Y Shen independently: (1) author and publication year; (2) study design; (3) characteristics of the patients regarding age, gender; (4) sample size; (5) follow-up time; (6) The outcomes pooled in this analysis included postoperative vascular crisis (including arterial crisis and venous congestion), postoperative venous congestion, complications about flap necrosis, reduced range of motion (ROM) of thumb, poor cortical reorientation, static 2-point discrimination (S-2PD) and satisfaction rate at the final follow-up. Since the follow-up duration of included studies was inconsistent, which was at least 6 months, data at the final follow-up were used for comparison. Disagreements were resolved by other referees (K Wu and HF Shi).

Risk of bias assessment

The randomized controlled trials (RCTs) were assessed based on the Cochrane Back Review Group (CBRG) [24]. If the study met at least 6 of the 11 criteria, the study was regarded as low risk of bias (RoB), otherwise it was labeled as high RoB. In contrast, the RoB of non-RCTs were assessed according to the Newcastle Ottawa Quality Assessment Scale (NOQAS) [25]. A maximum of nine points is allocated for quality of selection (four points), comparability (two points), exposure (three points), or outcome of study participants (three points). If the study met at least five points out of the nine criteria, the study was considered as low RoB, otherwise it was labeled as high RoB. All studies were categorized as low risk for selection bias. The performance bias was rated as having a high risk since blinding was not feasible during the selection of the surgical approach.

Statistical analysis

The statistical analysis was performed by the RevMan 5.4 software (Cochrane IMS). If data were missing from published studies, we tried to contact corresponding authors for original data via email. The acquired data were expressed in terms of odds ratio (OR) and 95% confidence interval (95% CI) for dichotomous outcomes, while mean difference (MD) and 95%CI for continuous outcomes. Standardized mean difference (SMD) and 95% CI were calculated when the same continuous outcomes were measured in different scales. Heterogeneity was estimated by the I^2 statistic. If the value of $I^2 > 50\%$, a Random-Effects Model (REM) was employed; the source of heterogeneity was measured by subgroup analysis and/or sensitivity analysis. The sensitivity analysis was performed to identify individual study effects on pooled results. Conversely, a Fixed-Effects Model (FEM) was applied. A $p < 0.05$ indicated statistical significance in the integration results. Publication bias of outcomes was assessed and treated using standard methodology. The funnel plots were used to analyze publication bias [26].

Results

Search results and characteristics of the included studies

The detailed search process and relevant results are shown in Figure 1. A total of 19 articles [27–45] included 5 RCTs [24,32–34,45], 13

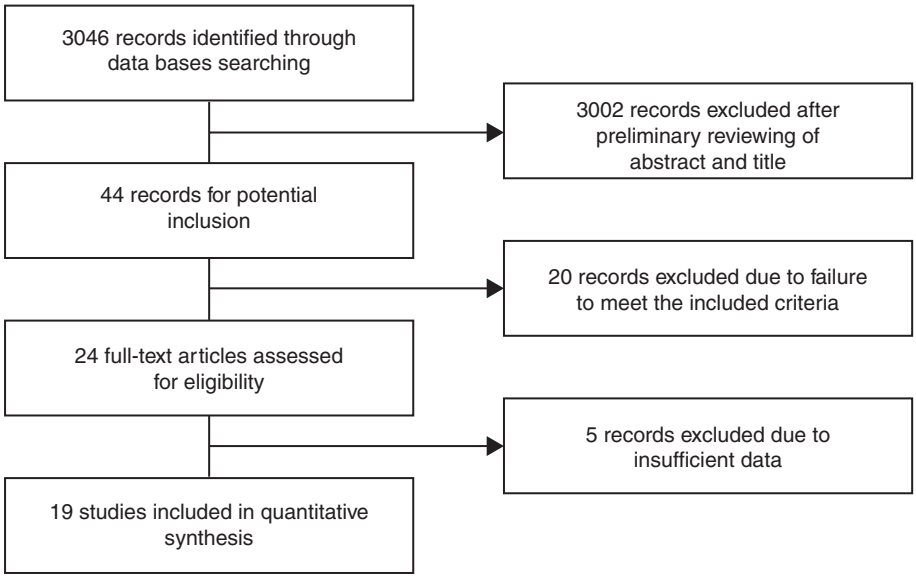

Figure 1. The initial search process and relevant included results.

nonrandomized prospective cohort studies [27,29–31,35–41,43,44] and 1 retrospective study [42]. All studies were conducted in China, comprising 396 patients in the FDMAF group and 423 patients in the RHDF group. The concrete characteristics of the included studies are summarized in Table 1.

Study quality assessment

The methodological quality of 5 RCTs had low RoB with scores of 6–7 according to the CBRG. During methodological quality assessment according to NOQAS, 3 non-RCTs had low RoB, 7 non-RCTs had moderate RoB, and the remaining 4 studies had high RoB (Table 2). Overall, the RoB in this study was moderate to high.

Table 2. Quality assessment according to the Newcastle–Ottawa scale of the non-randomized studies.

Study ID	Selection	Comparability	Exposure	Total score
HJ Sun 2018	3	1	2	6
HF Shi 2013	4	1	2	7
T Feng 2013	2	1	1	4
Q Fu 2008	2	0	2	4
AM Liu 2108	4	2	2	8
JM Li 2010	3	1	2	6
ML Feng 2010	4	1	2	7
HS Dong 2103	3	1	1	5
XF Wang 2007	3	0	2	5
BZ Yu 2011	2	0	2	4
B Feng 2012	3	1	2	6
XP Wu 2016	2	1	1	4
WQ Li 2004	3	1	1	5
W Wang 2020	2	1	2	5

Meta-analysis results

Vascular crisis

A total of 8 articles [28–31,35,36,41,44] reported postoperative vascular crisis, which included 178 cases in the FDMAF group and 235 cases in the RHDF group. The pooled results showed that no significant heterogeneity was detected from these trials (I^2 = 0%, p = 0.84) and an FEM was applied. The pooled estimates revealed that significant difference was found between the two surgical groups (OR = 3.15, 95% CI, 1.31–7.56, p = 0.01) (Figure 2).

Venous congestion

Venous congestion was especially reported in 6 articles [29,31,35,36,41,44], which enrolled 106 patients in the FDMAF group and 150 patients in the RHDF group. The pooled estimates suggested no significant heterogeneity (I^2 = 0%, p = 0.74) and no significant difference was found between the two surgical groups (OR = 1.34, 95% CI, 0.42–4.26) (Figure 3).

Flap necrosis

A total of 13 studies [28–30,34–41,42,45] reported total or partial flap necrosis after operation, including 273 cases in the FDMAF group and 312 cases in the RHDF group. The pooled estimates revealed no heterogeneity (I^2 = 1%, p = 0.44) and no significant difference was observed between the two groups (OR = 0.85, 95% CI, 0.42–1.73) (Figure 4).

Reduced ROM of thumb

Only 3 studies [28,29,31], including 67 cases in the FDMAF group and 95 cases in the RHDF group, discussed the reduced ROM of injured thumbs over that of contralateral side. Significant heterogeneity (I^2 = 85%, p = 0.001) was detected and a REM was adopted. The pooled effect size was not statistically significant for the outcome measures (OR = 1.04, 95% CI, 0.03–37.45) (Figure 5). Sensitivity analysis was performed and no study was found significantly influenced the results.

Cortical reorientation

The complications about poor cortical reorientation were reported in 4 articles [28–30,36], which enrolled 122 cases in the FDMAF group and 148 cases in the RHDF group. No significant heterogeneity existed among the studies (I^2 = 0%, p = 0.78). On pooled analysis, there were significant differences between the two groups (OR = 440.02, 95% CI, 91.97–2105.21, p < 0.00001) (Figure 6).

Table 1. The concrete characteristics of the included studies.

Study ID	Study design	Case		Sex (M/F*)		Age (year)		Follow-up (months)
		FDMAF	RHDF	FDMAF	RHDF	FDMAF	RHDF	
HJ Sun 2018	PCS*	15	15	UA*	UA	UA	UA	18~36
YQ Zheng 2010	RCT*	35	47	27/8	38/9	21–48	22–52	6~15
HF Shi 2013	PCS	25	33	19/6	27/6	UA	UA	6~18
T Feng 2013	PCS	37	38	23/14	22/16	26.8±4.2	27.4±4.7	12~24
Q Fu 2008	PCS	7	15	UA	UA	UA	UA	6~12
GR Cai 2014	RCT	25	20	UA	UA	UA	UA	13~15
ZX Liu 2009	RCT	27	21	UA	UA	19~57	19~57	15.7
P Gao 2014	RCT	8	10	UA	UA	21~45	21~45	11~32
AM Liu 2108	PCS	12	24	UA	UA	UA	UA	6
JM Li 2010	PCS	25	30	UA	UA	16~59	16~59	6~40
ML Feng 2010	PCS	18	5	UA	UA	19~51	19~51	6~108
HS Dong 2013	PCS	13	7	UA	UA	17~59	17~59	6~24
XF Wang 2007	PCS	20	20	UA	UA	30±7.6	30±7.6	6~24
BZ Yu 2011	PCS	10	10	UA	UA	30±7.8	30±7.8	5~24
B Feng 2012	PCS	7	18	UA	UA	16~49	16~49	6~36
XP Wu 2016	RCS*	48	50	29/19	30/20	UA	UA	UA
WQ Li 2004	PCS	14	15	UA	UA	17~35	17~35	6~36
W Wang 2020	PCS	30	30	18/12	17/13	36.2±4.1	35.5±3.6	6
HB Tang 2010	RCT	20	15	UA	UA	18~50	18~50	6~90

FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps; M/F: male/female; UA: unavailable; PCS: Prospective Cohort Study; RCT: Randomized Controlled Trials; RCS: Retrospective Cohort Study.

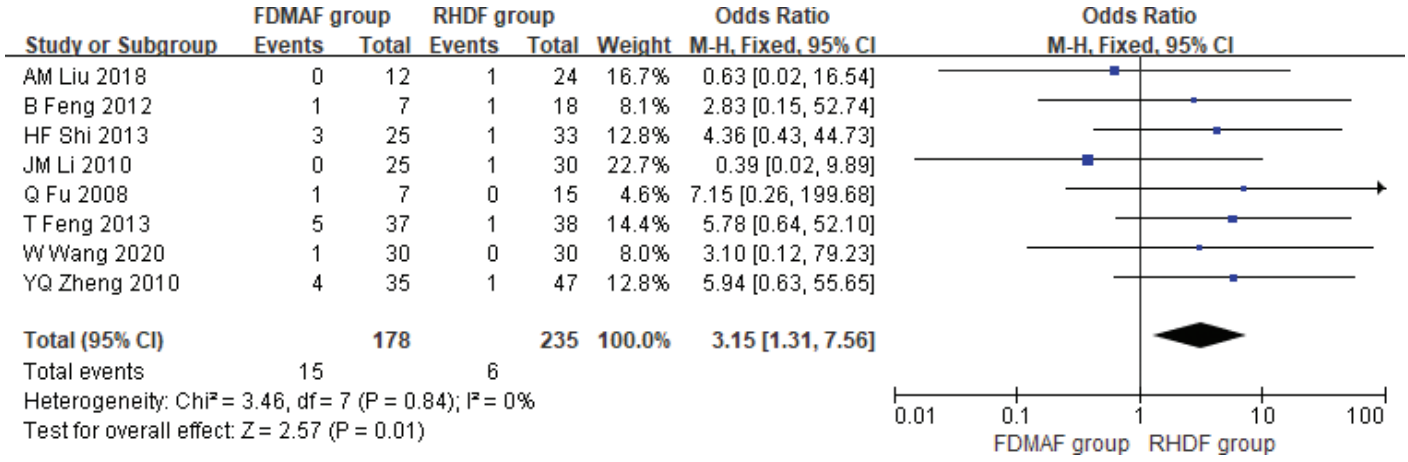

Figure 2. Forest plot comparing the postoperative vascular crisis between FDMAF group versus RHDF group. FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps.

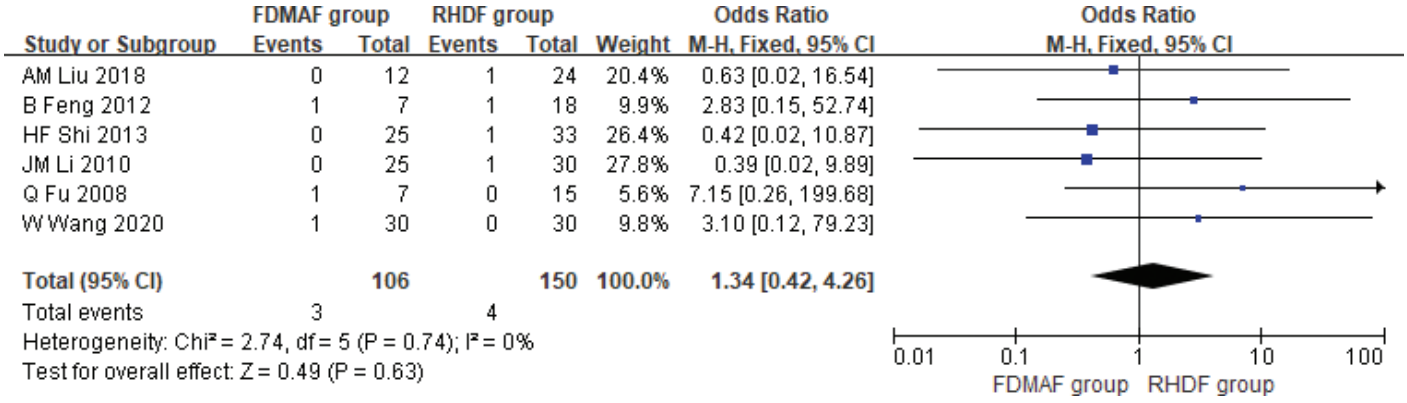

Figure 3. Forest plot comparing the postoperative venous congestion between FDMAF group versus RHDF group. FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps.

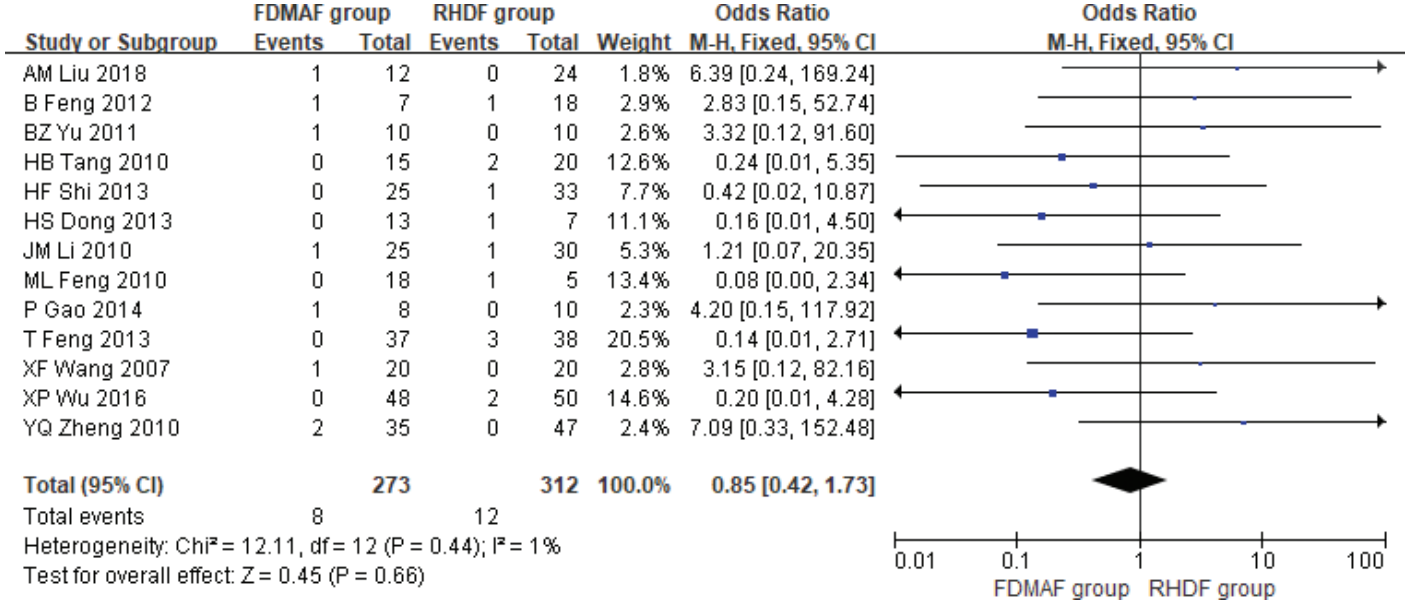

Figure 4. Forest plot comparing the complications about flap necrosis between FDMAF group versus RHDF group at the final follow-up. FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps.

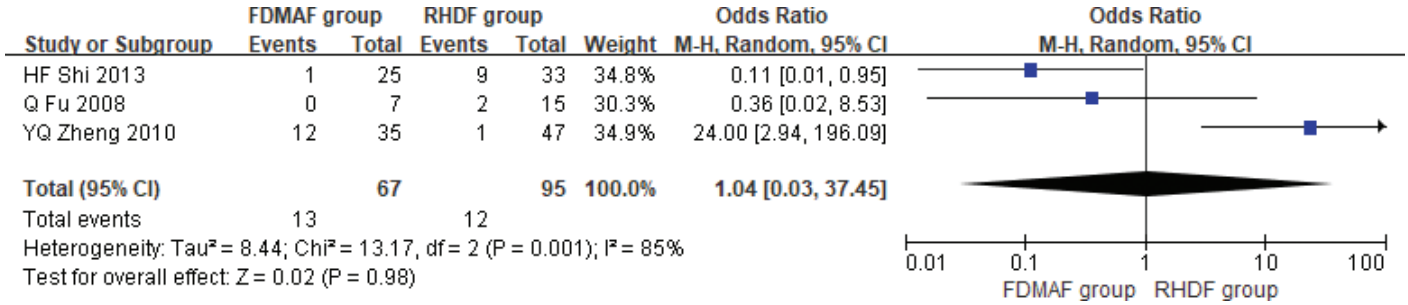

Figure 5. Forest plot comparing the complications about reduced range of motion of thumb between FDMAF group versus RHDF group at the final follow-up. FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps.

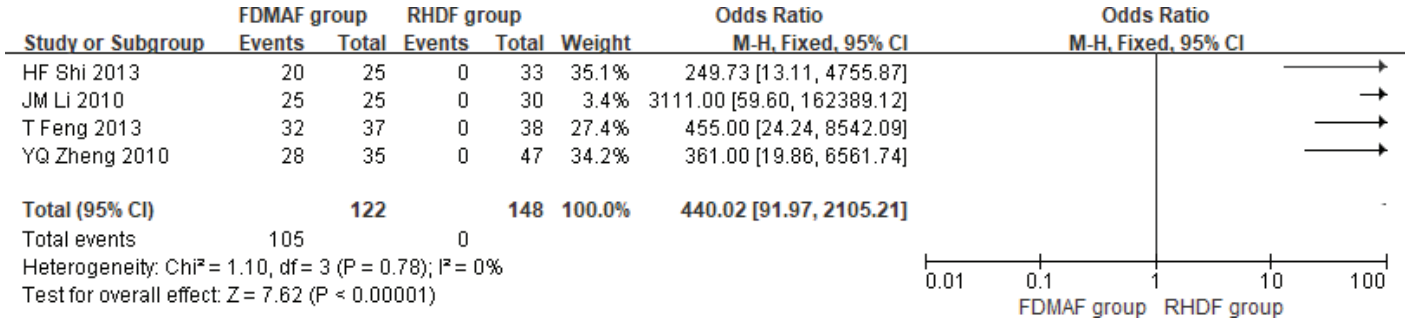

Figure 6. Forest plot comparing the complications about poor cortical reorientation between FDMAF group versus RHDF group at the final follow-up. FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps.

Static 2-point discrimination

Data related to S-2PD at the final follow-up were available in 8 trials [27,30,32,39,40,42–44], which included 199 patients in the FDMAF group and 198 patients in the RHDF group. Significant heterogeneity ($I^2 = 92\%$; $p < 0.00001$) was detected among the trails. After a REM was applied, the pooled results showed that the patients in the FDMAF group had no better S-2PD than those in the RHDF group (MD = −0.41, 95% CI, −1.22–0.40). What's more, subgroup analysis was performed based on the patients in the FDMAF group treated with or without neurorrhaphy. The pooled results showed the patients in the FDMAF group whether treated with neurorrhaphy or not, there was no significant difference in S-2PD between the two procedures (Figure 7).

Satisfaction rate

Satisfaction rate at the final follow-up was discussed in 6 studies [30,32,34,42,44,45], which enrolled 168 patients in the FDMAF group and 163 patients in the RHDF group. No significant heterogeneity existed among the studies ($I^2 = 0\%$, $p = 0.56$) and the pooled estimates suggested the patients in the RHDF group had higher satisfaction rate than those in the FDMAF group (OR = 0.56, 95% CI, 0.33–0.96, $p = 0.03$) (Figure 8).

Discussion

The first dorsal metacarpal artery (FDMA) originates from the radial artery after it has crossed the anatomical snuffbox, just distal to the extensor pollicis longus tendon. The artery runs over the fascia and it gives off three terminal branches: a radial branch to the thumb, an intermediate branch to the first web space, and an ulnar branch to the index finger [46,47]. In addition, the superficial branch of the radial nerve divides into four or five dorsal digital nerves. It provides branches to the skin of the radial dorsum of the hand to innervate the dorsum of the thumb, index, and middle phalanx of the third finger [48]. The FDMAF (also called kite flaps) harvested from the dorsum of the proximal phalanx of the index finger was firstly described and designed by Foucher and Braun [15]. It raises on a neurovascular pedicle including the FDMA with its concomitant veins and a branch of the superficial radial nerve. The flap has a wide arc of rotation and easily reaches to the palmar, radial aspects or the pulp of the thumb. It is a reliable alternative for thumb reconstruction as this procedure is a time-saving, one-stage operation and the rich blood supply ensures the survival rates of the flaps [49,50]. Eski [51] described the use of the FDMAF in thumb deformities after burns and the patients achieved satisfactory function and esthetic recovery after 3-year follow-up. Furthermore, El-Khatib [52] devised an extended version of the FDMAF for reconstruction of combined palmar and dorsal thumb defects in five patients; the survival rate of flaps was excellent in all cases.

Brunelli [20] studied the dorsal arterial supply of the thumb in fresh cadavers and found a constant and independent vascular axis, especially on the ulnar side, which originated from the radial artery. Zancolli [53] found this axis communicated at the level of the middle third of the proximal phalanx with the arterial palmar circuit, allowing the mobilization of a dorsal metacarpal skin flap. Based on the anatomical studies, RHDF including reverse homodigital dorsoradial flaps and reverse homodigital dorsoulnar flaps (also called Brunelli flap) are designed and applied for thumb reconstruction. RHDF has advantages including good esthetics, elasticity of the flaps, the simplicity of surgical techniques, and satisfactory sensibility [54,55]. Terán [56] reported successful use of reverse homodigital dorsoulnar flaps for thumb reconstruction in 15 consecutive patients and all flaps achieved satisfactory recovery without major complications. Moschella [57] reported 16 consecutive patients treated by reverse homodigital dorsoradial flaps for repairing distal defects of the thumbs; the results were good in terms of esthetical appearance as

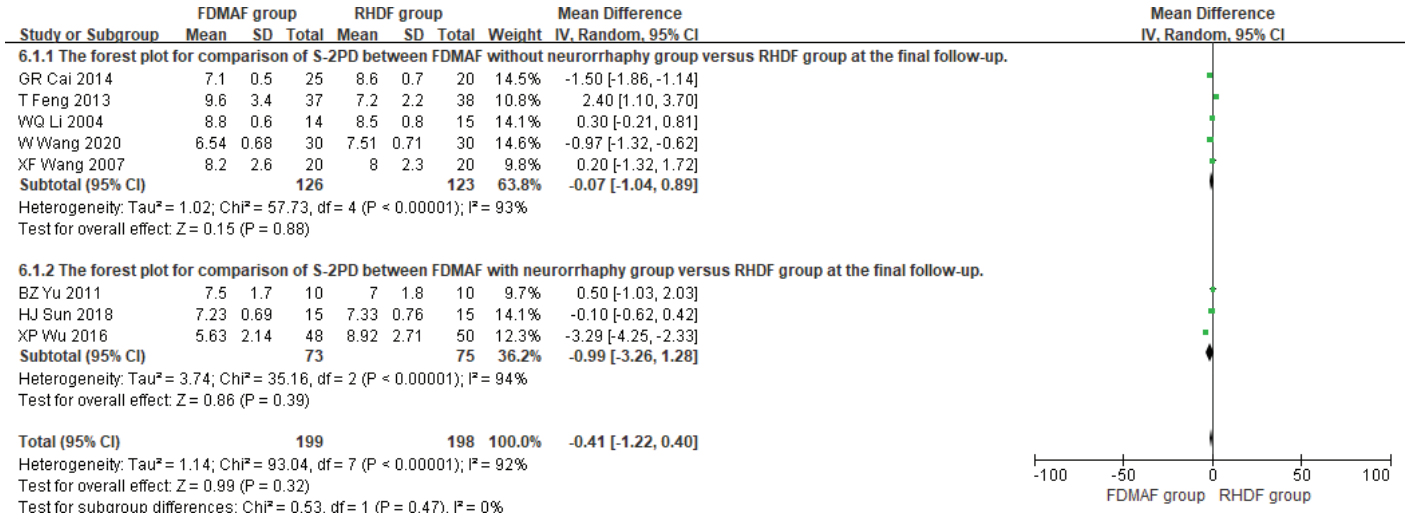

Figure 7. Forest plot comparing S-2PD between first dorsal metacarpal artery flaps (FDMAF) group versus reverse homodigital dorsal flaps (RHDF) group at the final follow-up. (A) Forest plot comparing S-2PD between FDMAF without neurorrhaphy group versus RHDF group at the final follow-up. (B) Forest plot comparing the S-2PD between FDMAF with neurorrhaphy group versus RHDF group at the final follow-up.

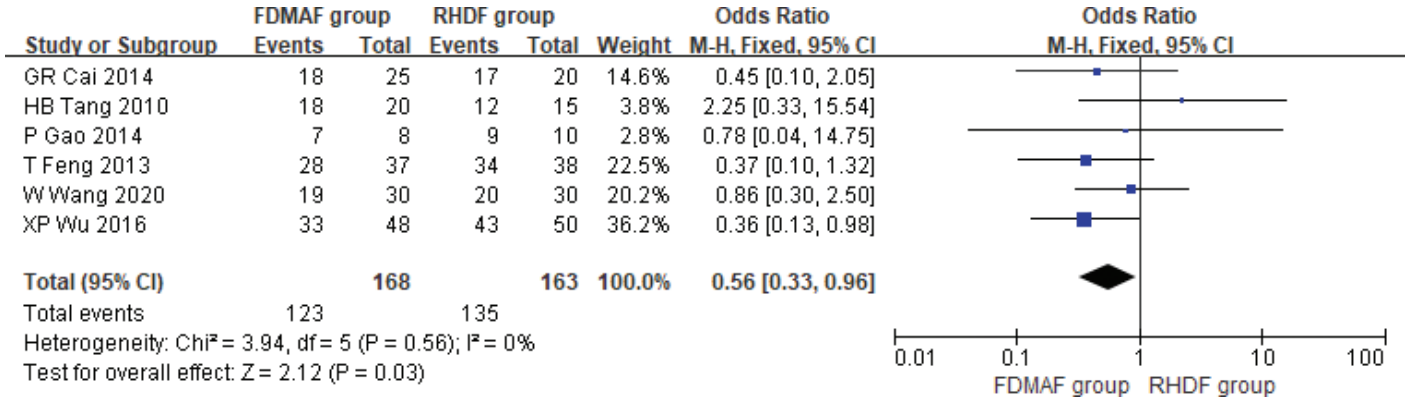

Figure 8. Forest plot comparing satisfaction rate between FDMAF group versus RHDF group at the final follow-up. FDMAF: first dorsal metacarpal artery flaps; RHDF: reverse homodigital dorsal flaps

well as sensate coverage. However, it should be borne in mind that any operation has limitations and flaws. Some Chinese scholars had compared the two surgical procedures for thumb reconstruction and expected to provide evidence-based basis for clinical decision-making and prediction. However, the controversy had been continuing for no procedure was perfect. Meta-analysis has been recognized as an effective method to resolve a wide variety of clinical questions by summarizing and reviewing published quantitative studies. Consequently, this meta-analysis was performed to comprehensively examine the effectiveness and applicability of the two surgical techniques.

Based on the above results in this study, the patients in the FDMAF group have a higher incidence of vascular crisis than those in the RHDF group despite the blood supply of FDMAF is theoretically more reliable. We speculate that the subcutaneous tunnels of FDMAF are longer and tended to be too narrow and compress the neurovascular pedicles of flaps. Interestingly, there is no difference in flap necrosis between FDMAF and RHDF, although significant difference about vascular crisis is observed between the two groups. We consider these flaps are small local flaps and flap necrosis could be reduced or avoided by some conservative treatments or surgical exploration after vascular crisis. Moreover, there is no significant differences in venous congestion between the two groups. We conjecture that the surgeons had given more attention to the problems and thus reduced the incidence of venous congestion. Partial or total flap necroses are rare and no significant differences are observed between the two groups. The results suggest that both the surgical procedures are safe and reliable for thumb reconstruction. The two procedures both have minor impact on the mobility function of the injured thumbs, because the complications such as reduced ROM of thumb are described only in three included articles, and no significant differences are found. Cortical reorientation is the fact that the brain recognizes a stimulus from the flap area as a stimulus from the thumb but not from the index finger [58]. The phenomenon of incomplete cortical reorientation is only observed in FDMAF group of four studies. Three studies [28–30] reported follow-up time ranging from 6 to 60 months and another study did not provide specific time. Ghoraba [59] that 60% patients who received operation of FDMAF had incomplete cortical reorientation and the least period needed for reorientation was 21 months in his study. Muyldermans [49] suggested it could be corrected surgically with a technique 'de'branchement–re'branchement' described by Foucher [15] if the patients wished. In this study, all innervated dorsal digital nerves were anastomosised with the stump of proper digital nerves in RHDF group. The pooled results reveal that the patients in the FDMAF group whether treated with neurorrhaphy or not, there is no significant differences in S-2PD between the two surgical procedures.

Poor sensory recovery is the common drawback of these two procedures. It had not yet been solved though the modified FDMAF or RHDF with repairing of the cutaneous nerve had been described by some scholars [60,61]. On the other hand, the patients in the RHDF group had higher satisfaction rate than FDMAF group according to the pooled results. Wu [40] proposed that compared to FDMAF, the procedure of RHDF didn't affect the uninjured index finger, which meant less scarring and being more popular with patients.

Limitations of the present study should be acknowledged. First, the absence of high-quality evidence regarding interventions may cause selection bias more easily and more RCTs are required. Besides, there were some inevitable clinical heterogeneity among the studies by confounding variables, such as age, patients' self-assessment or surgeons' skill proficiency and experience. Finally, all included studies were conducted in China in this meta-analysis, emphasizing the need for an international multicenter study.

Conclusion

The two surgical procedures were both safe and reliable for thumb reconstruction, despite more vascular crisis was reported in the FDMAF group. No significant difference with respect to flap necrosis was observed between the two groups. However, the patients in the RHDF group had less complications in terms of cortical reorientation, higher satisfaction rate and equivalent mobility and sensory function compared with FDMAF group. Consequently, we concluded that RHDF may be a better option for thumb reconstruction. Indeed, large sample size and high-quality multicenter research are warranted to increase our findings' robustness.

Disclosure statement

The authors declare that they have no conflict of interest.

Funding

Binhu Medical Expert Team of 'Light of Binhu Program'.

Notes on contributors

Haifeng Shi: Conceptualization; Haifeng Shi: Methodology; Yongjing Huang: Software; Yongjing Huang, Yong Shen: Validation; Yongjing Huang, Ke Wu: Formal analysis; Yongjing Huang, Qian Li: Investigation; Zhihai Zhang: Resources; Yongjing Huang, Yong Shen: Data Curation; Yongjing Huang: Writing – Original Draft; Yongjing Huang, Haifeng Shi, Yong Shen: Writing – Review & Editing; Yongjing Huang, Ke Wu: Writing – Visualization; Haifeng Shi: Writing – Supervision.

Ethical approval

Not applicable. Since this paper is a meta-analysis and does not involve human subjects or animal experiments, ethical approval is not required.

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