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Comparison of the efficacy of medial tarsal venous flaps and traditional venous/arterial free flaps in the reconstruction of hand soft tissue defects: a new type of physiological flap

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ABSTRACT

Background: The treatment of hand soft tissue defects primarily relies on flap reconstruction. However, traditional venous/arterial free flaps have several disadvantages, including damage to the donor site, blood stasis, cyanosis, blister formation, and even necrosis. These issues can significantly affect patient recovery and outcomes. Therefore, there is a need for alternative approaches that minimize these complications and improve overall patient treatment.

Objectives: To compare the efficacy of medial tarsal free venous flaps and traditional venous/arterial free flaps in the reconstruction of hand soft tissue defects, by evaluating various clinical outcomes and patient recovery metrics.

Materials and methods: We screened 30 suitable patients with hand soft tissue defects and

randomly assigned them to three groups. Patients in each group were transplanted with either medial tarsal free venous flaps or traditional arterial/venous free flaps to achieve coverage and reconstruction of the soft tissue defects. The results were compared and analyzed using the following metrics: operation time, complication rate, pain index, postoperative infection rate, and functional evaluations of both the donor and recipient areas.

Results: There was no significant difference in operation time between the medial tarsal free venous flaps and the traditional forearm free venous flaps. The operative time of both types of flaps above was shorter than that of the traditional fibular-side arterial flap of the hallux. The complication rate of the medial tarsal free venous flaps was comparable to that of the fibular-side arterial flaps from the great toes and significantly lower than that of the traditional forearm free venous flaps. In terms of pain, the pain index for the medial tarsal free venous flaps was significantly lower than that of the fibular-side arterial flap from the hallux and comparable to that of the forearm free venous flaps. Regarding postoperative infection rates, the forearm free venous flaps had the highest rate, while there was no significant difference between the medial tarsal free venous flaps and the fibular-side arterial flaps from the great toes. The functional recovery of the medial tarsal free venous flaps was outstanding in both the donor and recipient areas. There was no poor functional performance in the donor areas of the forearm free venous flaps or the recipient areas of the fibular-side arterial flaps of the halluces.

Conclusions: The medial tarsal free venous flaps effectively avoid the disadvantages of traditional venous and arterial free flaps, combining their advantages. This kind of flaps offer shorter operative times, and lower pain indices. They also provide excellent functional recovery in both donor and recipient areas. Thus, medial tarsal free venous flaps represent an ideal solution for reconstructing hand soft tissue defects.

Keywords: soft tissue defects of hands, medial tarsal free venous flap, Fibular-side arterial flap of the hallux, forearm free venous flap, physiologic flap

INTRODUCTION

In daily clinical work, hand trauma is the common injury. The corresponding incidence of soft tissue defects in the hands is high. No matter for individual or family, this kind of hand injury would be devastating [1]. And hand injury will affect the patient's daily life and productivity, the long-term inability to work with a hand injury can not only affect a patient's income, but also their physical and mental health [7, 9]. Basing on the different technical skills essential in hand trauma surgery: skin repair, tendon repair, fracture fixation, and microsurgical anastomosis, the hand trauma surgery can be classified into four types, and every hand trauma surgery always contains several progresses of these four types [8]. The reconstruction of soft tissue defects of the hands must include skin repair and microsurgical anastomosis, combining tendon repair and fracture fixation sometimes, which should be administrated as early as possible, especially the soft tissue defects of the hand palm that affect the holding function. Covering and repairing wound early can reduce the infection rate of defective wounds, shorten the time of hospitalization and make the rehabilitation training of the injured hands administrate early, providing possibilities for the function recovery of the affected hands [12]. In order to get the goal of the reconstruction of soft tissue defect of the hand, the following conditions must be satisfied: (1) the shape and structure of the flaps should be similar to that of the hands defects; (2) The flap should be thin and soft; (3) The flap must have a suitable blood vessel for micro anastomosis, and the damage of the donor area should be minimized during the flap acquisition process [3, 6]. The medial tarsal free venous flap, the fibular-side arterial flap of the hallux and the forearm free venous flap basically meet the above

requirements [2]. Due to the convenience of acquiring flaps, free venous flap of the forearm is often considered in the reconstruction of soft tissue defects of the hands, especially soft tissue defects of the palm of the fingers complicated with hemodynamic disorder. However, after operation, the flap often appeared blood stasis, cyanosis, blisters, oozing fluid and even infection necrosis [4, 5, 10]. As a physiological flap, the fibular-side arterial flap of the hallux of does not appear these situations, but the obtain of the fibular-side arterial flap of the hallux sacrifices the corresponding artery branches, resulting in irreversible damage to the donor area. In clinical work, we preliminarily found that the medial tarsal free venous flaps can avoid the drawbacks of traditional venous flap, and the reconstruction effect is comparable to that of the traditional arterial flap, like fibular-side arterial flap of the hallux. and the medial tarsal free venous flaps are convenient to gain, and the donor areas suffer from less damage. Therefore, we carried out this study to make a series of objective comparisons between the medial tarsal free venous flaps, fibular-side arterial flap of the hallux and the forearm free venous flaps. The physiologic characteristics of medial tarsal free venous flaps were scientifically investigated.

MATERIALS AND METHODS

Patients

The critical element of the successful surgery is high quality vascular anastomosis, so the factors of ages and diseases like hypertension, diabetes, hyperlipidemia, that affect the quality of blood vessels need to be excluded. In addition, the maximum area of the medial tarsal free venous flaps that can be cut is 6 × 4 cm, so the soft tissue defect of the hand with a large area is not suitable for repairing with the medial tarsal free venous flaps. What is more, the harvested forearm free venous flaps and fibular-side arterial flap of the hallux are also not

suitable for the reconstruction of the soft tissue defect of the hand with a large area. Basing on the objective facts illustrated above, we drafted the inclusion criteria and exclusion criteria below.

Inclusion criteria: Patients aged 18–60 years with hand soft tissue defects. Exclusion criteria: Patients younger than 18 years old or older than 60 years old, with underlying diseases such as hypertension, diabetes, hyperlipidemia, and large area defects. Since all soft tissue defects of the hand with different types, locations and damage degree can be debrided multiple times to achieve a uniform state for planting flaps, so if they meet the inclusion and exclusion criteria, they are suitable for this study.

According to inclusion and exclusion criteria, 30 patients were selected and assigned to 3 groups. The soft tissue defects of the hands were reconstructed with the medial tarsal free venous flaps, the fibular-side arterial flaps of the halluces and the forearm free venous flaps, respectively. In forearm free venous flap groups, the patients mostly suffered from soft tissue defects on the palmar side of fingers complicated with hemodynamic disorder.

Methods

Medial tarsal free venous flap group: patients received tracheal intubation for general anesthesia, routine disinfection after anesthesia effect. Under the condition of tourniquet hemostasis, the debridement of the soft tissue defects of the hands was implemented, and the medial tarsal free venous flaps were designed according to the sizes of the soft tissue defect areas of the hands, the arteries and related veins near defect areas. The incision range was 6 × 4 cm between the medial tarsal and the navicular bone of the foot. The two sets of veins in medial tarsal free venous flaps should be preserved and the capillary communicating branches in the two sets of veins should not be lost. During the operation, the artery was anastomosed

with the deep vein in the medial tarsal free venous flaps, and the related vein was anastomosed with the superficial vein in the medial tarsal free venous flaps. Suture the flap to cover the wound. The donor area was repaired by direct suture or groin skin graft. Routine treatment such as anti-infection, relieving pain, vasodilation and dressing change should be carried out after operation. Blood circulation and flap appearance were closely observed.

Forearm free venous flap group: Patients underwent brachial plexus anesthesia. After the anesthesia effected, tourniquet was tied to the proximal part of the upper arm and stop bleeding, then routine disinfection was performed. Conventional debridement of the soft tissue defects of the hands was performed, searching and separating the proper digital arteries and related veins. According to the sizes of defect areas and blood vessel condition, the forearm free venous flap was designed with the appropriate diameter veins at the appropriate position of the forearm. After anastomosing the corresponding blood vessels, the flap was sutured to fix and cover the wound, and the donor area was sutured to close. Routine treatments such as anti-infection, analgesia, blood vessel expansion and dressing change were carried out after surgery. Observe the blood flow of the affected fingers and the flaps closely and pay attention to the state of the flaps.

Fibular-side arterial flap of the hallux group: Patients underwent tracheal intubation and general anesthesia. After anesthesia effected, tourniquet was tied, and routine disinfection was performed. Under the condition of tourniquet hemostasis, the fibular-side arterial flaps of the halluces were designed according to the soft tissue defects of the hands after debridement of the tissue defects. Attention was paid to the selection and marking of the proper arteries of the halluces and related veins. After anastomosing the relevant blood vessels, the flap was sutured and fixed to cover the wound. The donor area was mostly repaired by groin skin grafting. Routine treatments such as anti-infection, analgesia, blood vessel expansion and dressing

change were administrated after operation. Observe the blood circulation of the flaps closely and pay attention to the conditions of the flaps.

Observation indicators

The results were compared and analyzed by the indexes of operation time, complication rate, pain index, postoperative infection rate, postoperative donor area and recipient area function evaluation. The VAS score was used to evaluate the pain level at 1 day before surgery, 1 day, 3 days, 7 days, 14 days after surgery. The functional evaluation of donor area and recipient area after surgery was performed using the limb function evaluation standard of the Hand-foot Surgery Branch committee of the Chinese Medical Association.

Statistical methods

SPSS 24.0 software was used for statistical analysis of all data, and the relevant measurement data was represented by mean ± standard deviation. One-way analysis of variance and Chi-square test were used to analyze the differences between groups. The test standard was set as 0.05. Differences were considered statistically significant at the values of $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$.

RESULTS

Comparison of operation time in each group

We compared the differences in operating time among three different surgical approaches (MTVF, HFAF and FVF) to assess the efficiency and clinical effectiveness of the different approaches. The results showed that among the three groups, the operation time was 2.56 ± 0.45 hours in the MTVF group, 3.72 ± 0.49 hours in the HFAF group and 2.50 ± 0.49 hours in the FVF group. Significant differences between the three groups were found using one-way

ANOVA ($F = 23.647$, $p < 0.001$). Further two-by-two comparisons showed a significant difference between the MTVF and HFAF groups ($p < 0.001$), and between the FVF and HFAF groups ($p < 0.001$), but not between the MTVF and FVF groups ($p = 0.766$) (Tab. 1).

Comparison of complication and infection rates among groups

We further compared the differences in complication rates and infection rates among the three different surgical approaches (MTVF, HFAF and FVF) to assess the safety and efficacy of the different approaches. The results of the study showed that among the three groups (Tab. 2), the complication rate was 10% in the MTVF group, 10% in the HFAF group, and 80% in the FVF group. The complication rate was lower in the MTVF and HFAF groups, while it was significantly higher in the FVF group ($\chi^2 = 14.700$, $p = 0.01$). In addition, the postoperative infection rate was 0% in the MTVF group, 10% in the HFAF group, and 40% in the FVF group ($\chi^2 = 6.240$, $p = 0.029$). The MTVF group had the lowest rate of postoperative infections, whereas the FVF group had the highest rate of postoperative infections. The overall infection rate was 0% in the MTVF group, 10% in the HFAF group, and 20% in the FVF group ($\chi^2 = 6.667$, $p = 0.026$). The MTVF group had the lowest overall infection rate, whereas the FVF group had the highest overall infection rate. In summary, the MTVF method performed best in reducing complication and infection rates, while the FVF method demonstrated higher complication and infection rates.

Comparison of pain index among groups at different time points

We made an in-depth comparison of the pain indices of three different surgical approaches (MTVF, HFAF and FVF) at different time points (1 day preoperatively and 1, 3, 7, 14 days postoperatively) to assess the effectiveness of the different approaches in controlling patients'

pain. The results (Tab. 3) showed no significant difference in pain indices between the three groups at 1 day preoperatively, 1 and 14 days postoperatively ($p > 0.05$). At 3 days postoperatively, the pain index in the MTVF group was significantly lower than that in the HFAF group ($p = 0.014$), but not significantly different from that in the FVF group ($p = 0.388$), nor was there a significant difference between the FVF group and the HFAF group ($p = 0.091$). At 7 days after surgery, the pain index was significantly lower in the MTVF group than in the FVF group ($p = 0.015$) but was not significantly different from that of the HFAF group ($p = 0.257$), nor was it significantly different from that of the FVF group and the HFAF group ($p = 0.159$).

In summary, the MTVF method was superior to the HFAF and FVF methods for pain control at 3 and 7 days after surgery, while there were no significant differences at other time points. Therefore, the MTVF method is more effective in controlling pain in patients at an early stage.

Function evaluation in each group

We compared the differences in functional evaluations between three different surgical approaches (MTVF, HFAF and FVF) to assess the effectiveness and clinical outcomes of the different approaches. The results of the study showed that the MTVF group had better functional evaluations, with a high percentage of excellent (7), 2 good, 1 acceptable, and no adverse evaluations. The HFAF group had the second best functional evaluation, with 6 excellent, 3 good, 1 acceptable, and no adverse evaluations, while the FVF group had the worse functional evaluation, with 2 excellent, 2 good, 2 acceptable, and 4 adverse evaluations. The MTVF method was significantly better than the FVF method in terms of functional evaluation, while the HFAF method was in between.

One year later, the function of the affected limb was evaluated. By the analysis of Chi square test, we found that the function of the affected limb in the medial tarsal free venous flap group was better than that in the fibular-side arterial flaps of the halluces group. The function of the affected limb was the worst in the forearm venous free flap group, and the difference among the three groups was statistically significant.

DISCUSSION

The free venous flap of forearm can repair and reconstruct the soft tissue defect of the hand; however, it is inevitable that this flap will blood stasis, cyanosis, blister and even infection and necrosis. As a physiologic flap, the application of the fibular-side arterial flaps of the halluces in the reconstruction of soft tissue defects of the hands has less complications than that in the forearm free venous flap group. While the price of the defect reconstruction in the fibular-side arterial flaps of the halluces group is the irreversible damage of the artery branchs and donor areas. In the application of the medial tarsal free venous flaps reconstructing the soft tissue defects of the hands, there are few flaps which have the complications of blood stasis ,cyanosis, blisters, infection and necrosis, and the damage of donor areas is not serious, which perfectly avoids the disadvantages of the traditional forearm free venous flaps and the fibular-side arterial flaps of the halluces. What is more, medial tarsal free venous flaps have the advantages of traditional forearm free venous flaps and fibular-side arterial flaps of the halluces. In the postoperative observation of the blood flow of the flaps, we found that the medial tarsus free venous flap was pale in color and low in tension at the beginning, and gradually turned red after the blood flow reconstruction, which is a postoperative period spanned 2 to 3 hours (Fig. 2, 3). This appearance indicates that the vessel construction of the medial tarsal free venous flaps is not the short circuit of the perforating branch between the

two-layer venous system as described in some previous researches [11, 13]. Therefore, we boldly speculated that the medial tarsal free venous flaps possess the capillary network between the two layers of venous system, which provides more blood perfusion and material exchange places for the flap tissue, so that the blood supply of the flaps tissue is significantly better than that of the traditional venous flaps. The medial tarsal free venous flap is a kind of venous flap with the characteristics of arterial flap. Therefore, we can define the medial tarsal free venous flap is a kind of quasi-physiological flap. Basic studies on blood flow construction and survival mechanism of medial tarsal free venous flaps are still in progress. We will confirm our conjecture in basic studies and present relevant research results in the next article.

Comorbidities such as hypertension, diabetes, and hyperlipidemia can significantly affect surgical outcomes. Patients with hypertension may experience increased perioperative risks, including cardiovascular complications. Diabetes can lead to impaired wound healing and higher infection rates, while hyperlipidemia can contribute to vascular issues that complicate recovery. Large defect areas also pose additional challenges, potentially leading to delayed healing and increased risk of complications.

Our analysis shows that patients with these comorbidities and larger defect areas require more careful preoperative planning and postoperative care. Specific interventions, such as tighter glycemic control for diabetic patients and optimized blood pressure management for hypertensive patients, can improve overall surgical outcomes. Additionally, addressing the size and complexity of defect areas through advanced surgical techniques and adjunctive therapies can enhance healing and reduce complication rates.

CONCLUSIONS

The medial tarsal free venous flap avoids the disadvantages of traditional venous/arterial free flaps perfectly, and has the advantages of both. It will be an ideal scheme for the reconstruction of soft tissue defects of the hands. The flap with the same blood flow structure of the medial tarsal free venous flap is the ideal flap we pursue. This shows the topological potential of the study of medial tarsal free venous flaps, and the importance of related researches is obvious.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The data could be obtained by contacting the corresponding author.

Ethics statement

This study protocol was approved by the Huizhou Central People's Hospital Ethics Committee (20230618hc).

Author contributions

Qiming-Chen designed the study. Xiangchang-Cao wrote the original draft. Fuzhou-Yang, Rong-Fang, Yaping-Zhu, Luo-Huang collected raw data. Fusan-Hua, Changqing-Bai performed statistical and bioinformatics analyses. Qiming-Chen supervised the study.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Table 1. Comparison of operation time in each group.

Groups	MTVF	HFAF	FVF	F	Sig
Operation time [h]	2.56 ± 0.45	3.72 ± 0.49	2.50 ± 0.49	23.647	< 0.001
p	MTVF vs. HFAF < 0.001	MTVF vs. FVF 0.766	FVF vs. HFAF < 0.001		

MTVF vs. HFAF: $p < 0.001$, MTVF vs. FVF: $p = 0.766$, FVF vs. HFAF: $p < 0.001$. One-way ANOVA shows significant differences in operation time among the three groups. No significant difference between MTVF and FVF. Significant differences between MTVF and HFAF, and between FVF and HFAF.

FVF — Forearm Venous Free Flap; HFAF — Fibular-side Arterial Flap of the Hallux; MTVF — Medial Tarsal free Venous Flap.

Table 2. Comparison of complication and infection rates among groups.

Groups	MTVF	HFAF	FVF
Complication rate	10%	10%	80%
χ^2	14.700		
p	0.01		
Postoperative infection rate [%]	0%	10%	40%
χ^2	6.240		
P	0.029		
Overall infection rate [%]	0%	10%	20%
χ^2	6.667		

P	0.026

χ^2 and p values: Statistical significance of differences among groups. Complication rate: Significant differences among groups (χ^2 = 14.700, p = 0.01). Postoperative infection rate: Significant differences among groups (χ^2 = 6.240, p = 0.029). Overall infection rate: significant differences among groups (χ^2 = 6.667, p = 0.026). FVF — Forearm Venous Free Flap; HFAF — Fibular-side Arterial Flap of the Hallux; MTVF — Medial Tarsal free Venous Flap.

Groups	**MTVF**	**HFAF**	**FVF**	**F**	**Sig**
Pain index	6.50 ± 0.85	6.20 ± 1.03	6.50 ± 0.85	0.358	0.702
p (1 day before surgery)	MTVF vs. HFAF 0.47	MTVF vs. FVF 1	FVF vs. HFAF 0.47		
Pain index	7.30 ± 0.95	7.40 ± 1.07	7.50 ± 0.97	1	0.905
p (1 day after surgery)	MTVF vs. HFAF 0.825	MTVF vs. FVF 0.658	FVF vs. HFAF 0.825		
Pain index	5.60 ± 0.70	6.50 ± 0.85	5.90 ± 0.74	3.589	0.041
p (3 day after surgery)	MTVF vs. HFAF 0.014	MTVF vs. FVF 0.388	FVF vs. HFAF 0.091		

Pain index p (7 day after surgery)	2.80 ± 0.79 MTVF vs. HFAF 0.257	2.90 ± 0.74 MTVF vs. FVF 0.015	3.70 ± 0.95 FVF vs. HFAF 0.159	3.410	0.048
Pain index p (14 day after surgery)	0.40 ± 0.52 MTVF vs. HFAF 0.688	0.80 ± 0.79 MTVF vs. FVF 0.234	1.30 ± 0.95 FVF vs. HFAF 0.424	0.768	0.474

F and p values: Statistical significance of differences among groups at different time points. 1 day before surgery: No significant differences among groups (F = 0.358, p = 0.702).1 day after surgery: No significant differences among groups (F = 1.00, p = 0.905). 3 days after surgery: Significant differences among groups (F = 3.589, p = 0.041). 7 days after surgery: Significant differences among groups (F = 3.410, p = 0.048). 14 days after surgery: No significant differences among groups (F = 0.768 , p = 0.474). FVF — Forearm Venous Free Flap; HFAF — Fibular-side Arterial Flap of the Hallux; MTVF — Medial Tarsal free Venous Flap..

Table 4. Groups function evaluation in each group.

Groups	**MTVF**	**HFAF**	**FVF**
Excellent	7	6	2
Good	2	3	2

Acceptable	1	1	2
Bad	0	0	4
χ^2	11.586		
p	0.047		

FVF — Forearm Venous Free Flap; HFAF — Fibular-side Arterial Flap of the Hallux; MTVF — Medial Tarsal free Venous Flap..

Figure 1. Comparison of flap types for hand defects repair. The intraoperative and postoperative images of patients in three different groups: those who received fibular-side arterial flaps of the halluces, forearm venous free flaps, and medial tarsal free venous flaps. The purpose of this figure is to compare the effectiveness and associated drawbacks of each flap type in repairing hand defects. **A–C.** The intraoperative images of patients in the three groups; **D.** The blood circulation and appearance images of postoperative flaps in the three

groups. The relevant images show that although the fibular-side arterial flaps of the halluces can repair the defects of the hands well, it has greater damage to the donor area at the sacrifice of the halluces arteries and function. Although the forearm venous free flap has little damage, the repair effect of hand defects wound is not as good as the fibular-side arterial flap of the hallux and the medial tarsal free venous flap due to blood stasis ,cyanosis and other drawbacks. The medial tarsal free venous flap perfectly avoids the related disadvantages of the fibular-side arterial flap of the hallux and the forearm venous free flap, while compatible with their advantages. FVF — Forearm Venous Free Flap; HFAF — Fibular-side Arterial Flap of the Hallux; MTVF — Medial Tarsal free Venous Flap..

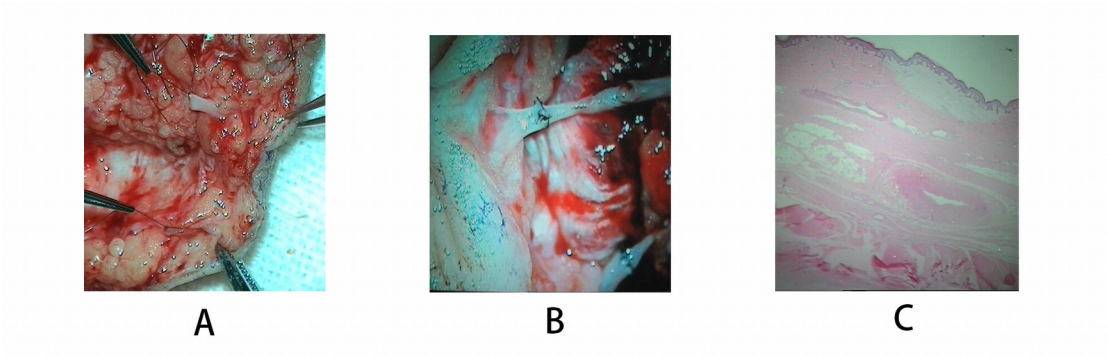

Figure 2. Anatomical basis and vascular anastomosis of medial tarsal free venous flaps . The unique deep and shallow venous system in the medial tarsal region, which serves as the anatomic basis for repairing hand defects using the medial tarsal free venous flaps . **A, B.** By anastomosing the deep and superficial veins with the artery and veins of the hand, the defect wound of the hand was covered and repaired. **C.** H&E staining showed the characteristic deep and superficial veins in the medial tarsal free venous flap. This figure shows the vascular anastomosis of the medial tarsal free venous flaps and the anatomical basis of the survival flaps.

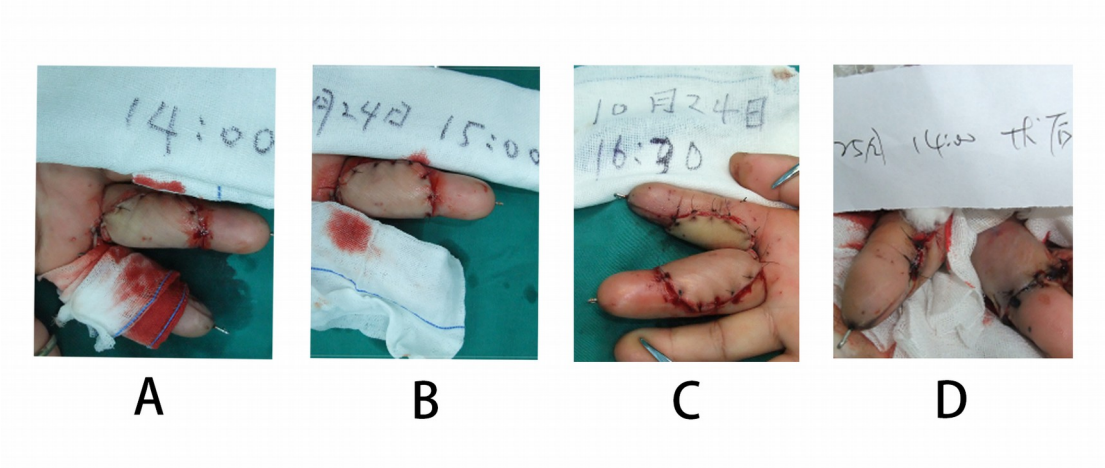

Figure 3. Blood perfusion dynamics of medial tarsal free venous flaps in hand defect repair. The unique blood perfusion dynamics observed when using the medial tarsal free venous flaps to repair hand defects. **A–C.** When the medial tarsal free venous flap was used to repair the defects of the hands, there was a unique phenomenon of blood perfusion: After the flap transplantation, the color of the flap changed from pale at the beginning to rosy 2–3 hours postoperatively. **D.** 3 hours after surgery, the flaps became rosier.