Clinical Utility of Laser Doppler Flowmetry for Monitoring Digital Circulation after Replantation: Differentiation between Tissue Ischemia and Congestion

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Digital replantation has recently become a common treatment method, and improvements in surgical techniques have increased its success rate.[1] However, the overall failure rate remains a significant issue. Appropriate measurement of blood flow in transplanted tissue is important to prevent critical circulation failure. Of the various modalities advocated for postoperative monitoring of blood flow, laser-Doppler flowmetry (LDF) is considered useful for assessing interstitial blood flow.[2,3] The aim of the present study was to demonstrate the utility of LDF for blood flow evaluation and differentiation between ischemia and congestion in replanted digits.

Patients and Methods

This study followed the principles outlined in the Declaration of Helsinki and was approved by the Institutional Ethics Committee of New Tokyo Hospital. Each patient gave an informed consent. A consecutive series of 18 fingers was originally registered, but 5 were excluded due to incomplete data. Therefore, this prospective analysis was performed involving 13 digits of 9 patients who underwent digital replantation and revascularization in the Department of Plastic Surgery at New Tokyo Hospital. A successful outcome was defined as wound healing by bonding of biological tissues after surgery. A commercially available LDF device was used (FLO-N1; OMEGAWAVE, Inc., Tokyo, Japan) (►**Fig. 1A–C**).[4] The blood volume and flow velocity in the tissue were measured independently, and the blood flow (mL/min/100 g of tissue) was calculated as the product of these two components. Graphically displayed continuous data revealed a saw-tooth waveform, showing high values in the systolic phase and low values in the diastolic phase. Digital circulation was evaluated using the absolute value of the blood flow, peak-to-peak (PP) value, and PP%. The PP value was defined as the difference between the minimum and maximum values of the flow signals as displayed in the waveform graph, and the PP% was defined as the PP value/average blood flow × 100.

Results

In eight digits with a successful outcome by a single surgery involving anastomosis of arteries and veins, the average blood flow volume was 12.4 mL/min/100 g immediately after surgery, remaining mostly constant (►**Fig. 1D**). Blood volume differences between the reconstructed and intact digits in this group showed that the approximate value gradually decreased as time elapsed postoperatively (data not shown). In three digits that developed necrosis, the average blood flow volume was 1.14 mL/min/100 g immediately after surgery, which was significantly lower than that of the eight digits with successful outcomes (►**Fig. 1D**).

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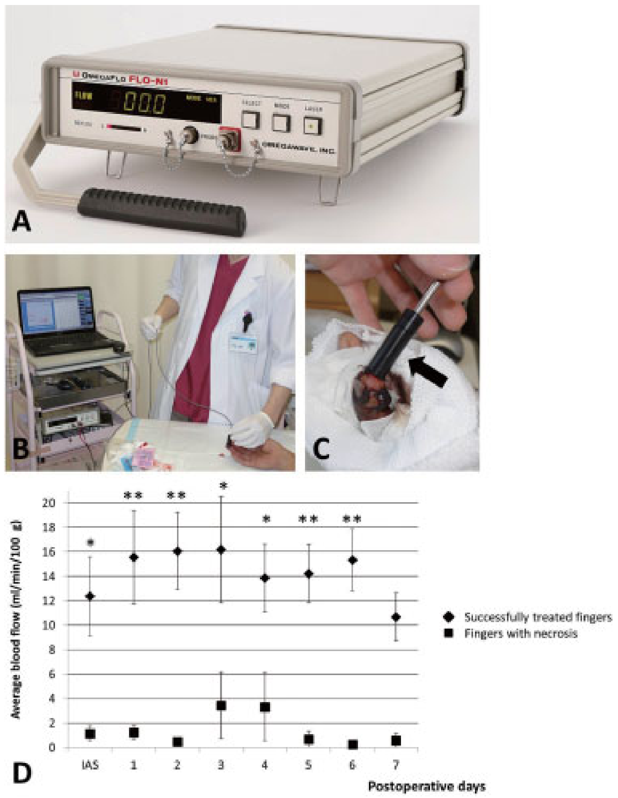

Fig. 1 (**A**) Photograph of the noncontact laser tissue blood flowmeter (FLO-N1; OMEGAWAVE, Inc., Tokyo, Japan) used in this study. (**B**) Blood flow measurement in the emergency room. (**C**) Measurement after surgery. The maximum measuring range of the probe is represented by a circular plate of 15 mm diameter and 1 mm depth. We fixed a plastic external cylindrical applicator of 10 mm diameter at the tip of the probe to achieve measurement stability and positioned the probe 20 mm away from the target finger site. The arrow indicates the external applicator. (**D**) Average blood flow of successfully treated fingers (diamonds) and fingers in which necrosis occurred (squares). Data are expressed as mean ± standard error of the mean. IAS, immediately after surgery. $^{*}p < 0.05$ and $^{**}p < 0.01$ between two groups with two-way analysis of variance with post-hoc Scheffe's test.

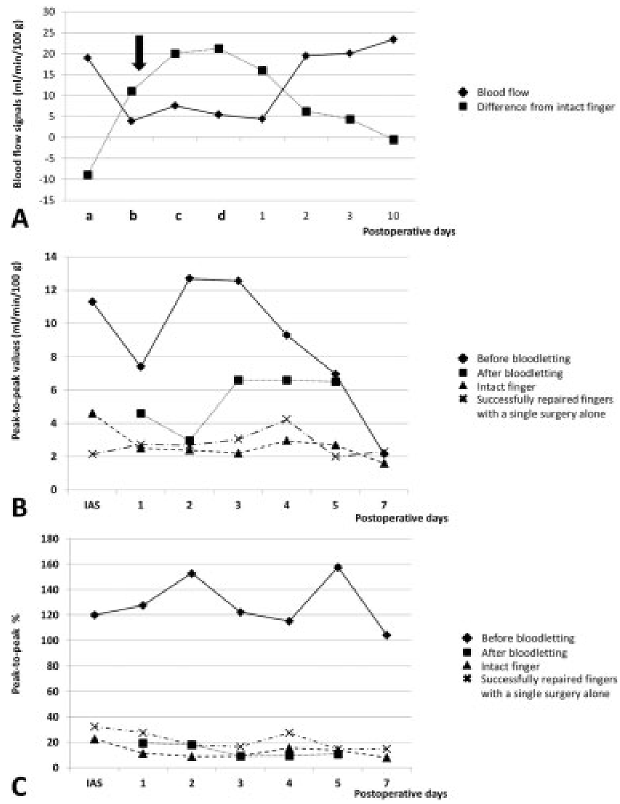

Fig. 2 (**A**) Blood flow of a salvaged digit after reanastomosis. Absolute values (diamonds) and the difference in blood flow between the re-repaired finger and intact finger (squares) are shown. Reanastomosis was conducted 8 hours after the first surgery (arrow). a, Immediately after the first surgery; b, 8 hours after the first surgery; c, Immediately after the reanastomosis; and d, 5 hours after the reanastomosis. (**B**) Peak-to-peak (PP) values (the difference between the minimum and maximum values) of the repaired finger of a patient with venous congestion (diamonds, before bloodletting; squares, after bloodletting), the intact finger of the patient (triangles), and successfully repaired fingers with a single surgery alone (Xs). (**C**) PP% (PP values/average blood flow volume × 100) of the repaired finger of a patient with venous congestion (diamonds, before bloodletting; squares, after bloodletting), the intact finger of the patient (triangles), and successfully repaired fingers with a single surgery alone (Xs). IAS, immediately after surgery.

We herein report the detailed progress of the other two cases. In a 78-year-old man with incomplete amputation of the left little finger, the digital blood flow markedly decreased at 8 hours postoperatively, and the difference in blood flow between the repaired and the intact finger increased (►**Fig. 2A**). Reanastomosis of the finger was performed. A blood clot was found at the arterial anastomosis site, and reanastomosis of the artery was conducted after removal of the clot. The blood flow gradually recovered (►**Fig. 2A**), and complete tissue bonding of the digit was achieved. In a 59-year-old man with complete amputation of the right middle finger, although the central artery was anastomosed, anastomosis of the vein was not possible. Congestion was observed soon after surgery, and bloodletting was performed using medicinal leeches once a day for 5 days. The PP value of the reconstructed finger was higher than that of this patient's intact finger and the repaired fingers of patients with successful treatment by a single surgery and decreased after bloodletting (►**Fig. 2B**), which might reflect the clinical improvement of venous congestion. The PP% value showed a similar tendency (►**Fig. 2C**).

Discussion

In transplanted tissue, early detection of circulation failure and appropriate timing of retreatment significantly improve the possibility of digital salvage. The present study demonstrates that LDF measurement is useful for both predicting outcomes and ascertaining whether ischemia or congestion cause low tissue blood flow. We defined the PP value and PP% as indices of congestion. When occlusion of the vein occurred, the blood volume increased and the velocity decreased in the systolic phase. In the diastolic phase, the blood volume decreases and velocity further decreases from the systolic phase, leading to a greater difference between the systolic and diastolic phases, and the PP value increases. In the patient with venous congestion in the present study, the PP value and PP% increased after surgery and decreased after bloodletting (►**Fig. 2B, C**), suggesting that the congestion had improved. Conventionally, the decision to perform emergent re-reconstruction and other additional treatments has been made by an experienced surgeon based on the results of a pinprick test, skin color, and turgor. LDF is technically easier to perform, and data interpretation is more straightforward; this allows even inexperienced personnel to evaluate the blood flow and identify signs of circulation failure. In conclusion, LDF evaluation for replanted digits can be clinically useful because it can display quantitative signs of tissue ischemia or congestion. A larger study is necessary to accurately evaluate the utility of LDF and calculate useful thresholds to predict the ischemia or venous congestion.

Conflict of Interest
None.

References

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