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Digital Artery Perforator Flap for Fingers Reconstruction: A Meta-Analysis Study with Clinical Cases

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ABSTRACT

Background: Local perforator flaps represent a new era for resurfacing soft-tissue defects of the hand. They provide durable coverage using flaps harvested from the closed vicinity of the defect. Digital artery perforator flaps [DAPF] have been recently used for finger reconstruction.

Purpose: This meta-analysis study with clinical cases was conducted to reveal the surgical and cosmetic outcomes of DAPF for reconstructing soft-tissue defects of the digits.

Methods: A systematic literature review was executed up to 1 April 2022. All clinical studies that included patients with finger defects and receiving DAPF for resurfacing finger defects were included. The flap survival rate and the rate of DAPF-related complications were evaluated.

Results: The present study included eleven articles comprehending 403 patients with 440 reconstructed finger defects. The rate of flap survival was 93.1% [95CI% 89.7%, 95.5%, $p<0.001$] while the rate of flap congestion was 17.3% [95CI% 6.8%, 37.6%, $p=0.004$]. Furthermore, the rate of flap necrosis was 8.9% [95CI% 5.7%, 13.7%, $P<0.001$] and the rate of superficial epidermolysis was 4.7% [95CI% 0.2%, 10.8%, $P<0.001$].

Conclusion: The DAPF is a reliable procedure for reconstructing soft-tissue defects in the fingers. It provides stable coverage with satisfactory functional and surgical outcomes. It is a convenient addition to the armamentarium for covering soft-tissue defects of the digits.

Keywords: Digital Artery Perforator Flaps; Finger Defects; Finger Reconstruction.

INTRODUCTION

Fingertips and pulps are unique structures for both functionality and cosmesis. The increased frequency of machine injuries, road traffic accidents, and burns is attributed to the high incidence of soft-tissue defects of the digits [1]. These defects resulted in deliberating functional disabilities of the hand. It results in exposed underlying functional structures, loss of unique mechanical properties, and the peerless discriminative sensory functions of the hand [2]. The ideal reconstruction procedure should restore the fingers' sensibility, stability, length, mobility, and strength. This also included preventing joint stiffness and secondary deformity of the nails. These advantages should be maintained while minimizing donor site complications and offering satisfactory cosmetic results [3-5].

Finger reconstruction is demanding in hand surgery and requires durable and versatile flaps. These flaps included local advancement flaps, homo-digital neurovascular island flaps, and heterodigital flaps. Moreover, advancement flaps are applicable for minor defects at the expense of extension of the interphalangeal joints. Cross-finger flap is a two-stage reconstructive option with a limited rotation arc, suitable only for coverage of distal defects. It needed a long period of immobilization, carrying a high risk of joint stiffness [6].

The neurovascular island flaps may provide a suitable option for covering soft-tissue defects of the digits. However, the main digital arteries needed to be sacrificed, resulting in considerable donor site morbidity [7]. The shortcomings of inadequate sensation, flexion contractures, donor site morbidity, and functional impairment represent a unique challenge for plastic surgeons when resurfacing soft-tissue defects of the digits [8-10].

Free flaps may provide convenient options for resurfacing defects of the fingers. However, these procedures necessitate advanced micro-surgical experience, special equipment, and prolonged operative time [11]. Furthermore, harvesting free flaps is time-consuming, not cost-effective, and associated with devastating donor site complications. These disadvantages pointed out the need for feasible and versatile flaps to cover soft-tissue defects of the fingers [12, 13].

Local perforator flaps represent a new era for resurfacing soft-tissue defects of the hand. They provide durable coverage using flaps harvested from the close vicinity of the defect. There is no need to sacrifice the main vessels of the finger. Digital artery perforator flaps [DAPF] have been recently used for finger reconstruction [14, 15].

The flaps are based on the versatility of the branches from the proper digital arteries that arise at the sides of the digits. These perforators traverse the thin facia and adipose tissue, terminating in multiple arterioles in the subdermal layer. Noteworthy, DAPF retains the proper digital arteries, reducing the possible complications caused by significant vascular injury. The perforator can be used as a pivot point, indicating the versatility of DAPF for reconstructing various soft-tissue defects of the fingers [16].

The flaps can be raised as adiposal, extended, or supercharged through the anastomosis between the perforators. DAPF preserves the fingers' length and volume with consistent functional and aesthetic results [17].

The employment of DAPF for covering soft-tissue defects of the fingers has been established. However, the usability of the DAPF for resurfacing fingertips and pulp defects deserved further assessment. This is because of the need for comprehensive clinical studies that could draw firm conclusions for current surgical practice [18]. The need for plastic surgeons to achieve the desired aesthetic results while maintaining reconstructive outcomes imposed the need to reveal the outcomes of DAPF for digits reconstruction [19].

Therefore, this meta-analysis study was conducted to reveal the surgical and cosmetic outcomes of DAPF for resurfacing soft-tissue defects of the digits.

MATERIALS AND METHODS

Our meta-analysis followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [PRISMA] guidelines [20] and the Cochrane Collaboration [21].

Data source

Using the following databases, a thorough search of databases was done up to April 1, 2022: Cochrane Collaboration, PubMed, Google Scholar, Web of Science [ISI], Scops, and EMBASE. The following keywords were used in every possible combination; 'Finger', 'Fingertip', 'Digit', 'Digital', 'Thumb', 'Artery', 'Perforator', 'perforators', 'Flaps', 'Flap', 'DAP', ' The manual search was performed to find all additional articles that were not retrieved throughout the searching of the databases.

Eligibility criteria

All clinical studies that encompassed patients with digit defects and received DAPF for resurfacing finger defects were included. Studies with unextractable data, non-human studies, review articles, guidelines, case reports, editorials, letters, posters, book chapters, and comments were excluded. The screening process was documented using the PRISMA Flowchart.

Data extraction

The following study characteristics were extracted from the included articles: the included studies' title, the first author's second name, study design, publication year, study period, and study region. The baseline patients' demographic characteristics were retrieved, including the sample size, number of affected fingers, age of patients, and gender. The data relating to digits injuries were extracted, including the mechanism of injury, the affected hand, the affected digit, and the geometry of the defect. The information related to surgical techniques was retrieved, including flap design, defect size, donor site closure, and flap size.

Quality Assessment

The quality of the included articles was evaluated using the National Institute of Health [NIH] quality assessment tool [22]. The studies were categorized into good, fair, and bad when the score was <65%, 30-65%, and> 30%.

Statistical Analysis

The flap survival rate and the rate of DAPF-related complications were evaluated by calculating the event rate and 95% CI for each study. This was succeeded by pooling the effect estimates of all articles to evaluate the summary proportion with 95% CI.

The fixed-effect model was implemented when a fixed population effect size was assumed; otherwise, the random-effects model was used. Statistical heterogeneity was evaluated using the Higgins I^2 statistic, at the value of > 50%, and the Cochrane Q [Chi^2 test], at the value of $p < 0.10$ [23].

Publication bias was assumed in the presence of an asymmetrical funnel plot and based on Egger's regression test [P-value <0.10] [24]. Data analysis was performed using Review Manager version 5.4 and Comprehensive Meta-Analysis v3 software [25, 26]. The significance was revealed at the value of P [Probability] < 0.05.

RESULTS

A systematic literature review resulted in a total of 514 articles. Of them, 78 articles were excluded being duplicates, resulting in 436 articles eligible for title, abstract, and full-text screening. The screening process resulted in 13 articles suitable for data extraction, with two articles excluded. A total of eleven articles were included for meta-analysis. The PRISMA Flow chart documents the process of searching databases and screening [Figure 1].

Demographic characteristics of the included studies

The present study included eleven articles comprehending 403 patients with 440 reconstructed finger defects [27-37]. There were eight articles on prospective design, while three articles were retrospective. The average age of the patients ranged from 32 to 56 years. There were 106 patients with avulsion injuries and 109 with crushing injuries. The right hand was affected in 72 patients, while the left was affected in 66 patients.

The thumb was affected in 22 patients, whereby the index finger was injured among 117 patients. Whereas the long finger was injured among 136 patients, the little finger was affected among 27 patients **[Table 1].**

The DAPF was designed as a laterally-based flap within seven articles. The dorsal design was implemented within five articles. The DAPF was used for reconstructing fingertips, volar, pulp, dorsum, and lateral finger defects.

The defect size ranged from 1.3 cm to 3 cm, and the flap size ranged from 1.5 to 3.25 cm. The full-thickness skin graft was used to close primary defects in ten articles. The follow-up period was reported in eight articles ranging from 1 to 62 months. All the included articles showed good quality based on the NIH quality assessment tool **[Table 2]**.

Outcomes of DAPF

Flap Survival

The rate of flap survival was evaluated within nine articles, including 403 patients with DAPF [27, 29-31, 33, 34, 37]. The rate of flap survival was 93.1% [95CI% 89.7%, 95.5%, p<0.001] in the random-effects model [I^2=0%, P=0.472].

There was no evidence of publication bias based on Egger's regression test [intercept= 0.75, P=0.18] and based on the symmetrical distribution of the available studies on the line of no effect **[Figure 2A]**.

Flap Congestion

Seven articles included 342 patients with DAPF and evaluated the risk of flap congestion [27, 29-31, 33, 34, 37]. In the random-effects model [I^2=82.1%, P<0.001], the rate of DAPF congestion was 17.3% [95CI% 6.8%, 37.6%, p=0.004] **[Figure 2B]**.

Cold Intolerance

Five articles included 150 patients with DAPF who reported a rate of cold intolerance [28, 29, 33, 34, 37]. The rate of cold intolerance was 16.7% [95CI% 7.2%, 34.1%, P=0.001] in the random-effects model [I^2=56.23%, P=0.057] **[Figure 2C]**.

Flap Necrosis

The risk of flap necrosis was evaluated within three articles, including 208 patients with DAPF [27, 35, 36]. The rate of flap necrosis was 8.9% [95CI% 5.7%, 13.7%, P<0.001] in the random-effects model [I^2 = 0%, P=0.42] **[Figure 2D].**

Superficial epidermolysis

The risk of superficial epidermolysis was estimated within two articles, including 108 patients with DAPF [29, 33]. The rate of superficial epidermolysis was 4.7% [95CI% 0.2%, 10.8%, P<0.001] in the random-effects model [I^2=0%, P=0.68] **[Figure 3A]**

Hyperpigmented Donor Site

Three studies included 269 patients with DAPF and assessed the risk of hyperpigmented donor sites [27, 29, 31]. The risk of hyperpigmented donor site was 8.2% [95CI% 2.3%, 25.8%, P<0.001] in the random-effects model [I^2=78%, P=0.010]. **[Figure.3B]**

Limited Range of Movement [ROM]

Two articles included 93 patients with DAPF and assessed the risk of limited ROM [27, 29]. The rate of limited ROM after DAPF was 4.6% [95CI% 1.7%, 11.7%, P<0.001] in the random-effects model [I^2=0%, P=0.36].

Case presentation

Male patient, 30 years old, non-diabetic, non-hypertensive, non-smoker, presented with a soft-tissue defect at the tip of the left middle finger due to sharp object injury.

A transverse defect measuring 1.3 cm x 2 cm resulted in the tip of the middle finger with exposed bone and was not associated with other injuries. The flap was designed on the ulnar side of the middle finger.

According to the constant anatomical site of the lateral perforator at the distal interphalangeal joint, the perforator was identified using loupe magnification during dissection.

The DAPF was harvested based on the lateral perforator nearby the vicinity of the defect as propeller based, measuring 1.5 cm x 3 cm. The donor site was closed with STSG, and the viability of the flap was established intra-operatively.

The duration from flap harvesting to insetting was 52 minutes. Three months postoperatively, the flap survived with an acceptable appearance and texture apart from partial loss of the STSG at the donor site.

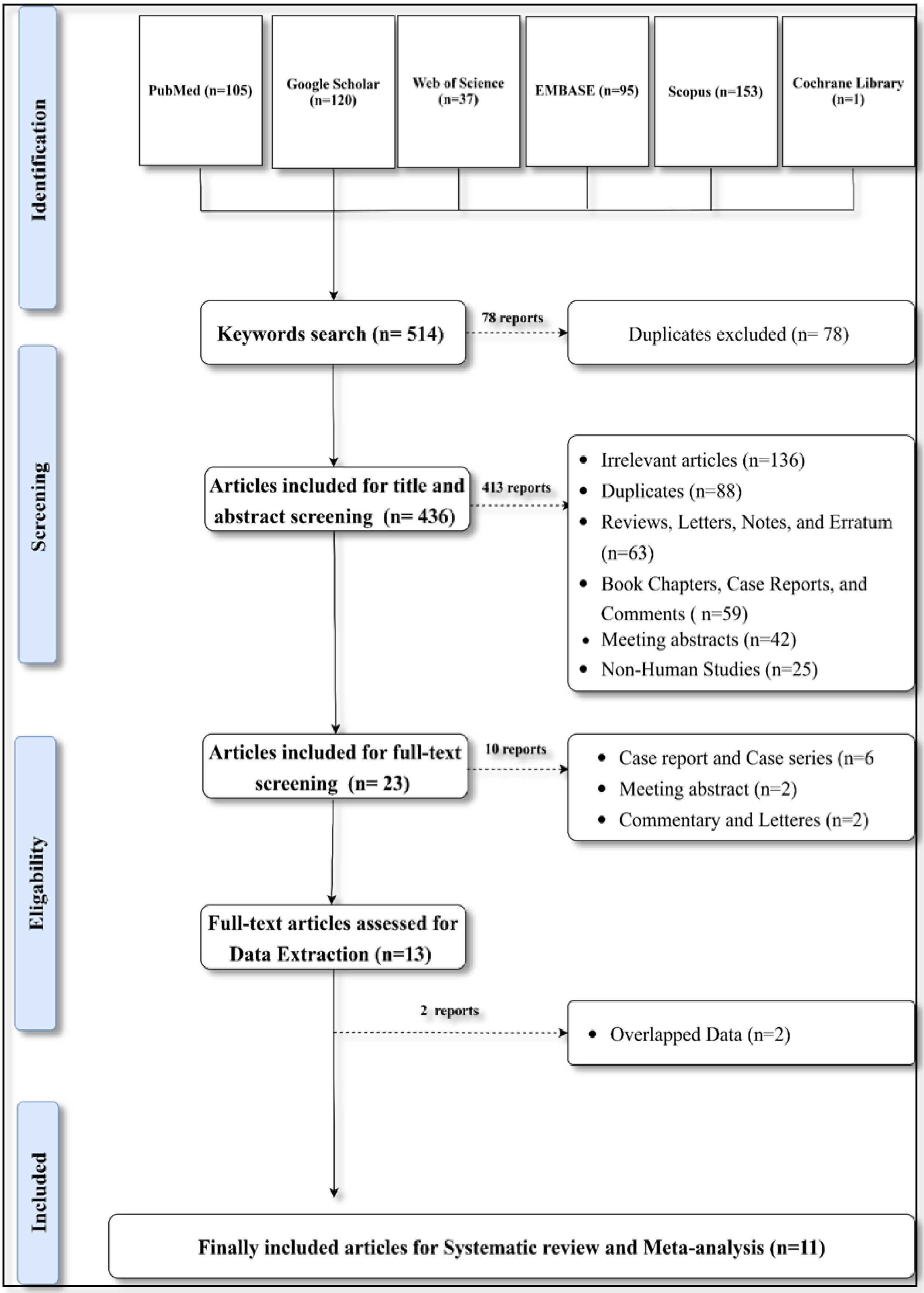

Figure [1]: PRISMA Flow chart showing the process of the literature search, title, abstract, and full text screening, systematic review, and meta-analysis

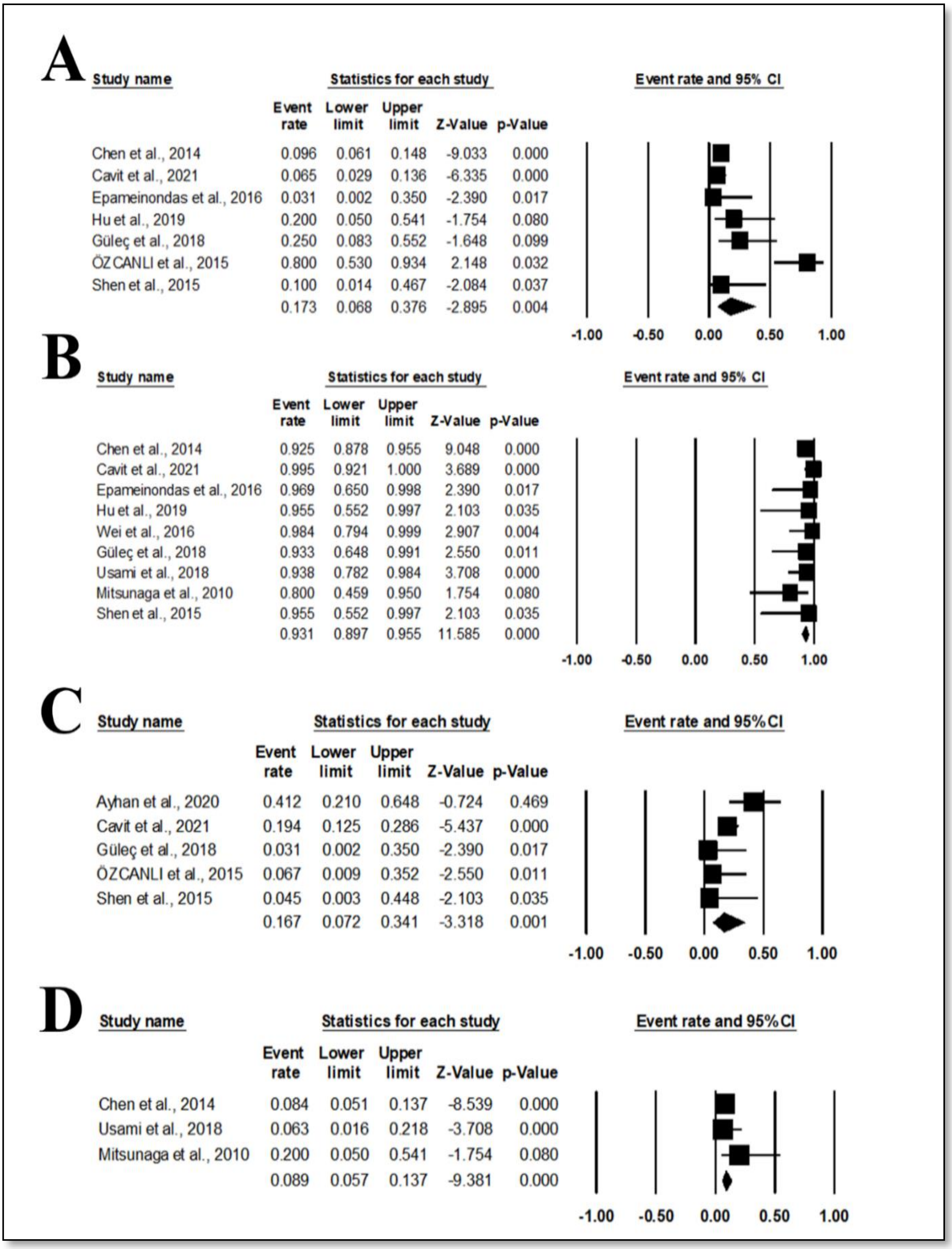

Figure [2]: Forest plot of summary analysis of the event rate and **95**% CI of [**A]** Flap survival rate **[B]** Flap congestion rate **[C]** Cold intolerance rate **[D]** The risk of flap necrosis. Size of the black squares is proportional to the statistical weight of each trial. The grey diamond represents the pooled point estimate. The positioning of both diamonds and squares [along with 95% CIs] beyond the vertical line [unit value] suggests a significant outcome [IV = inverse variance].

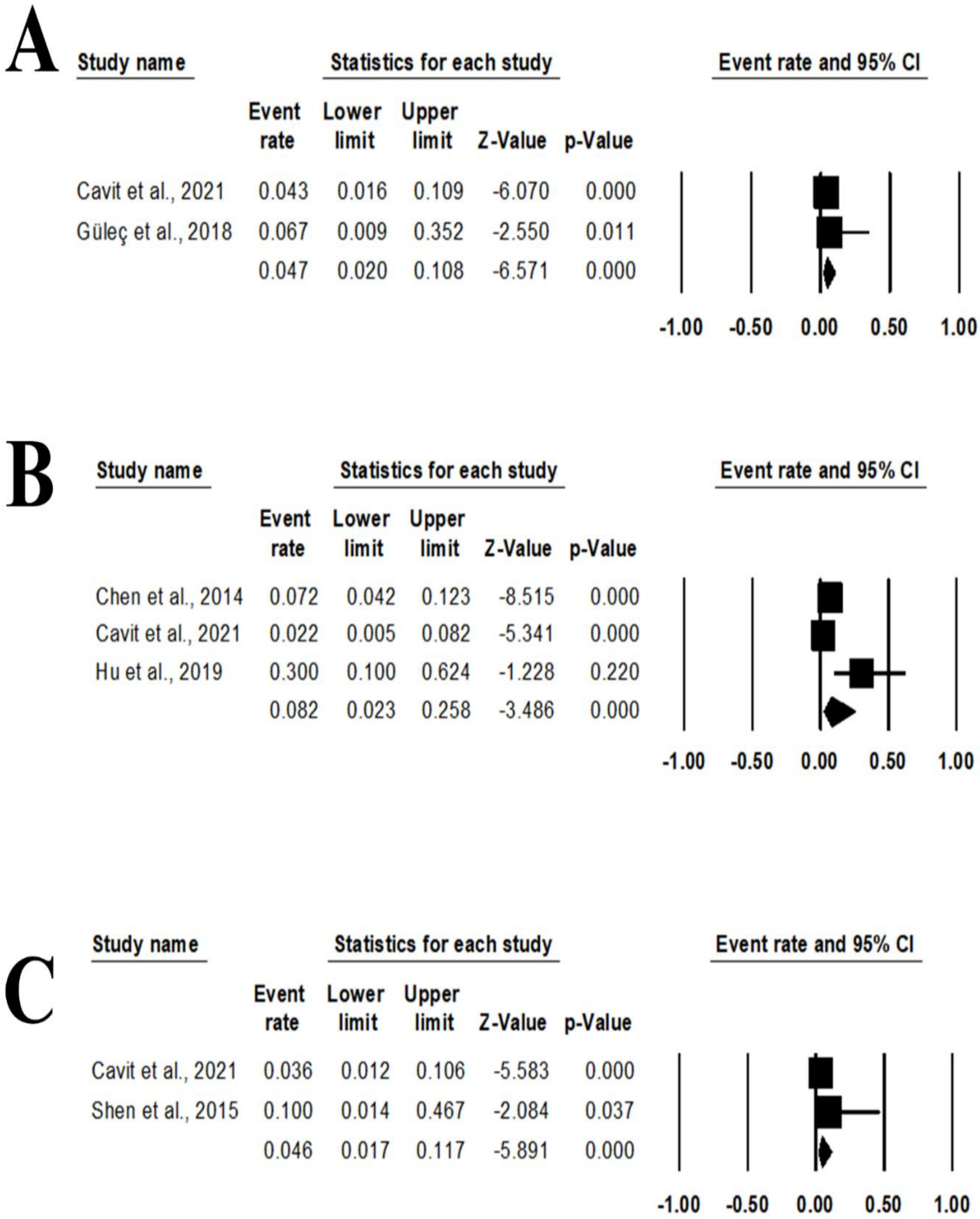

Figure [3]: Forest plot of summary analysis of the event rate and **95**% CI of [**A]** The risk of superficial epidermolysis **[B]** The risk of hyperpigmented donor site **[C]** The risk of limited ROM. Size of the black squares is proportional to the statistical weight of each trial. The grey diamond represents the pooled point estimate. The positioning of both diamonds and squares [along with 95% CIs] beyond the vertical line [unit value] suggests a significant outcome [IV = inverse variance].

Table [1]: Baseline demographic characteristics of the included studies

Study ID		**Study Region**	**Study**	**Registration Number**	**Study Period**	**Number of Patients**	**Number of Fingers**	**Gender**		**Age [Years]**	**Mechanism of Injury**			**Affected Hand**	
								Males	**Females**		**Avulsion**	**crush**	**Cut**	**Right**	**Left**
						n	**n**	**n**	**n**	**Mean±SD**	**n**	**n**	**n**	**n**	**n**
1	**Chen *et al.* [27]**	China	Prospective	NA	2004 to 2009	166	187	135	31	32 [17 to 52]	95	71			
2	**Ayhan *et al.* [28]**	Turkey	Prospective	NA	January 2016 and October 2016	15	17	14	1	47.2±12.9	NR	14	3	NR	NR
3	**Cavit *et al.* [29]**	Turkey	Prospective	NA	August 2011 and October 2016	83	93	70	13	35.2 [5 to 65]	NR	NR	NR	44	39
4	**Epameinondas *et al.* [30]**	Greece	Prospective	NA	November 2012 until March 2014	15	15	7	8	56 [21-77]	NR	NR	NR	9	6
5	**Hu *et al.* [31]**	China	Prospective	ChiCTR1800014588	December 2014 to December 2017	10	10	7	3	NR	1	7	1	6	4
6	**Wei *et al.* [42]**	China	Prospective	NA	February 2011 and December 2013	31	31	21	10	37.8 ± 13.9	10	17	NR	NR	NR
7	**Güleç *et al.* [33]**	Turkey	Prospective	NA	January 2014 and July 2016	15	15	14	1	29.27 ± 10.12	NR	NR	NR	6	9
8	**ÖZCANLI *et al.* [34]**	Turkey	Retrospective	NA	July 2007 and February 2012	15	15	13	2	33 [19 to 56]	NR	NR	NR	7	8
9	**Usami *et al.* [35]**	Japan	Prospective	NA	March 2010 to January 2017	32	32	29	3	51.7 [25–90]	NR	NR	NR	NR	NR
10	**Mitsunaga *et al.* [36]**	Japan	Retrospective	NA	October 1998 to December 2007	11	13	NR	NR	NR	NR	NR	NR	NR	NR
11	**Shen *et al.* [37]**	China	Retrospective	NA	2009 and 2014	10	12	5	5	NR	NR	NR	NR	NR	NR
Abbreviations; NA= Non Applicable, NR=Non-reported, SD=Standard Deviation															

Table [2]: Baseline demographic characteristics of the included studies and quality assessment

Study ID		Injured Finger					Surgical Technique	Flap design	Site of the defect	Donor site closure	Defect Size	Flap Size	Follow Up Period	Quality Assessment	
		Thumb n	Index n	Long n	Ring n	Little n								%	Decision
1	**Chen *et al.*** [27]	NR	56	67	51	13	Dorsal DAP, Dorsal IDAP	Island flap	Volar and dorsal defects of Distal, proximal phalanx, Fingertip	STSG	2.2×1.9 cm	2.4 × 2.1	22 [18 to 27]	76.92%	Good
2	**Ayhan *et al.*** [28]	NR	6	4	4	2	IDAP [lateral]	Rotation, transposition	Fingertip [palmar oblique or transverse fingertip amputations]	FTSG	NR	NR	NR	69.23%	Good
3	**Cavit *et al.*** [29]	12	23	38	16	4	IDAP [lateral]	Rotation	Fingertip [Transverse, Volar oblique, Lateral oblique, Dorsal oblique, Pulp defect]	FTSG	NR	1.6 × 0.7 and 4 × 2 cm	33.1 [12 to 62]	66.66%	Good
4	**Epameinondas *et al.*** [30]	NR	5	3	5	2	Lateral DAP	V-Y advancement or propeller	Dorsal, volar, side either radial or ulnar	FTSG, PC	NR	NR	6.9 [1-18]	66.66%	Good
5	**Hu *et al.*** [31]	6	1	2	1	0	Lateral, Dorsal DAP	Propeller, rotation	Volar, pulp and fingertip defects	FTSG	NR	NR	3 to 12	69.23%	Good
6	**Wei *et al.*** [42]	3	11	8	6	3	Dorsal IDAP	90° rotated island pedicle flap	fingertip defects	FTSG	1.3×1.5 cm to 2.4 cm × 3.0 cm	NR	5.7 ± 0.9	76.92%	Good
7	**Güleç *et al.*** [33]	NR	9	4	1	1	Lateral IDAP	Propeller	fingertip defects	FTSG	2.82 ± 0.93	NR	11.80 ± 8.75	69.23%	Good
8	**Özcanli *et al.*** [34]	1	3	5	4	2	Lateral DAP	Propeller	fingertip defects [Transverse, Volar oblique, Lateral oblique, Dorsal oblique	FTSG	NR	2x1 cm and 2.5x1.5 cm.	22 [range: 7 to 62]	69.23%	Good
9	**Usami *et al.*** [35]	NR	NR	NR	NR	NR	Dorsal DAP	Advancement, rotation, propeller and adipofascial	finger dorsum defects	FTSG, PC	NR	3.4 cm2 [range 0.6 to 10 cm2]	NR	66.66%	Good
10	**Mitsunaga *et al.*** [36]	NR	NR	NR	NR	NR	Lateral DAP	Propeller, rotational [adipocutaneous flaps, adipose-only flaps, supercharged flaps]	fingertip	ADS then 2ry healing	NR	3.25 [1.44 to 8]	NR	76.92%	Good
11	**Shen *et al.*** [37]	NR	3	5	4	NR	Dorsal IDAP	Propeller [rotation flap 90°]	Lateral Oblique Fingertip Defects	FTSG	NR	2.5 × 1.5 cm to 3.0 × 2.0 cm	8 [range, 8–12]	69.23%	Good

Abbreviations; IDAP=innervated digital artery perforator flap, **STSG=**split thickness skin graft, **FTSG=**full thickness skin graft**, PC=** primary closure, **ADS=**artificial dermal skin

DISCUSSION

Finger reconstruction poses functional and aesthetic challenges. The main is obtaining a stable, aesthetic pleasing, painless, sensate fingertip. The ideal reconstructive options should be versatile, sensate, reliable, single-stage, avoid prolonged immobilization with minimal donor site morbidity, and easy to be performed. The outcome of DAPF have been reported. However, there is a paucity of evidence regarding the versatility and survivability of DAPF for resurfacing finger defects of the hand [16, 38].

The present meta-analysis revealed the versatility, durability, and survivability of DAPF for resurfacing soft-tissue defects of the digits. This was achieved with a low rate of complications, including flap congestion, flap necrosis, and cold intolerance. Furthermore, the rate of superficial epidermolysis, limited ROM, and hyper-pigmented donor site was low with DAPF.

The present meta-analysis highlighted the usability of DAPF for reconstructing soft-tissue defects of the fingers. Parallel with these findings, **Khan *et al.*** revealed the versatility of pedicled DAPF for reconstructing fingertips and thumb defects. They revealed the feasibility of DAPF as an excellent option with desired aesthetic and functional outcomes [38].

In this respect, **Shimbo *et al.*** [39] reported that the dorsal metacarpal artery perforator flaps were versatile options for covering proximal to the middle phalanx and distal to the distal inter-phalangeal joint. This was associated with a lower rate of short-term consequences.

Vitse *et al.* [40] reported that Perforator pro-peller flaps are versatile procedures for resurfacing soft tissue loss of the upper extremities, highlighting the need for a good experience and close monitoring.

The current systematic review revealed a low rate of DAPF-related complications. The rate of flap congestion was 17.3%, whereby the rate of flap necrosis and superficial epidermolysis was 8.9% and 4.7%, respectively. In this concern, **Khan *et al.*** [38] reported a number of complications associated with DAPF. The rate of venous congestion was 7.87%, whereby 4.2% and 5.2% of patients had partial flap loss and cold intolerance, respectively.

In the present meta-analysis, approximately one of every five patients develops flap congestion. The perfusion of DAPF is tenuous, in which venous return is compromised. Venous drainage of DAPF through tiny venules and small capillaries in the perivascular fat of the pedicle. Venous congestion results in superficial epidermolysis in mild cases and partial necrosis or total flap loss in severe cases. Rotation of the pedicle could interrupt the blood flow, resulting in flap ischemia and necrosis. Division of the Grayson and Cleland ligaments and minimizing the extent of flap rotation reduce the risk of pedicle obstruction. Furthermore, leaving a soft tissue around the perforator preserves the venous return. Tight closure of the donor site should be avoided to minimize the pedicle's tension and avoid venous congestion [14, 41].

The present meta-analysis gathered the available literature related to the usability of DAPF for resurfacing finger soft-tissue defects. On the contrary, there were some limitations to be considered in clinical practice. There was considerable heterogeneity between the eligible articles. Such heterogeneity might be evolved due to the variation in study design, defect site, flap design, or demographic characteristics. Furthermore, the majority of the included studies did not implement a comparative arm. This highlighted the need for further studies to assess the outcomes of DAPF when compared with conventional reconstruction procedures.

Conclusions: The DAPF is a reliable procedure for reconstructing soft-tissue defects in the fingers. It provides stable coverage with satisfactory functional and surgical outcomes. It is a convenient addition to the armamentarium for resurfacing soft-tissue defects of the digits.

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