Article

Comparative Efficacy of Antegrade Versus Retrograde Island Flaps Based on the Second Dorsal Metacarpal Artery With Nerve Anastomosis for Thumb Soft Tissue Defect Repair

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AIM: This study seeks to compare the clinical outcomes of antegrade versus retrograde second metacarpal dorsal artery island flaps with nerve anastomosis, thereby providing evidence-based guidance for surgical decision-making.
METHODS: This single-center retrospective study included 180 patients with thumb soft tissue defects treated via nerve-anastomosed second metacarpal dorsal artery island flaps between December 2021 and December 2024. Among them, 96 underwent antegrade island flap repair (antegrade group) and 84 received retrograde island flap repair (retrograde group). Key evaluated metrics included surgical parameters, sensory recovery indicators [static two-point discrimination (s2PD), British Medical Research Council (BMRC) sensory grading], motor function metrics [interphalangeal joint range of motion (ROM), grip strength, and pinch strength], and postoperative complication rates.
RESULTS: The antegrade group demonstrated significantly longer operative times and higher intraoperative blood loss than the retrograde group ($p < 0.001$). The antegrade group exhibited superior s2PD at both 3-month and 6-month postoperative assessments ($p < 0.05$). 6 months postoperatively, 81.25% of antegrade group patients reached S4 grade compared to only 42.86% in the retrograde group ($p < 0.001$). For motor function outcomes, the retrograde group displayed significantly greater interphalangeal joint ROM at 1 month and 3 months after surgery ($p < 0.05$). This difference was no longer present by 6 months ($p > 0.05$). No significant differences were observed in grip or pinch strength between groups at either postoperative 3- or 6-month evaluations ($p > 0.05$). Multivariable analysis confirmed the antegrade group's advantages in sensory restoration ($p < 0.05$), while the retrograde group retained a substantial benefit in early ROM recovery ($p < 0.001$). Additionally, venous crisis was observed less frequently in the antegrade group ($p < 0.05$).
CONCLUSIONS: For soft tissue reconstruction of the thumb, both antegrade and retrograde second dorsal metacarpal artery island flaps combined with nerve anastomosis are feasible options. The antegrade approach is beneficial for the recovery of sensory function, while the retrograde approach is beneficial for early joint mobilization and has less surgical trauma. The choice of surgical approach should be based on clinical needs.

Keywords: soft tissue injuries; thumb; surgical flaps; sensation; surgical anastomosis

Introduction

The thumb contributes about 40–50% of overall hand function, and its fine opposition, grasp, and sensory roles are fundamental to daily tasks and occupational activities [1]. Soft tissue defects of the thumb are common in hand surgery, often resulting from mechanical trauma, crush injuries, lacerations, or acute mutilating events. These injuries expose the distal phalanges and tendons, and improper management can lead to significant functional impairment and permanent disability [2,3]. Therefore, selecting an appropriate reconstructive strategy that maximizes thumb function recovery while minimizing donor site morbidity is a critical challenge in hand surgeons.

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An effective reconstruction must achieve multiple objectives simultaneously: provide durable, tension-free coverage [4]; restore protective and refined sensation, maintain joint mobility, and preserve grip strength [3]; minimize donor site morbidity; and yield a satisfactory aesthetic outcome [5]. Among available options, island flaps with vascular-neural pedicles are particularly reliable due to their reliable perfusion, single-stage design, and potential for nerve coaptation to support sensory restoration [6,7].
Multiple surgical approaches are currently employed for thumb soft tissue reconstruction, each with distinct advantages and limitations. Free flaps, such as toe pulp flaps, offer excellent tissue compatibility and sensory recovery but require longer operative times, advanced microsurgical expertise, and sacrifice of foot tissue as a donor site [8]. Local perforator flaps are technically simpler but have a limited reach and struggle with larger defects [9]. The dorsal index finger island flap remains a well-established option for thumb reconstruction; however, its harvest area is small, and donor sites often require skin grafting, which may res-

ult in extensor tendon adhesions, graft necrosis, pigmentation changes, and functional impairment [2].

Island flaps based on the second dorsal metacarpal artery (SDMA) constitute another vital reconstructive option. The SDMA has a consistent vascular anatomy, lying deep to extensor tendons and superficial to the interosseous muscles, and is accompanied by two concomitant veins [10]. Depending on the direction of blood flow, the flap can be configured as an antegrade flap (proximally pedicled) or a retrograde flap (distally pedicled through anastomoses with palmar digital arteries). SDMA flaps provide thin and pliable tissue, long vascular pedicles, wide rotation arcs, generous harvest size, and recipient-site color and texture match, making them highly suitable for thumb reconstruction [2]. Despite their widespread clinical adoption, there is limited comparative evidence on whether antegrade or retrograde SDMA flaps are superior, particularly regarding long-term sensory outcomes after neural coaptation. Antegrade flaps are theoretically associated with more stable hemodynamics due to physiological flow direction, ensuring reliable perfusion and unimpeded venous drainage [11]. Conversely, retrograde flaps offer longer pedicles and more distal rotation points, facilitating reliable coverage of distal thumb defects [2,12].

Most existing studies report outcomes of individual flap types or comparisons involving conventional digital artery flaps, while head-to-head comparisons of neurotized SDMA antegrade versus retrograde island flaps remain limited. This study aims to address this gap through a retrospective cohort analysis directly comparing the clinical efficacy of neurotized SDMA antegrade and retrograde island flaps for thumb soft tissue reconstruction. Primary endpoints include flap survival, sensory restoration (two-point discrimination and sensory grading), motor outcomes (joint range of motion and grip/pinch strength), and postoperative complications.

Methods

Study Population

This retrospective cohort study included 180 patients with thumb soft tissue defects who underwent flap reconstruction at The First People's Hospital of Linping District, between December 2021 and December 2024. Among them, 96 patients received neurorrhaphy-assisted anterograde second dorsal metacarpal artery island flaps (anterograde group), and 84 underwent retrograde second dorsal metacarpal artery island flaps (retrograde group). The study protocol was approved by the Institutional Ethics Review Board of The First People's Hospital of Linping District (Approval No.: 2024-022) and strictly adhered to the principles outlined in the Declaration of Helsinki. All participants provided written informed consent before enrollment.

Inclusion and Exclusion Criteria

Patient inclusion criteria were as follows: (1) age between 18 and 60 years; (2) traumatic soft tissue defects of the thumb (such as crush, avulsion, lacerations, or machinery-related injuries) involving the fingertip, pulp, radial or ulnar sides, or dorsum; (3) defect size unsuitable for direct suture or split-thickness skin grafting, with a strong patient preference for preserving thumb length and function; (4) exposed tendons or bony structures requiring flap coverage to protect underlying structures; (5) wounds that were primarily clean or rendered relatively clean after debridement (Class II incision); (6) reconstruction using an island flap repair based on the SDMA as the vascular pedicle; (7) inclusion of the superficial branch of the radial nerve in the flap for microsurgical neurorrhaphy; and (8) availability of complete clinical information.

Exclusion criteria included: (1) severe concomitant injury to digital nerves, arteries, or major veins compromising residual thumb sensibility or perfusion, thereby interfering with independent assessment of flap efficacy; (2) concurrent thumb fractures or joint injuries requiring prolonged immobilization, which would impair early mobilization and functional evaluation; (3) extensive mutilating or crush injuries disrupting hand vasculature, preventing reliable assessment of second dorsal metacarpal artery integrity; (4) preoperative Doppler ultrasound confirming absence, hypoplastic (diameter $<$0.5 mm), or aberrant second dorsal metacarpal artery; (5) absence or damage of distal anastomotic branches (critical for retrograde flap viability); (6) systemic conditions adversely affecting microcirculation or wound healing (such as uncontrolled diabetes [Hemoglobin A1c $>$7.5%], peripheral vascular disease [e.g., Raynaud's phenomenon], connective tissue disorders, or coagulopathies); (7) Class III (contaminated) or Class IV (infected) wounds, according to the Centers for Disease Control and Prevention's wound classification; (8) a history of peripheral neuropathy (e.g., cervical spondylosis, carpal tunnel syndrome, alcohol-related neuropathy); and (9) requirement for additional complex reconstructive procedures potentially altering hand function or sensory outcomes.

Surgical Methods

All surgical procedures in both groups were conducted by the same team of specialists and surgeons. Preoperatively, the continuity and integrity of the second dorsal metacarpal artery were assessed using Doppler ultrasound. When the first dorsal metacarpal artery or the digital artery system was injured, an antegrade flap was preferred. Conversely, a retrograde flap was used when the proximal source of blood supply (such as the dorsal carpal branch of the radial artery) was compromised. If vascular conditions permitted and both flap types were suitable for the defect, the final surgical approach selection also reflected the surgical team's familiarity and technical expertise with each technique.

Anterograde Group

During brachial plexus block, anesthesia was administered while positioning the patient supine with the affected limb abducted. A pneumatic tourniquet was applied to the upper arm and inflated after limb exsanguination to establish a bloodless field. Using the dorsal midline between the second and third metacarpal bones (i.e., the line from the radial border of the extensor indicis tendon to the radial styloid process) as the axis, the rotation point was marked at the level of the metacarpal bases, distal to the anatomical snuffbox.

Based on the extent of the thumb defect, a skin flap was designed between the second and third metacarpals, up to 3 cm × 6 cm in size, extending proximally toward the rotation point. An incision was then made along the ulnar border of the designed flap. Blunt dissection was performed from ulnar to radial, deep to the deep fascia and superficial to the interosseous muscles, to expose the second dorsal metacarpal artery, its accompanying veins, and the superficial branch of the radial nerve lying radial to the extensor indicis tendon. After confirming that the neurovascular bundle was fully incorporated into the flap, the flap margins were completed.

The flap was then elevated from radial to ulnar side beneath the deep fascia, carefully preserving the neurovascular structures. Proximally, meticulous dissection was conducted to liberate an adequate length of the second dorsal metacarpal artery, vein, and the designated branch of the superficial radial nerve intended for anastomosis, ensuring sufficient pedicle length for tension-free transfer to the defect. A spacious subcutaneous tunnel or open passage was created between the thumb wound and the rotation point. The flap and its neurovascular pedicle were passed through this tunnel into the thumb defect.

Under the microscope, the flap's superficial radial nerve branch was precisely anastomosed end-to-end to either the residual digital nerve stump or the main trunk of the superficial radial nerve at the thumb recipient site, aiming to restore sensory function. Finally, the flap was sutured to the wound margins. The donor site was covered with a medium-thickness split-thickness skin graft harvested from the ipsilateral thigh, followed by abolster dressing and compressive bandaging.

Retrograde Group

During the brachial plexus block, anesthesia was administered with the patient in the supine position and the affected limb abducted. A pneumatic tourniquet was applied to the upper arm and inflated after exsanguination to obtain a bloodless field. The axis of rotation was identified approximately 1.0–1.5 cm distal to the metacarpophalangeal joint level, proximal to the free margin of the web space, corresponding to the distal anastomotic branch between the second dorsal metacarpal artery and the digital arterial system. The flap was designed between the second and third metacarpal bones on the dorsum of the hand, with its distal limit kept proximal to the web space margin to avoid injury to this anastomosis. A schematic illustration of the design, created using MedPeer (www.medpeer.cn), is shown in Fig. 1.

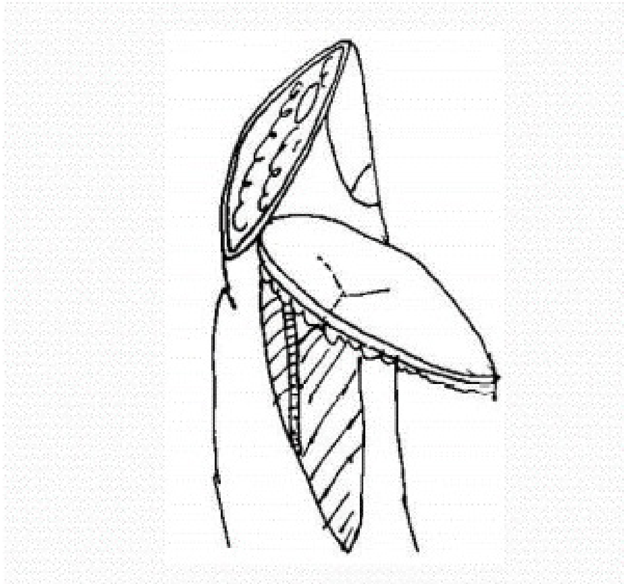

Fig. 1. A schematic presentation of retrograde flap design.

Surgery commenced with an incision at the rotation point in the first web space. The distal segment of the second dorsal metacarpal artery and its anastomosis with the common palmar digital or digital arteries were carefully exposed and confirmed to be intact. Subsequently, an incision was made along the ulnar border of the planned flap, followed by subfascial dissection from ulnar to radial.

The flap was elevated radially, ensuring that the underlying neurovascular bundle of the second dorsal metacarpal artery was entirely incorporated within the flap. Proceeding proximally, the second dorsal metacarpal artery was meticulously ligated and divided. The vascular pedicle was then dissected distally toward the predetermined rotation point with particular care to preserve the delicate distal anastomosis critical for retrograde perfusion. Once adequate pedicle length was achieved, the flap was rotated 180° through a subcutaneous tunnel or open passage across the first web space to secure tension-free coverage of the distal thumb defect, while avoiding twisting, compression, or tension on the pedicle.

Under the microscope, the proximal end (central stump) of the superficial radial nerve branch within the flap was precisely anastomosed end-to-end to the residual digital nerve stump at the thumb recipient site to restore sensory innervation. Finally, the flap was finely sutured to the wound margins, and the donor site was repaired with a split-thickness skin graft harvested from the ipsilateral thigh, followed by a bolster dressing and compression.

Observation Indicators

(1) Baseline data collection:

Clinical baseline characteristics recorded for all patients included gender, age, affected hand side, smoking history, type of injury, time from injury to surgery, area and location of soft tissue defect.

(2) Intraoperative metrics:

Operative time and intraoperative blood loss were documented for both groups.

(3) Static two-point discrimination (s2PD) sensitivity:

The s2PD assessments were performed at 3 and 6 months postoperatively using a standard Disk-Criminator two-point measurement device (NC12752-1, Sammons Preston, Bolingbrook, IL, USA). Each measurement was performed in triplicate, and the mean value was documented. With the patients seated quietly and eyes closed, a blunt-tipped esthesiometer (magnetic needle) stimulator was applied to the flap, advancing from proximal to distal. The distance between the instrument's dual prongs was progressively decreased, and the patient was instructed to indicate immediately whether one or two distinct points were perceived. This procedure was repeated until the patient could no longer reliably differentiate two points, and the shortest distance at which discrimination was still possible was recorded as the s2PD value [13].

(4) Sensory grading assessment:

Sensory function recovery was graded using the British Medical Research Council (BMRC) classification (S0–S4) at 3 and 6 months postoperatively. The grading criteria were as follows: S4: Normal sensation; S3+: Useful sensory discrimination restored; S3: Touch sensation intact without accurate discrimination; S2: Partial pain and touch sensitivity with hypersensitivity or dysesthesia; S1: Deep pain sensitivity only; S0: No sensation [13].

(5) Interphalangeal joint range of motion (ROM):

Active ROM of the thumb's interphalangeal joint was assessed at 1, 3, and 6 months after surgery using a standardized protocol. With the patient seated, the forearm was rested in a neutral position on the examination table, and the wrist was maintained at 0° dorsiflexion. Patients were instructed to actively flex the thumb from full extension to their maximum attainable angle. The degree of flexion was then documented using a finger goniometer [14].

(6) Grip and pinch strength testing:

Grip and pinch strength were assessed at 3 and 6 months postoperatively [15]. Grip strength was measured using a Jamar Hydraulic Dynamometer (Model 5030J1, Sammons Preston Rolyan, Bolingbrook, IL, USA). Patients were seated upright with shoulders in a neutral position, the elbow flexed 90°, the forearm in mid-prone, and the wrist dorsiflexed 0–30°. After adjusting the handle position, patients were instructed to exert maximal effort without trunk leaning or additional body movement. Three trials were conducted for each hand with intervals of 15–30 seconds, and the mean value was then calculated. Results were expressed as % age of the contralateral hand's strength.

Pinch strength was evaluated through a Pinch Gauge (PG-30, B&L Engineering®, Santa Ana, CA, USA). Patients sat with elbows flexed at 90° or supported on a table, with the forearm in a neutral position. The pulp of the thumb and index finger was placed on the gauge's jaws, and patients were instructed to exert maximal pinch force for 2–3 seconds. Three trials were performed with a 15–30 second interval between each, and the mean value was documented. Results were expressed as a percentage of the contralateral hand's strength.

All assessments were performed by the same group of experienced assessors who had received standardized training to ensure consistency and reliability.

(7) Postoperative complications:

Complications within 6 months after surgery were documented and compared between the two groups.

(a) Flap necrosis: Three weeks postoperatively, flap survival was assessed based on clinical examination and Doppler ultrasound. Necrosis was diagnosed when the flap exhibited pallor or purpura/black discoloration, cool temperature, reduced elasticity, absent capillary refill, and/or Doppler ultrasonography showed vascular thrombosis, with or without swelling or purulent discharge.

(b) Venous crisis: Venous compromise was suspected when the transplanted finger became suddenly cool, with progressive pallor replacing erythema, loss of nail bed and capillary refill, flattening of the pulp, and non-bleeding tip incisions with slow, dark venous leakage [16].

(c) Arterial crisis: Arterial insufficiency manifested as flaccid pallor and cold flap with absent capillary refill and lost arterial Doppler signals, suggestive of arterial spasm or thrombosis [16].

(d) Other complications: Including partial necrosis of the grafted skin at the donor site, infection at the donor site, delayed wound healing at the donor site, hypertrophic scarring, and numbness on the dorsal side of the index finger.

Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corporation, Armonk, NY, USA). The Kolmogorov–Smirnov test was employed to assess the normality of continuous variables. Variables with a normal distribution were expressed as mean ± standard deviation ($\bar{x} \pm$ s). Between-group comparisons were performed using the independent samples t test, and within-group comparisons were evaluated with the paired samples t test.

For repeatedly examined, normally distributed variables before and after surgery, repeated-measures analysis of variance (ANOVA) was conducted, followed by multiple comparisons using the least significant difference (LSD) t test. Non-normally distributed data were presented as median with interquartile range (Q1, Q3), with between-group comparisons performed using the Mann–Whitney U test and within-group comparisons with the Wilcoxon signed-rank test.

Categorical variables were reported as frequencies and percentages [n (%)], and differences were compared using the Pearson's χ^2 test or Yates' chi-square correction where appropriate. Given the retrospective design, a post-hoc power analysis was performed. Given the sample size (n = 180) and $\alpha = 0.05$, posterior power analysis based on observed effect sizes indicated that the primary outcome measures, particularly the 6-month s2PD and BMRC S4 recovery rates, had sufficient statistical power. The statistical power for detecting differences in the incidence of venous crisis was moderate.

For key continuous outcomes (s2PD and interphalangeal joint ROM), multiple linear regression was performed to estimate the regression coefficient (B), standard error (SE), and t value. For the ordinal categorical outcome (BMRC sensory grade), ordinal logistic regression was applied to obtain the adjusted odds ratio and its 95% confidence interval (CI). All regression models were pre-specified and adjusted for the clinically relevant covariates, including age, sex, smoking status, and mechanism of injury. The statistical significance level was set at $\alpha = 0.05$. All p-values were two-sided, and values <0.05 were considered statistically significant.

Results

Comparison of Baseline Characteristics Between the Two Groups

As shown in Table 1, there were no statistically significant differences between the anterograde and retrograde groups in terms of gender, age, injured side of the hand, smoking history, type of injury, time from injury to surgery, area of soft tissue defect, or location of soft tissue defect ($p > 0.05$).

Comparison of Intraoperative Indicators Between the Two Groups

The anterograde group had significantly longer operative times and greater intraoperative blood loss than the retrograde group ($p < 0.001$, Table 2).

Comparison of Sensory Function Restoration Between Groups

At 3 months after surgery, s2PD was significantly better in the anterograde group than in the retrograde group (p = 0.003). By 6 months, both groups showed further improvement, with the anterograde group continuing to show significantly superior s2PD ($p < 0.001$, Table 3).

One month after surgery, all patients in both groups were graded as S1 for sensory function. At 3 months, the proportion of patients achieving S3+ was significantly higher in the anterograde group compared to the retrograde group (78.13% vs. 59.52%, $p < 0.05$). By 6 months, 81.25% of patients in the anterograde group recovered to S4 grade, compared with only 42.86% in the retrograde group, with a larger proportion of retrograde patients remaining at S3+ ($p < 0.001$, Table 4).

Comparison of Motor Function Between Groups

At 1 month postoperatively, interphalangeal joint ROM was substantially greater in the retrograde group than in the anterograde group ($p < 0.001$). At 3 months, the retrograde group continues to demonstrate superior ROM compared with the anterograde group ($p < 0.05$). By 6 months, no statistically significant differences in ROM were observed between the two groups, with both achieving satisfactory functional recovery ($p > 0.05$, Table 5).

As shown in Table 6, a statistically significant main effect of time on ROM was observed across both groups ($p < 0.001$), indicating that postoperative ROM changed over time in both the anterograde and retrograde groups. A significant main effect of group was also detected ($p < 0.001$), suggesting varying recovery trajectories between the two surgical techniques. Furthermore, a statistically significant interaction effect (time $\times$ group) was found ($p < 0.001$), demonstrating that the influence of time on postoperative ROM recovery differed according to the surgical approach.

At 3 months, there were no statistically significant differences in grip or pinch strength between the two groups ($p > 0.05$). At 6 months, both grip and pinch strength had improved significantly compared with 3-month estimates in each group ($p < 0.001$), while intergroup differences remained non-significant ($p > 0.05$, Tables 7,8).

Comparison of Postoperative Complications Between the Two Groups

We observed that neither group experienced flap necrosis, resulting in a 100% flap survival rate. The incidence of venous crisis was significantly lower in the anterograde group compared with the retrograde group ($p < 0.05$). Other postoperative complications, including arterial crisis, partial necrosis of skin grafts, donor site infection, hypertrophic scarring, and dorsal index finger numbness, did not differ considerably between the two groups ($p > 0.05$, Table 9).

Adjusted Effect Size Analysis of Key Outcome Measures

Multivariate regression analyses for key outcome measures are shown in Tables 10,11. After adjusting for age, sex, smoking status, and injury type, the anterograde group continued to demonstrate significantly superior s2PD at 3 months (B = –0.920, 95% confidence interval (CI) = –1.497~–0.343; p = 0.002) and at 6 months postoperatively (B = –1.553, 95% CI = –1.965~–1.140; $p < 0.001$).

Table 1. Comparison of preoperative characteristics between the two groups [$\bar{x} \pm$ s, median (Q1, Q3), n (%)].

Characteristic	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	t/χ^2/Z value	*p*-value
Gender (male)	76 (79.17)	67 (79.76)	0.010	0.921
Age (years)	40.39 ± 11.80	38.63 ± 11.31	1.021	0.309
Injured side of the hand (right hand)	59 (61.46)	52 (61.90)	0.004	0.951
Smoking (yes)	34 (35.42)	26 (30.95)	0.402	0.526
Type of injury				
Compression injury	42 (43.75)	35 (41.67)	0.079	0.778
Avulsion injury	20 (20.83)	20 (23.81)	0.230	0.632
Cutting injury	19 (19.79)	18 (21.43)	0.074	0.786
Contused laceration	15 (15.63)	11 (13.10)	0.232	0.630
Time from injury to surgery (h)	7.14 ± 1.93	6.95 ± 1.86	0.674	0.501
Area of soft tissue defect (cm^2)	4.50 (4.30, 4.60)	4.50 (4.30, 4.60)	1.690	0.091
Location of soft tissue defect				
Fingertip	37 (38.54)	30 (35.71)	0.153	0.695
Finger pulp	43 (44.79)	40 (47.62)	0.144	0.704
Radial dorsum	16 (16.67)	14 (16.67)	<0.001	1.000

Q1, quartile 1; Q3, quartile 3.

Table 2. Comparison of operative time and intraoperative blood loss between the two groups [$\bar{x} \pm$ s].

Group	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	*t* value	*p*-value
Operative time (min)	133.37 ± 20.84	95.87 ± 15.46	13.817	<0.001
Intraoperative blood loss (mL)	43.96 ± 13.79	34.24 ± 10.51	5.358	<0.001

Table 3. Comparison of s2PD between the two groups [mm, median (Q1, Q3)].

Time-point	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	Z	*p*-value
3 months after surgery	10.00 (9.00, 11.00)	11.00 (9.00, 12.00)	3.017	0.003
6 months after surgery	7.00 (6.00, 8.00) **	9.00 (8.00, 10.00) **	6.747	<0.001

s2PD, static two-point discrimination. Compared with the postoperative 3 months in the same group, **$p < 0.001$.

Table 4. Comparison of sensory function classification between the two groups [n (%)].

Time-point	Anterograde group (*n* = 96)		Retrograde group (*n* = 84)		χ^2 value	*p*-value
3 months after surgery	S3+: 75 (78.13)		S3+: 50 (59.52)		7.305	0.007
6 months after surgery	S3+: 18 (18.75)	S4: 78 (81.25)	S3+: 48 (57.14)	S4: 36 (42.86)	28.436	<0.001

Table 5. Comparison of the interphalangeal joint ROM between the two groups [°, $\bar{x} \pm$ s].

Time-point	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	*t* value	*p*-value
1 month after surgery	35.48 ± 8.62	43.60 ± 7.36	6.743	<0.001
3 months after surgery	56.50 ± 9.28 **	60.48 ± 8.68 **	2.956	0.004
6 months after surgery	73.50 ± 6.58 **##	74.35 ± 7.42 **##	0.810	0.419

ROM, range of motion. Postoperative 1 month in the same group, **$p < 0.001$; compared with the postoperative 3 months in the same group, ##$p < 0.001$.

Table 6. Results of repeated-measures ANOVA for ROM after surgery.

Variable	Time effect		Intergroup effect		Interaction effect	
	F	*p*	F	*p*	F	*p*
ROM	915.163	<0.001	34.890	<0.001	10.119	<0.001

ANOVA, analysis of variance.

Binary logistic regression analysis confirmed that patients in the anterograde group were significantly more likely than those in the retrograde group to achieve BMRC S4 grade at 6 months after surgery (odds ratio (OR) = 6.183, 95% CI = 3.070~12.451; $p < 0.001$). However, the anterograde group retained a significant disadvantage in interphalangeal joint

Table 7. Comparison of grip strength between the two groups [%, $\bar{x} \pm$ s].

Time-point	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	*t* value	*p*-value
3 months after surgery	67.80 ± 10.30	70.20 ± 9.74	1.600	0.111
6 months after surgery	85.41 ± 6.98 **	86.89 ± 7.21 **	1.404	0.162

Compared with the postoperative 3 months in the same group, $^{**}p < 0.001$.

Table 8. Comparison of pinch strength between the two groups [%, median (Q1, Q3)].

Time-point	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	Z value	*p*-value
3 months after surgery	66.00 (58.25, 72.00)	67.00 (60.25, 74.00)	0.981	0.327
6 months after surgery	90.00 (82.25, 94.00) **	90.00 (84.00, 95.00) **	0.890	0.374

Compared with the postoperative 3 months in the same group, $^{**}p < 0.001$.

Table 9. Comparison of postoperative complications between the two groups [n (%)].

Group	Anterograde group (*n* = 96)	Retrograde group (*n* = 84)	χ^2 value	*p*-value
Venous crisis	3 (3.13)	12 (14.29)	7.305	0.007
Arterial crisis	3 (3.13)	3 (3.57)	<0.001	1.000
Partial necrosis of the skin graft area	5 (5.21)	0 (0.00)	Fisher	0.062
Donor site infection	4 (4.17)	0 (0.00)	Fisher	0.124
Poor healing of the donor site	0 (0.00)	3 (3.57)	Fisher	0.100
Hypertrophic scarring	8 (8.33)	6 (7.14)	0.089	0.766
Sensory numbness on the dorsal aspect of the index finger	15 (15.63)	12 (14.29)	0.063	0.802

Table 10. Multiple linear regression analyses of key postoperative outcomes.

Outcome variable	Time point	B (95% CI)	*t* value	SE	*p*-value
s2PD (mm)	Postoperative 3 months	–0.920 (–1.497~–0.343)	–3.146	0.292	0.002
s2PD (mm)	Postoperative 6 months	–1.553 (–1.965~–1.140)	–7.424	0.209	<0.001
ROM (°)	Postoperative 1 month	–8.101 (–10.521~–5.682)	–6.609	1.226	<0.001
ROM (°)	Postoperative 3 months	–4.174 (–6.851~–1.497)	–3.078	1.356	0.002

B, regression coefficient.

Table 11. Multiple logistic regression analyses of key postoperative outcomes.

Outcome variable	Time-point	OR (95% CI)	B	SE	Wald χ^2	*p*-value
BMRC (reach S4)	Postoperative 6 months	6.183 (3.070~12.451)	1.822	0.357	26.020	<0.001

BMRC, British Medical Research Council; OR, odds ratio.

ROM after adjustment, both at 1 month (B= –8.101, 95% CI= –10.521~–5.682; $p < 0.001$) and 3 months after surgery (B= –4.174, 95% CI= –6.851~–1.497; $p = 0.002$).

Discussion

This study provides valuable evidence-based comparative data to inform clinical decision-making regarding the efficacy of neurotized anterograde versus retrograde second dorsal metacarpal artery island flaps for thumb soft tissue reconstruction. The lack of significant differences in baseline characteristics between groups supports the validity of the comparison. Overall, both surgical approaches were safe and effective, with a 100% flap survival rate in each group; however, they differ in several characteristics, including surgical trauma, the rate and quality of sensory recovery, early interphalangeal joint function, and the pattern of postoperative complications.

Regarding surgical trauma and efficiency, the retrograde group exhibited distinct advantages. Our findings demonstrated that the retrograde group had significantly shorter operative times and reduced intraoperative blood loss than the anterograde group. These differences are primarily attributable to the distinct anatomical foundations and dissection requirements of the two techniques. However, limited studies report detailed surgical parameters for both procedures through head-to-head comparisons, which restrict numerical comparisons with previous findings. Therefore, the comprehensive data documented in this study serve as a useful reference for future investigations.

From an anatomical perspective, the observed differences are well justified. The anterograde flap uses the proximal segment of the second dorsal metacarpal artery as its pedicle, necessitating dissection proximally towards its origin (e.g., the deep palmar arch or the dorsal carpal branch of the radial artery). This entails a broader operative field and more extensive pedicle mobilization to enable rotation to distal thumb defects, thereby increasing technical complexity, procedural time, and blood loss [10,17]. In contrast, the retrograde flap is based on distal anastomotic branches, typically communicating with digital arteries, with a rotation point positioned closer to the thumb defect site. This approach enables comparatively shorter pedicle dissection within a more confined area, making the procedure technically simpler, faster, and less invasive [18].

At the primary postoperative evaluation points (3 months and 6 months), the antegrade flap group demonstrated significantly better early recovery patterns in key sensory outcomes (s2PD and BMRC grade). This early sensory advantage holds significant clinical importance, as it supports rapid functional recovery of the hand in the early rehabilitation stage. Consistent with previous reports, multiple studies have documented better sensory outcomes with antegrade homodigital island flap reconstruction compared to retrograde digital artery flaps [12,19]. In our cohort, both s2PD and sensory grading (defined as the proportion of patients reaching S3+/S4 grades) improved significantly more in the anterograde group than in the retrograde group at both 3- and 6-month follow-up.

The superiority of the anterograde approach likely stems from its neurophysiological advantages. The end-to-end or end-to-side neurorrhaphy between the flap's dorsal digital nerve and the recipient thumb nerves preserves orthodromic axonal regeneration along a pathway that matches native nerve direction and preserves physiological hemodynamics within the flap. This configuration facilitates efficient axoplasmic transport and organized nerve fiber growth, promoting rapid and high-quality sensory reinnervation. Conversely, retrograde flaps face distinct physiological challenges during neural restoration [20]. Nerve coaptation in retrograde designs may involve suboptimal size matching between donor and recipient nerves, potentially compromising the quality of sensory recovery [12]. Although retrograde flaps provide reliable perfusion, their hemodynamic profile entails reversed blood flow [21]. We hypothesize that this retrograde perfusion may subtly alter intraneural microcirculation and disrupt the perineurial microenvironment, thereby reducing the efficiency and maturation of neural regeneration.

Regarding early joint mobility, the retrograde group demonstrated a superior advantage. At both 1 and 3 months postoperatively, interphalangeal joint mobility was substantially better in the retrograde group. This advantage was closely associated with shorter durations of external fixation. Because the retrograde flap pedicle is positioned closer to the fingertip, it imposes minimal restriction on thumb metacarpophalangeal and wrist joint movement, enabling patients to initiate functional exercises earlier and more smoothly, thereby preventing the risk of joint stiffness [2]. By 6 months, both groups achieved comparable, well-recovered joint mobility without statistically significant differences. This suggests that despite initial mobilization constraints in the anterograde group, more intensive late-stage rehabilitation enabled them to attain functional outcomes comparable to those of the retrograde group.

Similarly, no statistically significant differences were observed in grip or pinch strength between groups at either 3 or 6 months. This indicates that both surgical approaches ultimately provide sufficient support and stability to the thumb to meet daily functional needs such as grasping, holding, and pinching. Recovery of strength primarily depends on the integrity of underlying bone and tendon structures and on comprehensive rehabilitation, while the flap mainly offers durable soft tissue coverage and a favorable environment for functional restoration [22].

Both groups in this study exhibited a low overall complication rate, and no significant differences were observed in major complications such as arterial crisis or infection. However, the incidence of venous crisis was significantly lower in the anterograde group compared to the retrograde group. In island flaps, venous drainage in retrograde designs relies on reverse outflow through the dorsal venous network and its communicating branches, which inherently increases the risk of postoperative venous insufficiency [23,24]. In contrast, the anterograde flap maintains physiological venous outflow in the forward direction, promoting more efficient venous return and thereby reducing the risk of venous crisis.

The multivariable regression analysis in this study provided more robust estimates of the treatment effects by adjusting for potential confounders. The results confirm that the sensory superiority of the antegrade approach (better s2PD and higher BMRC grades) is both independent and clinically meaningful, as evidenced by effect sizes such as approximately 2 mm mean improvement in mean s2PD and nearly a 5-fold higher odds of achieving S4 grade. Conversely, the advantage of the retrograde approach in promoting early recovery of joint mobility was also clearly demonstrated. These observations strengthen the primary conclusion that the observed differences in outcomes are primarily attributable to the intrinsic characteristics of the flaps regarding vascular supply and nerve coaptation, rather than residual confounding from baseline imbalances. Consequently, clinical decision-making should be guided by an informed understanding of these trade-offs.

In summary, both anterograde and retrograde neurorrhaphic second dorsal metacarpal artery island flaps are effective reconstruction options, each with distinct advantages and disadvantages. Clinical decision-making should be individualized based on patient-specific characteristics, surgeon and institutional expertise, and specific rehabilitation goals. Preferred indications for the anterograde flap include:

(1) *Patients requiring optimal sensory recovery*: Young individuals, those performing precision-dependent work (such as craftsmen, surgeons, musicians), or patients demanding high tactile sensitivity, are likely to benefit most from the anterograde approach due to its faster and supe-

rior sensory regeneration, which better supports occupational and functional demands.

(2) *Situations with elevated risk of venous insufficiency*: In patients with vasculopathies (e.g., diabetes, peripheral vascular disease) or substantial risk factors such as smoking, the anterograde flap is beneficial due to its lower incidence of venous crisis.

Whereas preferred indications for the retrograde flap encompass:

(1) *Need for a shorter, minimally invasive procedure*: Elderly patients or those with systemic comorbidities who would benefit from shorter operative time and surgical trauma may be favored for the retrograde technique.

(2) *Emphasis on early mobilization*: Patients particularly concerned about joint stiffness or requiring early return to daily activities or work can benefit from the retrograde flap, which facilitates earlier initiation of functional rehabilitation.

(3) *Favorable anatomical alignment with the defect*: When the location and configuration of the thumb defect are more compatible with the rotational arc of a retrograde flap, this method can simplify operative planning and execution [25].

Despite multiple encouraging outcomes, this study has several limitations which should be considered before interpreting these findings. First, its retrospective design may have introduced selection and measurement biases that cannot be entirely eliminated, even though baseline characteristics did not differ significantly between groups. Second, this study evaluated multiple clinically relevant endpoints (such as sensory and motor function) at several postoperative time points without formal adjustment for multiple comparisons, which may increase the risk of Type I errors. Future prospective studies with a focus on a single primary endpoint are warranted to further validate these findings. To mitigate this concern, our interpretation emphasized findings that demonstrated both clinical significance and consistency across different measures and time points, and we considered effect sizes together with their confidence intervals. Third, as a single-center study, the limited sample size may compromise the generalizability of the results. Finally, although the 6-month follow-up period allowed assessment of intermediate outcomes, complete maturation of sensory nerves typically requires one year or longer; therefore, a longer follow-up would provide a more comprehensive evaluation of long-term efficacy. Furthermore, future prospective, multicenter, large sample randomized controlled trials with extended follow-up periods are warranted to validate these findings.

Conclusions

The findings of this study demonstrate that both anterograde and retrograde second dorsal metacarpal artery island flaps with nerve anastomosis are reliable options for reconstruction of thumb soft tissue defects. The anterograde flap technique demonstrates a significantly superior early advantage in key sensory outcomes and was associated with a lower risk of venous crisis, although this came at the cost of somewhat greater surgical trauma and delayed early recovery of joint mobility. In contrast, the retrograde flap offers advantages, including a simpler procedure, minimal surgical trauma, and better early joint mobility, albeit with marginally inferior sensory grade outcomes and a relatively higher risk of venous crisis. Surgical choice should therefore be individualized, balancing the specific characteristics of each technique with the patient's functional needs, comorbidities, and priorities to achieve optimal functional and aesthetic outcomes.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

GL and YY designed the research study and wrote the first draft. GL and YY performed the research. GL and YY analyzed the data. Both authors have been involved in revising the manuscript critically for important intellectual content. Both authors gave final approval of the version to be published. Both authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity

Ethics Approval and Consent to Participate

The study protocol was approved by the Institutional Ethics Review Board of The First People's Hospital of Linping District (Approval No.: 2024-022) and strictly adhered to the principles outlined in the Declaration of Helsinki. All participants provided written informed consent before enrollment.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Mohammed T, Jimma TM, Zerfu TT, Kassaahun ME. Pollicization of index Fingers For Bilateral Hypoplastic Thumbs of Twin Babies: Case Series At Cure Children's Hospital of Ethiopia. International Medical Case Reports Journal. 2024; 17: 327–333. https://doi.org/10.2147/IMCRJ.S454360.

[2] Wei Z, Zhao Y, Wei H, Liu S, Song J, Chen Y, *et al*. The second dorsal metacarpal artery flap relaying the dorsal island flap of the index finger for the repair of soft tissue defect of thumb. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi = Zhongguo Xiufu Chongjian Waike Zazhi = Chinese Journal of Reparative and Reconstructive Surgery. 2023; 37: 37–40. https://doi.org/10.7507/1002-1892.202209052. (In Chinese)

[3] Mao T, Xie R, Wang G, Xing S. Application of a modified dorsoulnar artery pedicle flap in the repair of thumb tip defects: A case report. Experimental and Therapeutic Medicine. 2020; 19: 3300–3304. https://doi.org/10.3892/etm.2020.8583.

[4] Saha S. Minimally Invasive Reconstruction of an Allen Three Traumatic Thumb Injury with Platelet-rich Fibrin and Stacked Dermal Regeneration Template. Journal of Orthopaedic Case Reports. 2022; 12: 90–94. https://doi.org/10.13107/jocr.2022.v12.i12.3478.

[5] Tang JB, Elliot D, Adani R, Saint-Cyr M, Stang F. Repair and reconstruction of thumb and finger tip injuries: a global view. Clinics in Plastic Surgery. 2014; 41: 325–359. https://doi.org/10.1016/j.cps.2014.04.004.

[6] Osaki T, Nomura T, Hashikawa K, Terashi H. Reverse vascular pedicle digital island flap with preservation of the dorsal branch of the digital nerve. Case Reports in Plastic Surgery & Hand Surgery. 2019; 6: 74–78. https://doi.org/10.1080/23320885.2019.1632202.

[7] Chen LM, Wang G, Liu Y. Clinical effects of lateral supramalleolar perforator island flaps with low rotation points in repairing foot skin and soft tissue defect wounds. Zhonghua Shao Shang Yu Chuang Mian Xiu Fu Za Zhi. 2022; 38: 932–936. https://doi.org/10.3760/cma.j.cn501120-20210630-00231.

[8] Yuan C, Liu H, Zhang H, Wang T, Gu J. Reconstruction of Thumb Pulp Defects Using Free Lateral Great Toe Flaps. The Journal of Hand Surgery. 2021; 46: 421.e1–421.e7. https://doi.org/10.1016/j.jhsa.2020.10.004.

[9] Hu H, Chen H, Hong J, Mao W, Tian M, Wang L, *et al*. Propeller perforator flaps from the dorsal digital artery perforator chain for repairing soft tissue defects of the finger. BMC Surgery. 2019; 19: 188. https://doi.org/10.1186/s12893-019-0649-7.

[10] Yang HY, Zhang JF, Huo YX, Wang W, Wang B, Li RG. Second dorsal metacarpal artery-based index finger dorsal island flap for the management of thumb defects. Journal of Plastic, Reconstructive & Aesthetic Surgery: JPRAS. 2022; 75: 325–331. https://doi.org/10.1016/j.bjps.2021.08.016.

[11] Bovill J, Huffman S, Cach G, Haffner Z, Deldar R, Abu El Hawa AA, *et al*. Propeller Perforator Flaps Used for Hand and Digit Reconstruction: A Systematic Review. Journal of Hand and Microsurgery. 2024; 16: 100035. https://doi.org/10.1055/s-0043-1768482.

[12] Zhang Y, Wang Y, Zhou J, He X, Wu R. Clinical Application of a Modified Local Transposition Flap (Parallelogram Flap) Surgery in Repairing Fingertip Defects. Annals of Plastic Surgery. 2022; 89: 510–516. https://doi.org/10.1097/SAP.0000000000003283.

[13] O'Brien M. Aids to the examination of the peripheral nervous system: 6th edition. Practical Neurology. 2023; 23: 263–264. https://doi.org/10.1136/pn-2022-003686.

[14] Hume MC, Gellman H, McKellop H, Brumfield RH, Jr. Functional range of motion of the joints of the hand. The Journal of Hand Surgery. 1990; 15: 240–243. https://doi.org/10.1016/0363-5023(90)90102-w.

[15] Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S. Grip and pinch strength: normative data for adults. Archives of Physical Medicine and Rehabilitation. 1985; 66: 69–74.

[16] Wang X, Wang W, Liu J, Li X. Clinical application and influencing factors of free flap transplantation for the reconstruction of skin and soft tissue defects: A retrospective cohort study. Medicine. 2025; 104: e42976. https://doi.org/10.1097/MD.0000000000042976.

[17] Liu P, Deng Z, Zhang T, Li X. Anatomical Characteristics of Cutaneous Branches Extending From the Second Dorsal Metacarpal Artery. Frontiers in Bioengineering and Biotechnology. 2020; 8: 995. https://doi.org/10.3389/fbioe.2020.00995.

[18] Unluer Z, Ruston J, Nikkhah D. The retrograde approach to the reverse dorsal metacarpal artery flap. Journal of Plastic, Reconstructive & Aesthetic Surgery: JPRAS. 2021; 74: 1355–1401. https://doi.org/10.1016/j.bjps.2020.12.012.

[19] Xiong X, Xu M, Shuai M, Guo CJ, Wang C, He ZL, *et al*. Comparative Study of the Clinical Effects of Reverse Digital Artery Island Flaps and Antegrade Homodigital Neurovascular Island Flaps for Fingertip Reconstruction. Annals of Plastic Surgery. 2022; 88: 395–400. https://doi.org/10.1097/SAP.0000000000002967.

[20] Wei P, Chen W, Mei J, Ding M, Yu Y, Xi S, *et al*. Repair of Fingertip Defect Using an Anterograde Pedicle Flap Based on the Dorsal Perforator. Plastic and Reconstructive Surgery. Global Open. 2016; 4: e730. https://doi.org/10.1097/GOX.0000000000000732.

[21] Demmer W, Sorg H, Steiert A, Hauser J, Tilkorn DJ. Wound Healing and Therapy in Soft Tissue Defects of the Hand and Foot from a Surgical Point of View. Medical Sciences (Basel, Switzerland). 2021; 9: 71. https://doi.org/10.3390/medsci9040071.

[22] De Francesco F, Marchesini A, Mani O, Zingaretti N, Parodi PC, Riccio M. Thumb tip reconstruction for apical substance loss using a bipedunculated homodigital V-Y advancement FLAP: OUR experiences. Journal of Hand and Microsurgery. 2025; 17: 100319. https://doi.org/10.1016/j.jham.2025.100319.

[23] Pertea M, Ciobanu P, Velenciuc N, Poroch V, Filip A, Moraru DC, *et al*. Utility of "reposition-flap" in the reconstruction of the avulsed thumb. Medicine. 2021; 100: e27290. https://doi.org/10.1097/MD.0000000000027290.

[24] Boissiere F, Gandolfi S, Riot S, Kerfant N, Jenzeri A, Hendriks S, *et al*. Flap Venous Congestion and Salvage Techniques: A Systematic Literature Review. Plastic and Reconstructive Surgery. Global Open. 2021; 9: e3327. https://doi.org/10.1097/GOX.0000000000003327.

[25] Wang YL, Chang Y, Li SL, Wang JG. Methods and effects of high-frequency color Doppler ultrasound assisted reverse island flap of dorsal digital artery of ulnar thumb for repairing skin and soft tissue defects in the distal end of the same finger. Zhonghua Shao Shang Za Zhi = Zhonghua Shaoshang Zazhi = Chinese Journal of Burns. 2021; 37: 555–561. https://doi.org/10.3760/cma.j.cn501120-20210223-00063. (In Chinese)