INTRODUCTION

Perforator flaps are a reliable reconstructive technique, with versatility and minimal donor site morbidity [1-3]. High mobility and ample transposition are clear advantages of perforator flap surgery. However, flap movement directly affects the small perforator pedicles. When used as pedicled flaps, venous congestion and partial necrosis have been reported to occur in up to...
42% of cases [4,5]. The early detection of possible complications is related to the surgeon’s experience, and is essentially based on flap clinical monitoring, including skin color, turgor, swelling, capillary refill time, temperature, and bleeding characteristics after a pinprick [6-8]. All of these evaluations are made postoperatively, when little can be changed in the planned reconstruction.

Many new instrumental techniques have been proposed to support clinical monitoring of free flaps [9,10]. Near-infrared spectroscopy (NIRS)–based technology measures the capillary blood oxygen saturation (SpO\textsubscript{2}) in the dermal capillaries, immediately after its noninvasive application. A sterile probe can be used for intraoperative measurements. However, the use of NIRS in flap monitoring has only been reported in two animal studies. A decrease in SpO\textsubscript{2} within hours after flap elevation was reported to predict flap viability [11,12].

The aim of this study was to use NIRS technology for the immediate evaluation of flap vascularization and to assess the ability of immediate NIRS to predict the postoperative clinical course.

**METHODS**

We prospectively analyzed 12 consecutive patients needing 13 pedicled perforator flaps for reconstructive surgery, who were referred to our department from March 2017 to July 2018. All patients were preoperatively studied with Huntleigh Doppler ultrasound for perforator vessel identification and mapping. Intraoperative flap superficial oximetry was recorded with Somanetics INVOS 5100C Cerebral/Somatic Oximeter (Medtronic, Dublin, Ireland) sterile patch sensors, both before transposition and after transposition of the flap to the definitive recipient site (Figs. 1, 2).

The change in SpO\textsubscript{2} (ΔSpO\textsubscript{2}, expressed in percentage points) indicates the absolute intraoperative drop in SpO\textsubscript{2}. The SpO\textsubscript{2} ratio, defined as (SpO\textsubscript{2} before transposition–SpO\textsubscript{2} after transposition)/SpO\textsubscript{2} before transposition, refers to the relative intraoperative drop of SpO\textsubscript{2} and allows a better comparison of results, independent from the absolute values of SpO\textsubscript{2}. The arc of rotation (in degrees) and area of harvesting (in square centimeter) were registered intraoperatively for every pedicled flap. In all cases, perforator identification, oximetry measurement, and flap dissection were performed by the same surgeon in the same department. The differences between oximetry changes were evaluated using the Wilcoxon signed-rank test. The association between flap saturation and necrosis occurrence was analyzed using linear regression analysis.

**RESULTS**

Seven male and five female patients were referred to our department for reconstruction with a perforator flap. Nine patients suffered from axillary Hurley stage III hidradenitis suppurativa. A thoraco-dorsal artery perforator flap was the most frequent reconstruction. Patients’ mean age was 38.7 ± 20.0 years, with a mean body mass index (BMI) of 26.5 ± 5.1 kg/m\textsuperscript{2}. Seven patients were active smokers. Only one patient had diabetes mellitus. No other known comorbidities were present that would constitute a risk factor for the outcomes of perforator flap reconstruction. Details about the diseases and reconstruction tech-
niques are outlined in Table 1.

The mean flap area was 82.79 ± 32.88 cm², with a mean rotation angle of 114.17° ± 35.02°. The mean flap SpO₂ before and after transposition were 92% ± 3% and 78% ± 19%, respectively. The mean ΔSpO₂ registered was 14% ± 17%, with a range of 0% to 55%. The mean SpO₂ ratio was 15% ± 19%. Details about flap characteristics and oximetry measurements are outlined in Table 2.

Partial necrosis of the flap occurred in three patients, and total necrosis was observed in only one patient (the patient with diabetes mellitus).

No differences in age, BMI, smoking history, flap dimensions, or arc of rotation were found to be statistically significant between patients with and without postoperative flap necrosis. Linear regression analysis did not show significant associations of BMI, flap size, and rotation angle with the saturation ratio.

No significant difference was found in before-transposition flap saturation between patients with and without necrosis. However, differences in after transposition SpO₂ (61.6% vs. 89.6%, P = 0.025), ΔSpO₂ (28.8% vs. 3.1%, P = 0.021) and the mean saturation ratio (32.3% vs 3.5%, P = 0.027) were found to be significant between patients with and without postoperative flap necrosis.

Despite the significant difference in the mean saturation ratio between the necrotic and non-necrotic flaps, no significant correlation was found between the saturation ratio and the percentage of necrotic area.

**DISCUSSION**

Perforator flap reconstruction is a transposition of skin islands, based on tiny arterial vessels usually smaller than 2 mm. Flap movement affects the perforator pedicle, but its effects may be detectable only after some hours after the operation. Prompt detection of a vascular issue in pedicled perforator flaps may help the surgeon to reduce the complication rate. Thus, surgeons have consistently pointed out the need for technical support to early predict possible vascular complications.

In 1975, Creech and Miller outlined the criteria they considered essential for an "ideal" free flap monitoring device [13]. These included safety to the patient and flap, applicability to all flap types, rapid response to blood flow changes, accuracy, affordability, and ease of interpretation [14]. Many techniques have been proposed, such as an implantable Doppler ultrasound

| Patient | BT SpO₂ (%) | AT SpO₂ (%) | ΔSpO₂ (%) | SpO₂ ratio | Necrosis |
|---------|-------------|-------------|-----------|------------|---------|
| 1       | 95          | 78          | 17        | 18         | 1       |
| 2       | 90          | 68          | 22        | 24         | 1       |
| 3       | 94          | 61          | 33        | 35         | 1       |
| 4       | 88          | 71          | 17        | 19         | 1       |
| 5       | 95          | 95          | 0         | 0          | 0       |
| 6       | 89          | 85          | 4         | 4          | 0       |
| 7       | 88          | 79          | 9         | 10         | 0       |
| 8       | 95          | 95          | 0         | 0          | 0       |
| 9       | 92          | 81          | 11        | 12         | 0       |
| 10      | 93          | 92          | 1         | 1          | 0       |
| 11      | 95          | 95          | 0         | 0          | 0       |
| 12      | 95          | 95          | 0         | 0          | 0       |
| Mean Necr | 90.4 | 61.6 | 28.8 | 32.3 |
| Mean No Necr | 92.75 | 89.6 | 3.1 | 3.5 |
| P-value  | 0.31 < 0.05 < 0.05 < 0.05 |

ΔSpO₂ and the SpO₂ ratio indicate the absolute and relative intraoperative change in SpO₂. BT, before transposition; AT, after transposition; SpO₂, saturated oxygen; Necr, flaps with partial or total necrosis; No Necr, flaps without necrosis.

**Table 1. Patient demographics and operative data**

| Patient | Age (yr) | BMI (kg/m²) | Smoke | Diagnosis | Flap | Area (cm²) | Rotation (°) |
|---------|----------|-------------|--------|-----------|------|------------|--------------|
| 1       | 47       | 38          | +      | HS        | TDA P| 144        | 100          |
| 2       | 54       | 21.6        | –      | Trauma    | TDA P| 36         | 110          |
| 3       | 51       | 26.6        | +      | HS        | SIE A| 90         | 90           |
| 4       | 51       | 26.6        | –      | HS        | SIE A| 30         | 90           |
| 5       | 19       | 32          | –      | HS        | TDA P| 98         | 100          |
| 6       | 19       | 20.9        | +      | HS        | TDA P| 84         | 120          |
| 7       | 24       | 30.3        | +      | HS        | TDA P| 80         | 110          |
| 8       | 24       | 22          | +      | Trauma    | ALT  | 78         | 170          |
| 9       | 21       | 24.7        | +      | HS        | TDA P| 52.5       | 60           |
| 10      | 85       | 24          | –      | Skin cancer | ALT  | 126        | 60           |
| 11      | 52       | 30.9        | –      | Skin cancer | DIE P| 90         | 90           |
| 12      | 20       | 20.8        | –      | HS        | TDA P| 84         | 170          |
| Mean ± SD | 36.69 ± 20.01 | 26.48 ± 5.12 | 82.79 ± 32.88 | 114.17 ± 35.02 |

BMI, body mass index; HS, hidradenitis suppurativa; TDA P, thoracodorsal artery perforator; PTP, posterior tibial artery perforator; SIE A, superficial inferior epigastric artery; ALT, antero-lateral thigh; DIE P, deep inferior epigastric perforator.
probe, pulse oximetry, laser Doppler flowmetry, color Duplex sonography, NIRS, and tissue pH monitoring with microdialysis [15]. Although all these devices have improved flap salvage rates, none has proved to be superior to others.

NIRS is a tool for noninvasive measurement of tissue components. It is operator-independent and easy to manage, even by non-experts. It is important to avoid unstable probe contact and external light irradiation that can cause impossible or incorrect measurements. Regarding free flaps, NIRS has been reported to be a reliable technique to accurately detect decreases in flap perfusion (sensitivity, 99.1%; specificity, 99.9%) [14,16]. As reported in the literature, NIRS seems to detect vascular compromise of free flaps prior to clinical or Doppler monitoring [17,18].

Ozturk et al. [19] demonstrated no significant correlation between SpO\textsubscript{2} and blood pressure, supplemental O\textsubscript{2}, flap type, perforator number, or vessel caliber. There is also no universally accepted consensus regarding a risk threshold during free-flap monitoring by NIRS, but the most widely supported criteria, proposed by Keller, indicate that a flap SpO\textsubscript{2} lower than 30% or a drop rate in SpO\textsubscript{2} equal to or greater than 20% per hour sustained for more than 30 minutes is predictive for vascular complications [20]. In our experiences with pedicled perforator flaps, an intraoperative drop rate in SpO\textsubscript{2} ratio equal to or greater than 15%–20% was significantly associated with partial or total flap necrosis. Thus, intraoperative NIRS seems to be a useful tool to predict vascular issues in the very first minutes after flap inset, when it is otherwise clinically silent. However, it should be kept in mind that the NIRS probes commercialized for flap monitoring have a measurement depth within 10 mm [21].

We did not find significant correlations between the saturation ratio and the percentage of necrotic area. This finding may be related to the restricted number of analyzed patients, and further studies are needed to confirm or refute our results. Finally, we did not find significant associations of BMI, flap size, and rotation angle with the saturation ratio. These data seem to suggest that pedicled perforator flaps are equally safe in different patients and defects.

The average before-transposition SpO\textsubscript{2} was overall good, ranging from 85% to 95%. Therefore, these perforator vessels were consistently sufficient to perfuse the entire skin paddle. In our case series, necrosis was most likely related to an insufficient length of the dissected pedicles to tolerate the torsion or minimal, but significant kinking. The ideal vessels should be larger than 0.5 mm in caliber and pulsatile, and the pedicle length should be at least 4 cm to reduce the risk of torsion.

An intraoperative drop rate in SpO\textsubscript{2} ratio equal or greater than 15%–20% was predictive for vascular complications in pedicled perforator flaps. Conversely, flap size and rotation angle did not seem to be correlated with the risk of flap necrosis. Prompt detection of a vascular issue in pedicled perforator flaps could help the surgeon to reduce the complication rate; consequently, an immediate exploration of pedicle vessels is recommended to exclude the presence of kinking, twisting, or tension.

This is the first study regarding the immediate effect of flap transposition on vascularization, as measured using NIRS monitoring. The main limitations of our study are the limited population and the single-center design. Further studies are needed to analyze the efficacy of changes in the intraoperative reconstruction plan following immediate NIRS measurements.

**NOTES**

**Conflict of interest**
No potential conflict of interest relevant to this article was reported.

**Ethical approval**
An official institutional review board (IRB) waiver of ethical approval was obtained from the IRB of Ospedale San Raffaele (exemption No. CE-11/int/2017) and performed in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained.

**Patient consent**
The patients provided written informed consent for the publication and the use of their images.

**Author contribution**
Conceptualization: A Marchesi. Data curation: F Amendola. Formal analysis: F Amendola. Methodology: S Marcelli. Project administration: L Vaienti. Visualization: P Garieri. Writing - original draft: A Marchesi, F Amendola. Writing - review & editing: A Marchesi, F Amendola.

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