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ORIGINAL ARTICLE

# Use of nailfold capillaroscopy for the assessment of patients undergoing digit replantation and revascularization

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## ABSTRACT

**Objectives:** In this study, we aimed to evaluate microvascular changes using nailfold capillaroscopy in patients who underwent digit replantation and revascularization.

**Patients and methods:** A total of 46 patients (34 males, 12 females; mean age: 45.8±17.6 years; range, 18 to 75 years) who underwent replantation or revascularization procedures between February 2012 and May 2023 were retrospectively analyzed. Nailfold capillaroscopy images were assessed for various parameters including capillary count, diameter, dilatation, presence of giant capillaries, capillary disarrangement, microhemorrhages, neoangiogenesis, subpapillary plexus appearance, crossing capillaries, tortuosity, and microaneurysm. We investigated the association between microvascular alterations and clinical outcomes.

**Results:** Of 46 patients, 25 patients underwent replantation and 21 patients underwent revascularization. Significant microvascular changes, including subpapillary venous plexus, microvascular enlargement, microhemorrhages, neoangiogenesis, and tortuosity were observed in replantation patients (p=0.000[b], p=0.020, p=0.021[b], p=0.001, and p=0.004, respectively). However, these changes were not significant in revascularization patients. Revascularization patients exhibited an increase in capillary diameter and disarrangement (p=0.019 and p=0.016[b], respectively). A significant negative correlation existed between digital nerve repairs and microvascular enlargement in replantation patients. Hyperesthesia was significantly correlated with neoangiogenesis and capillary disarrangement, while a statistically significant positive relationship was found between subpapillary venous plexus and patient satisfaction in replantation patients.

**Conclusion:** Our study showed that replantation patients who underwent two nerve repairs exhibited a well-regulated microvascular tone. However, we did not observe a statistically significant relationship between the number of nerve repairs and cold intolerance. Based on these findings, we highlight the potential of nailfold capillaroscopy in detecting microvascular changes following replantation and revascularization, which may contribute to a better understanding of the etiology of neurovascular complications.

***Keywords:*** Capillaroscopy, cold intolerance, digit, nailfold, replantation, revascularization.

Around four centuries ago, Johann Christophorus Koolhaas became the first physician to employ a primitive microscope to illustrate capillary loops.[1] Capillaroscopy is a non-invasive and safe device for the microscopic visualization of the proximal end of digit's nailfold, the epinychial fold, commonly used for diagnostic purposes in rheumatic diseases. In the nailfold, the capillaries are aligned vertically to the skin and microscopic imaging reveals morphological alterations in the capillary loop, including diminished capillary count, microhemorrhages, aneurysmal loops and neovascularization, which may occur as a result of vascular inflammation and hypoxia.[2] In rheumatic diseases, microvascular involvement

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advances incrementally, beginning with perivascular inflammation and proceeding to the excessive accumulation of extracellular matrix, culminating in capillary damage and subsequent pathological neoangiogenesis.[3]

Replantation can be defined as the reattachment of a completely amputated part by restoring arterial and venous flow and reconstruction of nerve and musculoskeletal structures. After vascular repair, reperfusion has the potential to adversely impact the tissue, thereby leading to microvascular changes.[4] Amputation can be incomplete, and there is disruption of blood flow with some soft tissue attachment with distal devascularization, which is referred to as subtotal amputation. The main goal is to restore limb vascularization with microvascular techniques which is termed as revascularization. Similarly, microvascular changes can be seen after vascular repair, as reperfusion has the potential to adversely impact the replanted or revascularized digits. Algodystrophic complications such as hypoesthesia, hyperesthesia, and cold intolerance may develop after surgical treatment in patients undergoing replantation and revascularization. To better understand these complications, it is necessary to analyze the changes in the capillary vasculature in the chronic postoperative period. There is a need to elucidate the possible relationship between complications and vascular changes in order to fully understand the etiology of complications.

In the present study, we aimed evaluate the nailfold capillary structure of patients who underwent replantation and revascularization using video-capillaroscopy and to assess the relationship between the observed microvascular alterations and clinical results. Additionally, we aimed to identify differences in microvascular changes between patients who underwent replantation and revascularization.

## PATIENTS AND METHODS

This single-center, retrospective study was conducted at Department of Orthopedics and Traumatology of Turgut Özal Medical Center, İnönü University Faculty of Medicine between February 2012 and May 2023. A total of 600 patients who underwent finger replantation and revascularization procedures for hand injuries were reviewed. The study included adult patients aged 18 and above with a single digit injury. Patients with multiple finger injuries were excluded. Among the patients who underwent replantation and revascularization, those whose digits were affected by acute local trauma within the past two weeks before the capillaroscopy were excluded from the study due to the missing clear capillaroscopy imaging data. Furthermore, all patients were evaluated for chronic rheumatic disease by a senior rheumatologist using patient history, physical examination, and laboratory tests, and patients with chronic rheumatic diseases were excluded. Also, we excluded patients with primary and secondary Raynaud's phenomenon, as digits without replantation and revascularization may also have an abnormal capillary morphology. Patients who underwent surgery on the thumb were also excluded due to device incompatibility and anticipated difficulties in obtaining clear images. Patients with nail bed level injuries were not included either, as appropriate imaging could not be performed. Finally, a total of 46 patients (34 males, 12 females; mean age: 45.8±17.6 years; range, 18 to 75 years) who met the inclusion criteria and had routine follow-up and clear capillaroscopic images were recruited. The patients were divided into two groups as those undergoing replantation (n=25) and revascularization (n=21). All of these patients underwent capillaroscopic examination once at the time of their final follow-up.

A written informed consent was obtained from each patient. The study protocol was approved by the Inonü University Scientific Research and Publication Ethics Committee (date: 28/05/2024, no: 2024/5532). The study was conducted in accordance with the principles of the Declaration of Helsinki.

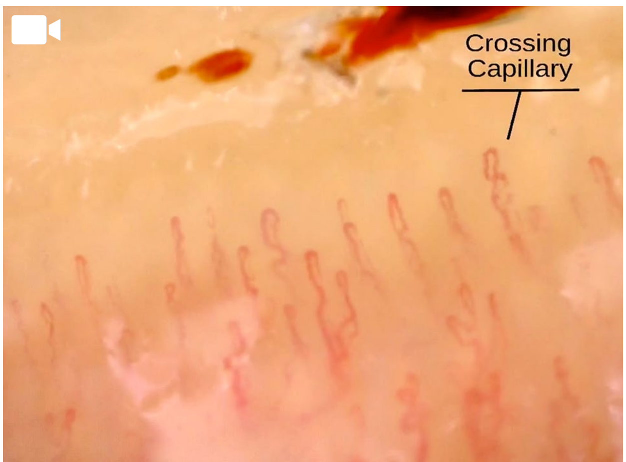
The capillaroscopic procedure was also performed on the corresponding finger on the opposite hand to compare chronic vascular changes in the operated finger. The patients were evaluated clinically in terms of age, sex, injured side, injured digit, dominant side, injury mechanism, injury level (zone I: distal to the insertion of flexor digitorum superficialis, zone II: proximal to the insertion of flexor digitorum superficialis), smoking history, and chronic disease history (diabetes mellitus, hypertension, asthma, epilepsy). In addition, the duration of cold ischemia, duration of warm ischemia, number of digital vein repairs, number of digital artery repairs, number of digital nerve repairs, and the Weber two-point discrimination test results were noted (mm). The patients were assessed for conditions such as nonunion, hypoesthesia, hyperesthesia, and cold intolerance. Cold intolerance was evaluated subjectively by questioning the patient's clinical findings in daily activities and seasonal changes. Two-point discrimination, hypoesthesia, and hyperesthesia were evaluated by comparing them with the corresponding finger on the opposite hand. The duration of hospitalization, total follow-up time (month), Visual Analog Scale (VAS) (from 0 to 10), and patient satisfaction (good, moderate, poor) were recorded. Patient satisfaction was assessed by subjective results based on self-assessment of function, activities of daily living, and quality of life after orthopedic intervention. Hypoesthesia, hyperesthesia, cold intolerance, two-point discrimination test, VAS score, and patient satisfaction were recorded at the final follow-up.

**Examination protocol**

The median time between replantation and capillaroscopic examination was 75.7 (range, 6 to 170) months. The median time interval between revascularization and capillaroscopic examination was 71.8 (range, 6 to 156) months. The nailfold capillaroscopy images were captured using a 200× capillaroscopy device (Dino-Lite Pro Capillary Scope 200 Digital Microscope; Dino-Lite Europe, IDCP B.V., NN Almere, The Netherland) and recorded to the computer with the Dino Capture 2.0 program. Each patient was kept in the examination room for a minimum of 15 min prior to analysis. Immersion oil was carefully poured to the nail fold to enhance the translucency of the keratinous surface, thereby facilitating optimal visualization. All digits of both hands, except for the bilateral thumbs, underwent examination with capillaroscopy. Images were obtained from the operated finger, as well as from the corresponding fingers of the non-operated side as a control group for statistical analysis. The other digits except for the operated digit of the operated side were also examined by capillaroscopy to determine whether there were any vascular changes by the one senior rheumatologist. The clearest images among these were selected for analysis. All images were meticulously examined at a 200× magnification within a 1 mm area, assessing parameters including capillary count, capillary diameter, dilated capillaries, giant capillaries, capillary disarrangement, microhemorrhages, neoangiogenesis, subpapillary venous plexus, crossing capillaries, tortuosity, and microaneurysm (Video 1).

**Image analysis**

The acceptance criteria for the changes in the vascular structures evaluated in the study were given by conducting an extensive literature review and making appropriate references to each one. Capillaroscopy is a non-invasive, easy, and safe diagnostic technique designed to evaluate the microcirculation of small vessels in the nailfold. It can reveal both the general architecture of capillary rows and specific details of individual vessels (Figure 1). The entire skin is filled with capillaries, but they extend vertically to the skin surface, with only the tip of the loop visible. Normal capillaries are hairpin shaped and have a homogeneous distribution in a "comb-like" structure (Figure 2a).[5] Cases exhibiting significant differences in capillary distances were considered as capillary disarrangement (Figure 2b and 2c). In the nailfold, the terminal rows of capillaries run parallel to the skin surface, allowing for the examination of all morphological details and the nature of blood flow. A normal capillary density in adults is between 7 and 12 per millimeter.[6] A lower density indicates capillary loss. Avascular area is defined as the absence of two or more consecutive capillaries (Figure 2d).[7] Loss of capillaries can lead to critical tissue hypoxia. The extensive reduction of capillaries may create large avascular areas, resulting in a "desert-like" aspect of the nailbed.[8] The capillary diameter is measured from the apex of the capillary loop and is considered normal up to 20 µm in diameter. Dilated capillary vessels, with a caliber between >20 µm and <50 µm, are considered "non-specific size abnormalities" (non-scleroderma pattern) (Figure 2e). Giant capillaries are defined as homogeneously dilated capillaries with an apical diameter ≥50 µm[8] (Figure 2f). The diameter of the loops indicates ectasia when the loop diameter is between 1 and 3 times the normal measurement, characterized by circumscribed and asymmetric expansion. If the loop diameter is between 4 and 10 times the normal size, it is defined as a microaneurysm (Figure 3a).[9] Microvascular




**VIDEO 1.** Video of nailfold capillaroscopy performed at 6-month follow-up of a patient who underwent finger replantation.

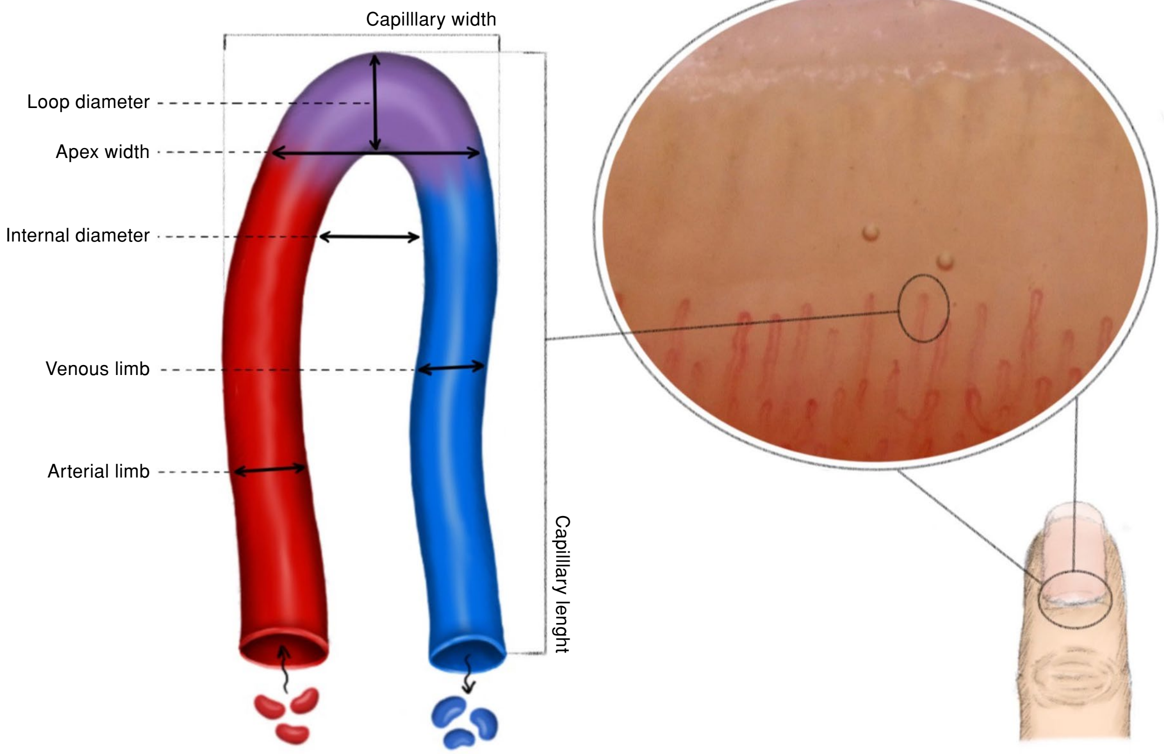



**FIGURE 1.** Schematic representation and anatomical structure of nailfold capillaries.

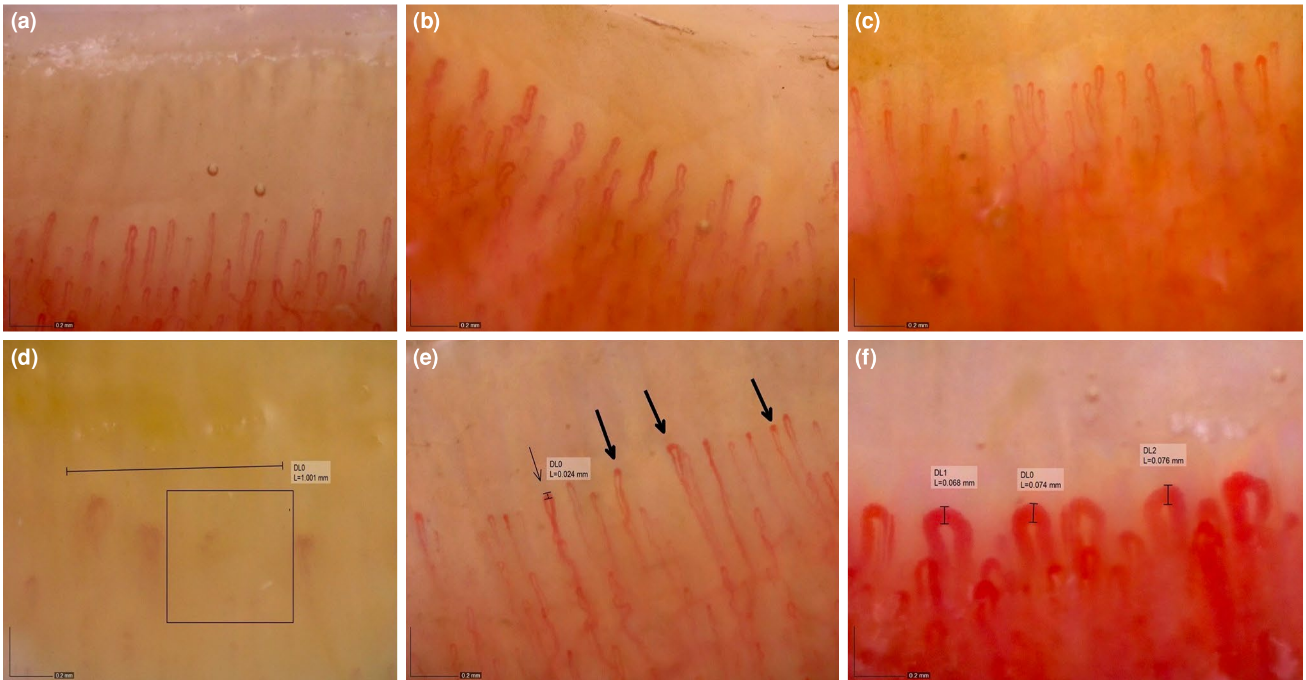



**FIGURE 2.** Nailfold capillaroscopy image of normal capillary loops **(a)** and capillaroscopy image showing normal capillary arrangement **(b)**. Capillaroscopy image showing capillary disarrangement **(c)**. Three capillaries and avascular areas at the distance of 1 mm **(d)**. Capillaries showing larger than 20 micrometers in diameter and smaller than 50 micrometers (capillary enlargement) **(e)**. Capillaries showing larger than 50 micrometers in diameter (giant capillary) **(f)**. (The magnification of all figures ×200).

dilatation, or enlarged capillaries, may represent a local autoregulatory response to tissue hypoxia, according to some suggestions.[6] Microhemorrhages appear as red or brown hemosiderin deposits, representing leakage of red blood cells from disrupted capillary walls. They can occur in any connective tissue disease and are always classified as "non-specific abnormalities" (Figure 3b). Neoangiogenesis is characterized by clustering of twisted and abundant capillaries with marked heterogeneity in shape and size, surrounded by loss of normal capillary loops (Figure 3c). The primary morphological characteristic of angiogenesis is the clustering of tortuous capillaries with a pronounced shape heterogeneity, which includes thin or large tortuous and bushy capillaries (ramified capillaries).[8] Tortuosity is described as the bending and undulating of afferent and efferent limbs without intersecting (Figure 3d).[8] Crossing capillaries refer to the formation resulting from the intersection of arterial and venous limbs at a single point (Figure 3e).[10] Subpapillary venous plexus visibility is defined as the observation of larger and interconnected vessels than capillaries, indicating the enlargement and congestion of venules and capillaries associated with the permanent opening of arteriovenous anastomoses (Figure 3f).[10]

Vascular findings were prepared for statistical analysis. Capillary count and diameter were evaluated as numerical parameters, while dilated capillaries, giant capillaries, capillary disarrangement, microhemorrhages, neoangiogenesis, subpapillary venous plexus, crossing capillaries, tortuosity, and microaneurysms were evaluated as categorical parameters. During categorical assessment, microvascular changes in the operated finger were considered present, if the same findings were absent in the corresponding digit of the opposite hand and the adjacent fingers on the operated side.

### Statistical analysis

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous data were presented in mean ± standard deviation (SD) or median (min-max), while categorical data were presented in number and frequency. Normality of distribution was assessed using the Shapiro-Wilk test. For vascular alterations,

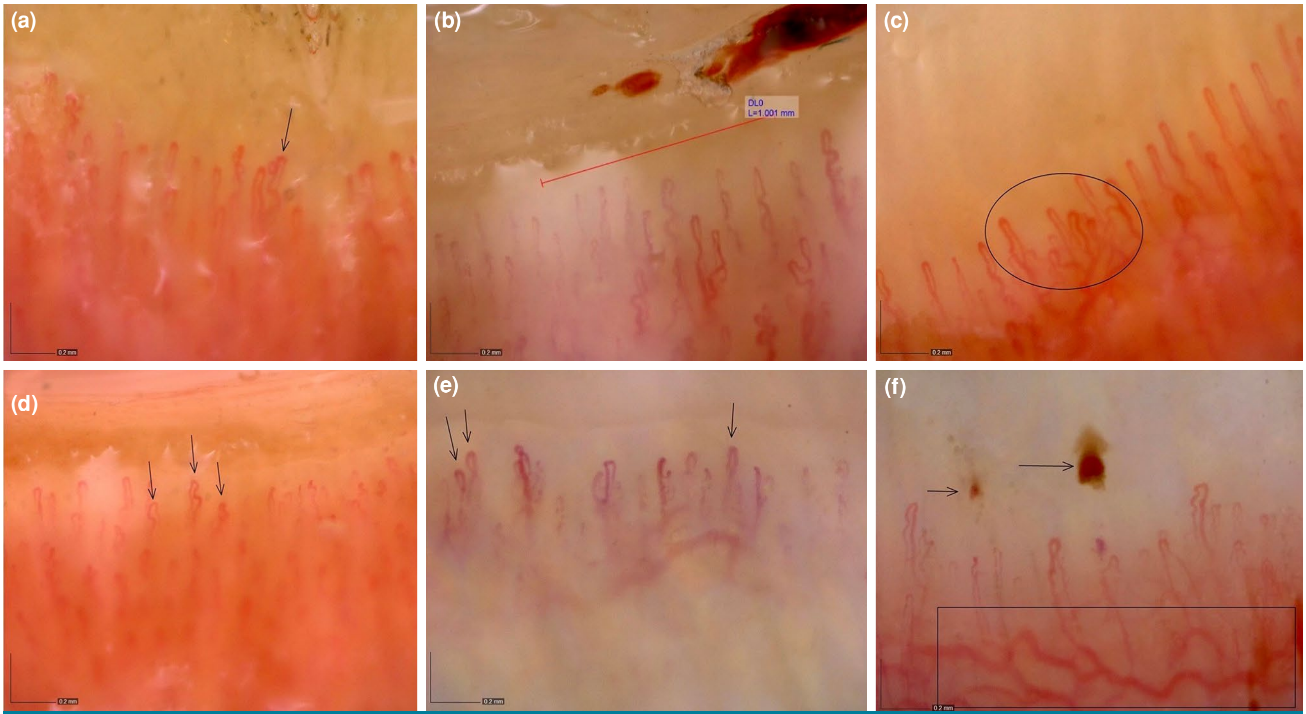


**FIGURE 3.** Capillaroscopy image of 33-year-old male patient who had little finger replantation, showing microaneurysm at the 11-year follow-up **(a)**. Capillaroscopy image showing microhemorrhage **(b)**. Capillaroscopy image of neoangiogenesis **(c)**, capillary tortuosity **(d)**, capillary crossing **(e)**. Capillaroscopy image of 21-year-old male patient who had right-hand index finger replantation, showing subpapillary venous plexus (rectangular) and microhemorrhage (arrows) at 32 months **(f)**. (The magnification of all figures ×200).

the Wilcoxon and McNemar tests were used, where appropriate. The Pearson, eta, phi, and Cramer's V correlation coefficients were utilized to evaluate the association between vascular alterations and clinical outcomes. A $p$ value of <0.05 was considered statistically significant.

## RESULTS

In this study, the mean follow-up was 71.8±47.7 (range, 6 to 156) months. The median duration of hospitalization was 7 (range, 1 to 30) days. The median time to surgery was 4 (range, 1 to 24) h. In the replantation group, 14 (56%) patients were operated on the right side and 11 (44%) were operated on the left side. In the revascularization group, nine (43%) patients were operated on the right side and 12 (57%) patients were operated on the left side (Table I).

We found statistically significant alterations in microvascularity, including subpapillary venous plexus ($p=0.000^b$), microvascular enlargement

**TABLE I**
Demographic and clinical characteristics of patients

| | Replantation | | | Revascularization | | | | |
|---|---|---|---|---|---|---|---|---|
| | n | % | Mean±SD | n | % | Mean±SD | Median | Min-Max |
| Age (year) | | | 44.6±12.7 | | | 45.8±17.6 | | |
| Follow-up (month) | | | 75.76±39.7 | | | 71.81±47.72 | | |
| Duration of Ischemia (h) | | | 4.28±1.67 | | | | 4 | 1-24 |
| Hospitalization time (day) | | | 10.88±6.8 | | | | 7 | 1-30 |
| Sex | | | | | | | | |
| Male | 21 | 84 | | 13 | 61.90 | | | |
| Female | 4 | 16 | | 8 | 38.10 | | | |
| Injured hand | | | | | | | | |
| Right | 14 | 56 | | 9 | 42.86 | | | |
| Left | 11 | 44 | | 12 | 57.14 | | | |
| Digit | | | | | | | | |
| 2 | 7 | 28 | | 6 | 28.57 | | | |
| 3 | 11 | 44 | | 8 | 38.10 | | | |
| 4 | 3 | 12 | | 4 | 19.05 | | | |
| 5 | 4 | 16 | | 3 | 14.29 | | | |
| Mechanism of injury | | | | | | | | |
| Sharp | 15 | 60 | | 16 | 76.19 | | | |
| Crush | 3 | 12 | | 2 | 9.52 | | | |
| Avulsion | 7 | 28 | | 3 | 14.29 | | | |
| Zone | | | | | | | | |
| 1 | 3 | 12 | | 5 | 23.81 | | | |
| 2 | 22 | 88 | | 16 | 76.19 | | | |
| Dominant hand | | | | | | | | |
| Right | 22 | 88 | | 21 | 100 | | | |
| Left | 3 | 12 | | 0 | 0 | | | |
| Duration of ischemia | | | | | | | | |
| Cold | 14 | 56 | | - | - | | | |
| Warm | 11 | 44 | | - | - | | | |
| Smoking | | | | | | | | |
| Yes | 11 | 44 | | 10 | 47.62 | | | |
| No | 14 | 56 | | 11 | 52.38 | | | |
| Chronic disease | | | | | | | | |
| Yes | 4 | 16 | | 5 | 23.81 | | | |
| No | 21 | 84 | | 16 | 76.19 | | | |

SD: Standard deviation

(p=0.020), microhemorrhages (p=0.021[b]), neoangiogenesis (p=0.001), and tortuosity (p=0.004), in patients who underwent replantation. However, these microvascular changes were not found to be significant in patients who underwent revascularization. On the other hand, we identified statistically significant changes in capillary loops, including an increase in capillary diameter (p=0.019) and capillary disarrangement (p=0.016[b]), in patients who underwent revascularization. We also observed statistically significant alterations in capillary disarrangement among patients who underwent replantation (p=0.039[b]) (Tables II and III).

The effect of capillary changes on clinical outcomes was not statistically significant in revascularization patients, whereas some vascular changes were statistically significant with clinical outcomes in replantation patients (Table IV). We identified a statistically significant relationship between dominant hand and microvascular enlargement (p=0.010) and microvascular hemorrhage (p=0.037) in replantation patients. There was a statistically significant negative relationship between the number of digital nerve repairs and microvascular enlargement in replantation patients (p=0.049) (Table V). Moreover, there was a statistically significant negative and moderate relationship between tortuosity and two-point discrimination (mm) in replantation patients. We established a significant relationship between hyperesthesia and neoangiogenesis (p=0.048) and capillary disarrangement in replantation patients (p=0.027). Furthermore, there was a statistically significant positive moderate relationship between subpapillary venous plexus and patient satisfaction in replantation patients (p=0.037) (Table IV). Smoking, hot and cold ischemia times had no statistically significant effect on clinical outcomes in both revascularization and replantation patients.

## DISCUSSION

The main finding of the present study was the detection of significant alterations within the microvascularity, including subpapillary venous plexus, microvascular enlargement, microhemorrhages, neoangiogenesis, and tortuosity, among patients who underwent replantation. However, these microvascular changes were not significant in patients who underwent revascularization. In addition, our study revealed that microvascular changes were only detected in

**TABLE II**
Analysis of microvascular alterations in patients undergoing replantation and revascularization

| | Replantation | | | | Revascularization | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean±SD | Median | Min-Max | *p* | Mean±SD | Median | Min-Max | *p* |
| Non-operated digit capillary loop count (per 1 mm) | 9.24±1.42 | 9 | 6-12 | 0.591* | 9±1.05 | 9 | 7-11 | 0.382* |
| Operated digit capillary loop count (per 1 mm) | 9.36±1.52 | 9 | 7-12 | | 8.71±1.55 | 8 | 7-13 | |
| Non-operated digit crossing capillary (per 1 mm) | 2.08±2.02 | 1 | 0-8 | 0.099* | 2.52±1.72 | 2 | 0-5 | 0.335* |
| Operated digit crossing capillary (per 1 mm) | 2.48±1.48 | 2 | 0-5 | | 2.24±1.67 | 2 | 0-7 | |
| Non-operated digit tortuosity (per 1 mm) | 0.71±1.04 | 0 | 0-4 | **0.004*** | 0.62±1.12 | 0) | 0-3 | 0.102* |
| Operated digit tortuosity (per 1 mm) | 1.6±1.26 | 1 | 0-4 | | 1.24±1.3 | 1 | 0-4 | |
| Non-operated digit average capillary diameter (per 1 mm) | 0.36±0.81 | 0 | 0-3 | **0.016*** | 0.19±0.51 | 0 | 0-2 | **0.019*** |
| Operated digit average capillary diameter (per 1 mm) | 1.08±1.08 | 1 | 0-4 | | 0.86±1.24 | 0 | 0-4 | |
| Non-operated digit microvascular enlargement (per 1 mm) | 0.48±092 | 0 | 0-3 | **0.020*** | 0.24±0.54 | 0 | 0-2 | 0.321* |
| Operated digit microvascular enlargement (per 1 mm) | 1.12±1.09 | 1 | 0-4 | | 0.57±1.12 | 0 | 0-2 | |

SD: Standard deviation; * Wilcoxon test.

**TABLE III**

Analysis of microvascular alterations in patients undergoing replantation and revascularization

| Replantation | | Operated digit subpapillary venous plexus (per 1 mm) | | | Revascularization | | Operated digit subpapillary venous plexus (per 1 mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Yes | No | *p* | | | Yes | No | *p* |
| Non-operated digit subpapillary venous plexus (per 1 mm) | Yes | 0 | 0 | <0.001* | Non-operated digit subpapillary venous plexus (per 1 mm) | Yes | 1 | 0 | 0.125* |
| | No | 16 | 9 | | | No | 4 | 16 | |

| | | Operated digit microaneurysm (per 1 mm) | | | | | Operated digit microaneurysm (per 1 mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No | Yes | | | | No | Yes | |
| Non-operated digit microaneurysm (per 1 mm) | No | 22 | 3 | 0.25* | Non-operated digit microaneurysm (per 1 mm) | No | 20 | 1 | 1.000* |
| | Yes | 0 | 0 | | | Yes | 0 | 0 | |

| | | Operated digit neoangiogenesis (per 1 mm) | | | | | Operated digit neoangiogenesis (per 1 mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No | Yes | | | | Yes | No | |
| Non-operated digit neoangiogenesis (per 1 mm) | Yes | 1 | 0 | **0.001*** | Non-operated digit neoangiogenesis (per 1 mm) | Yes | 1 | 0 | 1.000* |
| | No | 11 | 13 | | | No | 0 | 20 | |

| | | Operated digit capillary disarrangement (per 1 mm) | | | | | Operated digit capillary disarrangement (per 1 mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No | Yes | | | | No | Yes | |
| Non-operated digit capillary disarrangement (per 1 mm) | No | 12 | 8 | **0.039*** | Non-operated digit capillary disarrangement (per 1 mm) | No | 6 | 7 | **0.016*** |
| | Yes | 1 | 4 | | | Yes | 0 | 8 | |

| | | Operated digit microhemorrhage (per 1 mm) | | | | | Operated digit microhemorrhage (per 1 mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Yes | No | | | | Yes | No | |
| Non-operated digit microhemorrhage (per 1 mm) | Yes | 0 | 1 | **0.021*** | Non-operated digit microhemorrhage (per 1 mm) | Yes | 0 | 2 | 1.000* |
| | No | 9 | 15 | | | No | 2 | 17 | |

* Mc-Nemar test.

**TABLE IV**
The impact of microvascular alterations in replantation and revascularization on clinical prognosis of patients

| | Replantation | | | | | |
|---|---|---|---|---|---|---|
| | Two-point discrimination | VAS score | Patient satisfaction | Cold intolerance | Hyperesthesia | Hypoesthesia |
| Tortuosity | −0.480Ω | 0.065Ω | 0.344† | 0.416† | 0.402† | 0.392† |
| | 0.017* | 0.764* | 0.785* | 0.595* | 0.634* | 0.663* |
| Capillary diameter | −0.085Ω | 0.078Ω | 0.433† | 0.434† | 0.408† | 0.506† |
| | 0.686* | 0.713* | 0.659* | 0.655* | 0.727* | 0.437* |
| Microvascular enlargement | −0.162Ω | −0.058Ω | 0.431† | 0.395† | 0.425† | 0.304† |
| | 0.440* | 0.783* | 0.522* | 0.630* | 0.540* | 0.852* |
| Subpapillary venous plexus | 0.608† | 0.408† | 0.514‡ | 0.031Ø | 0.238Ø | 0.127Ø |
| | 0.496* | 0.431* | 0.037* | 0.876* | 0.234* | 0.524* |
| Capillary disarrangement | 0.573† | 0.509† | 0.356‡ | 0.226Ø | 0.442Ø | 0.127Ø |
| | 0.610* | 0.179* | 0.205* | 0.258* | 0.027* | 0.524* |
| Microhemorrhage | 0.693† | 0.470† | 0.293‡ | 0.068Ø | 0.263Ø | 0.053Ø |
| | 0.220* | 0.265* | 0.343* | 0.734* | 0.188* | 0.792* |
| Neoangiogenesis | 0.673† | 0.302† | 0.293‡ | 0.121Ø | 0.395Ø | 0.167Ø |
| | 0.278* | 0.736* | 0.343* | 0.546* | 0.048* | 0.404 |
| | Revascularization | | | | | |
| Capillary diameter | 0.063Ω | −0.136Ω | 0.380† | 0.615† | 0.466† | 0.273† |
| | 0.786* | 0.555* | 0.767* | 0.169* | 0.547* | 0.937* |
| Capillary disarrangement | 0.558† | 0.239† | 0.153‡ | 0.001Ø | 0.001Ø | 0.229Ø |
| | 0.575* | 0.794* | 0.781* | 1.000* | 1.000* | 0.293* |

* P value; Ω Pearson correlation; † Eta correlation; ‡ Cramer's V correlation; Ø Phi correlation.

the replanted digits, with no observable capillary changes in the adjacent and corresponding fingers. Sikorska et al.[11] used nailfold capillaroscopy for the early diagnosis of vasculopathy in hand transplant patients, as it is easy, non-invasive, and repeatable. The capillaroscopic assessment of the hand allografts showed considerable capillary disorganization, characterized by a decrease in capillary count, the presence of enlarged and branched loops, and microhemorrhages. The study found a correlation between serum vascular endothelial growth factor (VEGF) levels and average capillary diameter. The authors reported that elevated VEGF and significant capillary abnormalities were observed in patients with hand allografts. Hand transplant recipients also showed capillary abnormalities in healthy hands, suggesting chronic rejection and systemic effect of VEGF on microvascular structures. Microvascular changes on the transplants side disrupt normal capillary blood flow, leading to tissue hypoxia, which is considered a potent stimulus for the synthesis of VEGF.[12] Of note, VEGF serves as the principal stimulant of pathological angiogenesis.[13] Microvascular changes can be ascribed to endothelial cell dysfunction causing transition to activated myofibroblasts, reduced levels of serum vasodilators and the excessive production of vasoconstrictors.[14] The extended impairment of microvascular tone leads to the dilation of endothelial junctions, resulting in an up-regulation of microvascular permeability and a reduction in capillary loops, contributing to the development of microhemorrhages and localized edema.[15] These changes serve as indicators of capillary loop damage, effectively bridging the gap between the presence of enlarged capillaries and desertification.[16]

The incidence of complications, including digital artery spasm and thrombosis following digital replantation has been documented to be as high as 50 to 70% within the first 48 to 92 h after replantation.[17] Early recognition of such problems is essential for effective replantation. If not recognized promptly, a vascular crisis may lead to the loss of a replanted finger. Numerous techniques for post-replantation circulatory monitoring have been

**TABLE V**
Assessing the impact of digital vein, artery, and nerve repairs on microvascular alterations in patients undergoing replantation and revascularization

| | Replantation | | | | | | Revascularization | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Digital vein repair | *p* | Digital artery repair | *p* | Digital nerve repair | *p* | Digital vein repair | *p* | Digital artery repair | *p* | Digital nerve repair | *p* |
| Capillary loop count | 0.001* | 0.995 | −0.175* | 0.404 | −0.32* | 0.119 | 0.424* | 0.055 | 0.42* | 0.058 | 0.35* | 0.120 |
| Crossing capillary | −0.15* | 0.474 | −0.084* | 0.689 | 0.02* | 0.925 | 0.157* | 0.497 | −0.193* | 0.403 | 0.165* | 0.475 |
| Tortuosity | −0.23* | 0.28 | −0.376* | 0.07 | −0.346* | 0.098 | −0.169* | 0.464 | −0.155* | 0.503 | 0.111* | 0.632 |
| Capillary diameter | −0.137* | 0.513 | −0.302* | 0.142 | −0.408* | 0.043 | −0.129* | 0.577 | −0.09* | 0.697 | 0.376* | 0.093 |
| Microvascular enlargement | −0.045* | 0.831 | −0.272* | 0.188 | −0.398* | 0.049 | −0.228* | 0.319 | 0* | 1 | −0.033* | 0.886 |
| Subpapillary venous plexus | 0.046** | 0.977 | 0.161** | 0.442 | 0.089 | 0.916 | 0.235** | 0.599 | 0.23** | 0.316 | 0.251** | 0.555 |
| Capillary disarrangement | 0.188** | 0.674 | 0.329** | 0.108 | 0.486 | 0.052 | 0.41** | 0.191 | 0.224** | 0.33 | 0.405** | 0.199 |
| Microaneurysm | 0.172** | 0.719 | 0.327** | 0.11 | 0.302 | 0.35 | 0.108** | 0.899 | 0.354** | 0.116 | 0.354** | 0.301 |
| Microhemorrhage | 0.337** | 0.266 | 0.351** | 0.086 | 0.425 | 0.112 | 0.499** | 0.076 | 0.23** | 0.316 | 0.251** | 0.555 |
| Neoangiogenesis | 0.242** | 0.516 | 0.026** | 0.902 | 0.232 | 0.544 | 0.235** | 0.599 | 0.23** | 0.316 | 0.251** | 0.555 |

* Pearson correlation; ** Eta correlation.

documented in the literature, including capillary refill time assessment,[18] Doppler ultrasound,[19] digital subtraction angiography,[17] and computed tomography (CT) angiography.[19] Furthermore, Lu et al.[20] suggested that employing nailfold capillaroscopy for observation and monitoring could serve as an effective and valuable strategy for promptly diagnosing and subsequently managing vascular perfusion irregularities in replanted digits through non-invasive means. Their publication highlighted that replanted digits with acute microvascular discontinuity could be salvaged from necrosis by rapid surgical intervention facilitated by capillaroscopy.

Meuli-Simmen et al.[21] indicated that the nail-fold capillaries detected by capillaroscopy did not exhibit pathologic changes in the 10 years following the replantation of fingers and upper limbs. Unlike, we did not detect pathological changes in patients who underwent revascularization in our study, but we detected microvascular changes in the replanted fingers over an average period of six years. To the best of our knowledge, there is a limited number of studies in the literature on this subject. Our study identified significant microvascular alterations, including changes in the subpapillary venous plexus, neoangiogenesis, and tortuosity, among replantation patients. Additionally, we found noteworthy alterations in capillary microvascular structure among patients who underwent revascularization, notably, an enlargement in capillary diameter and capillary disarrangement. These findings emphasize the impact of replantation surgery on microvascular condition. Therefore, our study demonstrates how replantation surgery can affect microvascular condition over the long term, emphasizing the need for patient monitoring to achieve optimal outcomes.

Cutolo et al.[22] suggested that vascular tone control was linked to the regulation of the microvasculature and that defective innervation of the microvasculature might be the primary cause of tone control loss. The prolonged impairment of microvascular tone is due to the dilatation of endothelial junctions with an up-regulation of microvascular permeability and a reduction of capillary loops, leading to microhemorrhages and local edema.[15] Building upon this knowledge, our study revealed that the number of nerve repairs had a significant effect on microvascular capillary diameter in patients who underwent replantation, indicating that the presence of neural stimulus may play a crucial role in regulating microvascular tones. We also established that microvascular alterations were not influenced by the number of repaired arteries and veins in replantation patients. Determining the clinical effects of neurovascular changes separately is challenging. Cold intolerance subsequent to digit replantation is aggravated by diminished blood flow within the affected digits.[23] The precise etiology of cold intolerance ensuing from digital nerve injury remains elusive. While several hypotheses have been proposed suggesting that cold sensitivity may stem from neurogenic rather than vascular etiologies,[23,24] alternative hypotheses have identified post-surgical circulatory disturbances as significantly impeding sensory recovery.[25,26] The etiology of cold intolerance appears to involve complex vascular and neural interactions. In our study, we found no association between the number of nerve repairs and cold intolerance during six years of follow-up, suggesting that a single nerve repair may have sufficed to prevent its development. In the current study, although a single nerve repair seemed to be sufficient to prevent the complication of cold intolerance, we usually made an effort to perform two nerve repairs in our operations as recommended by the current literature.[27] On the other hand, we found no significant microvascular changes during capillaroscopic examinations performed in patients with cold intolerance. Klein-Weigel et al.[28] similarly reported no significant microvascular changes in patients with cold intolerance in their capillaroscopic evaluation, consistent with our study. In addition, we noticed that the condition was not affected by cold and warm ischemia time. Hyperesthesia, another cardinal neurogenic disorder, may emerge after digit replantation and is characterized by increased sensitivity to touch, often resulting in severe pain with minimal contact. Hyperesthesia typically resolves within months or years of surgery, whereas some patients experience it as a persistent symptom. We identified a remarkable relationship between unresolved hyperesthesia and the presence of neoangiogenesis in the capillary microstructure through microvascular investigation. Furthermore, we determined capillary disarrangement in replantation patients.

In their study, Yuksel et al.[29] reported that chronic smoking led to morphological changes in nailfold capillaries, with smokers showing more microvascular abnormalities, particularly capillary enlargement and microhemorrhages, compared to non-smokers. However, we observed that smoking status did not correlate to any significant microvascular changes in patients who underwent replantation and revascularization. There was no significant association between smoking and clinical outcomes at six years of follow-up or patient satisfaction. Although there are studies in the literature showing that smoking in the acute period has an adverse effect on the success of replantation and revascularization,[30,31] some authors have advocated that there is no significant difference in replantation success between smokers and non-smokers.[32,33] The subpapillary venous plexus within the dermis is thought to play a role in the regulation of skin temperature.[34] In children, the subpapillary vascular network is conspicuously visible; conversely, in adults, the subpapillary venous plexus tends to be rudimentary in the nailfold.[35] Gumina et al.[36] reported a statistically significant correlation between the presence of subpapillary venous plexus in the nailfold and rotator cuff tear associated with microcirculatory impairment. In our study, we revealed the subpapillary venous plexus to be a significant microvascular change in patients who underwent digit replantation. We also observed a statistically significant correlation between the subpapillary venous plexus and patient satisfaction which can be attributed to thermoregulatory function.

Capillaroscopy may be a promising tool for the diagnosis of complications in the replantation patient cohort and for assessing the outcome of the replanted digit. Currently, there is a lack of consensus on what the critical outcomes in replantation and revascularization surgery are and how best to measure them. This lack of consistency between the outcomes and measures used makes it difficult to pool and compare results of individual studies. This heterogeneity introduces biases, impedes clinical decision-making, and obstructs the ability to compare results.[37] Taken together, we believe that capillaroscopy can contribute to objectivity in measuring outcomes for patients undergoing replantation and revascularization.[38]

Nonetheless, there are some limitations to this study. First, the sample size is relatively small. Second, the study was designed in a retrospective nature. Another limitation of the study is that the capillaroscopic examination of the patients was only evaluated once at the last follow-up visit. In a larger cohort, observing changes in capillary condition during the early, mid, and late stages, accompanied by multiple capillaroscopy examinations, would yield more robust outcomes.

In conclusion, our study showed that replantation patients who underwent two nerve repairs exhibited a well-regulated microvascular tone. However, we did not observe a statistically significant relationship between the number of nerve repairs and cold intolerance. To the best of our knowledge, this is the first study to investigate the association between replantation and revascularization in terms of changes in nailfold capillaries. Based on these findings, we highlight the potential of nailfold capillaroscopy in detecting microvascular changes following replantation and revascularization, which may contribute to a better understanding of the etiology of neurovascular complications. Further comprehensive, controlled studies evaluating early, mid, and long-term microvascular changes related to nailfold capillaroscopy and correlating these with clinical outcomes would contribute to improving the results and complications of replantation and revascularization surgery.

**Data Sharing Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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