Head and neck

Free flaps monitoring by Laser-Doppler Flowmetry in head and neck surgery

Monitoraggio dei lembi liberi mediante flussometria Laser-Doppler nella chirurgia della testa e del collo

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SUMMARY

Objective. Early recognition of free flap vascular impairment is essential for flap salvage attempts. Several methods for surveillance of post-operative flaps are available. Among these, we have extensively used Laser-Doppler Perfusion Flowmetry (LDF) monitoring. We report our experience on this topic and illustrate the advantages and weak points.

Methods. Over seven years, 110 consecutive free flaps for head and neck reconstruction were monitored using the Periflux System 5000® (Perimed AB, Järfälla, Sweden). In addition to maximum and minimum peaks, a pattern called vasomotion can be detected. Monitoring time lasted from 3 to 7 days, 24/24 h.

Results. Six of 110 (5.5%) cases of vascular problems were detected and clinically confirmed. In 5 cases, venous thrombosis was present: 4 patients were successfully treated. In 1 case, both arterial and venous thrombosis occurred. Flowmetry data always showed a more or less sudden disappearance of vasomotion.

Conclusions. LDF is a highly sensible, specific and reliable method. It is easy to use and interpret at low cost. Remote monitoring could also be developed.

KEY WORDS: free flap, monitoring, thrombosis, salvage, Laser-Doppler Flowmetry

RIASSUNTO

Obiettivi. *Il riconoscimento precoce della compromissione vascolare del lembo libero è essenziale per i tentativi di salvataggio del lembo. Sono disponibili molti metodi per la sorveglianza postoperatoria dei lembi. Tra questi, abbiamo ampiamente utilizzato la flussometria Laser-Doppler (FLD). Lo scopo del presente articolo è di riportare la nostra esperienza, illustrando vantaggi e punti deboli.*

Metodi. *In un lasso di tempo di sette anni, sono stati monitorati 110 lembi liberi consecutivi per la ricostruzione della testa e del collo utilizzando Periflux System 5000® (Perimed AB, Järfälla, Svezia). Oltre ai picchi massimi e minimi, veniva rilevato il pattern chiamato vasomotricità. Il tempo di monitoraggio è durato da 3 a 7 giorni, 24/24 h.*

Risultati. *Sono stati rilevati e clinicamente confermati 6/110 (5,5%) casi di disturbi vascolari. In 5 casi si è verificata una trombosi venosa: 4 di questi sono stati trattati con successo. In 1 caso si è verificata sia trombosi arteriosa che venosa. I dati della flussometria hanno sempre mostrato una più o meno improvvisa scomparsa della vasomotricità.*

Conclusioni. *FLD è un metodo altamente sensibile e specifico, quindi molto affidabile. È facile da usare e interpretare con un costo contenuto. Potrebbe essere sviluppato il monitoraggio in remoto.*

PAROLE CHIAVE: *lembi liberi, monitoraggio, trombosi, chirurgia di salvataggio, flussometria Laser-Doppler*

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Introduction

Microvascular free tissue transfer is recognised as an important method for the reconstruction of large and complex defects, owing to its superior functional and aesthetic outcomes, especially for the head and neck region even in older patients [1]. Free flap surgery appears to also be rewarding in terms of long-term outcomes and survival [2]. Despite success rates of around 95% or more[3], flap failure secondary to vascular impairment remains a demanding complication, leading to higher patient morbidity, prolonged hospital stay and increased healthcare costs.

Although salvage rates of failing free flaps vary with aetiology, flap type and experience, there is large consensus that early detection of vascular compromise and swift surgical re-exploration significantly increases the likelihood of successful free flap salvage [4]. Vascular impairment leading to flap failure occurs because of problems in either the flap's arterial inflow, capillary microcirculation, or venous outflow. As a consequence, monitoring methods to aid the early recognition of disturbances in flap circulation are critical in performing revision, thus maximising the success of free flap reconstruction. Numerous flap monitoring strategies and technologies exist, which vary in complexity, invasiveness, efficiency and cost [5,6]. Properties of the ideal free flap monitoring technique should be: inexpensive; harmless to both patient and flap; produce rapid, reliable, and objective results; simple to interpret by relatively inexperienced personnel; and applicable to all types of free flaps [6]. Various methods have been proposed, including prick test [7], microdialysis [8], Doppler (both implantable and external) [9], Near-Infrared Spectroscopy (NIRS) [10], Single Photon Emission Computed Tomography (SPECT) [11], thermal scan [12], Macrophage Migration Inhibitory Factor [13] and Laser-Doppler Flowmetry (LDF) [14,15]. The latter exploits wavelength variations of photons hitting blood red cells (BRC) while flowing. In other words, it is the known Doppler effect applied to the light laser instead of ultrasounds.

We have gained a considerable experience with LDF monitoring and report on the use of this technique for flap monitoring.

Materials and methods

We retrospectively studied 110 consecutive free flaps for head and neck reconstruction over seven years, which were postoperatively monitored with the Laser-Doppler Periflux System 5000® (Perimed AB, Järfälla, Sweden). Demographics are shown in Table I. The device includes a suturable probe and the main unit, coupled with specific software (Perisoft) in a laptop; continuous recording is plotted on a chart: the y-axis indicates the Relative Flow Values (RFV), and the X-axis reports the time. Besides the sinusoid indicating the minimum and maximum peaks of RFV (Fig. 1, blue line) – whose frequency is similar to the cardiac one – a further sinusoid with a frequency of about 0.05-0.15 Hz (3-9 cycles per minute) is detectable, indicating how the clusters of minimum/maximum peaks vary over time [14]. This wave conveys vasomotion (Fig. 1, green line). Vasomotion is the spontaneous oscillation in vascular tone in microcirculation and is believed to be a physiological mechanism facilitating the transport of blood gases and nutrients to and from tissues. Vasomotion can be described as recurrent organised fluctuations in vessel diameter over time. By frequency analysis, distinct frequency intervals related to physiological aspects can be presented as heart rate, respiration and myogenic, neurogenic, and endothelial-dependent activity [15].

Table I. Demographics

Characteristics	Value (%)
Age, years	
Median	58
Range	17-85
Gender	
Male	79 (71.8)
Female	31 (28.2)
Type of free flap	
Forearm	51 (46.3)
Fibula	21 (19.1)
ALT	12 (11)
Rectus abdominis	11 (10)
Jejunum	9 (8.2)
Dorsalis major	6 (5.4)
Reconstructed site	
Oral cavity	78 (70.9)
Larynx-hypopharynx	18 (16.4)
Pharynx	8 (7.3)
Cranio-maxillo-facial	6 (5.4)

According to the Doppler effect, ischaemia or reduced RBC speed (i.e. venous stasis) cause alterations that are shown as decreasing values in the chart. An arbitrary threshold of RFV can be set, below which an alarm is triggered. The threshold value was usually chosen according to prudential behaviour (i.e. better a false alarm than a missed critical event). The probe (reusable) was stitched to the flap at the most suitable position before the end of reconstruction or, whenever possible, before removal of clamps (Fig. 2). We always raised the flap together with a skin island – even when the main goal was bone reconstruction – to allow a more reliable signal. The skin island (or omentum, in the case of the jejunum) was systematically superficialised in the case of buried flaps. Monitoring time lasted from 3 to 7 days, 24/24 h. In the beginning, the recording was checked by physicians or instructed paramedics on an hourly basis. later, the control was integrated remotely using an app on a dedicated smartphone.

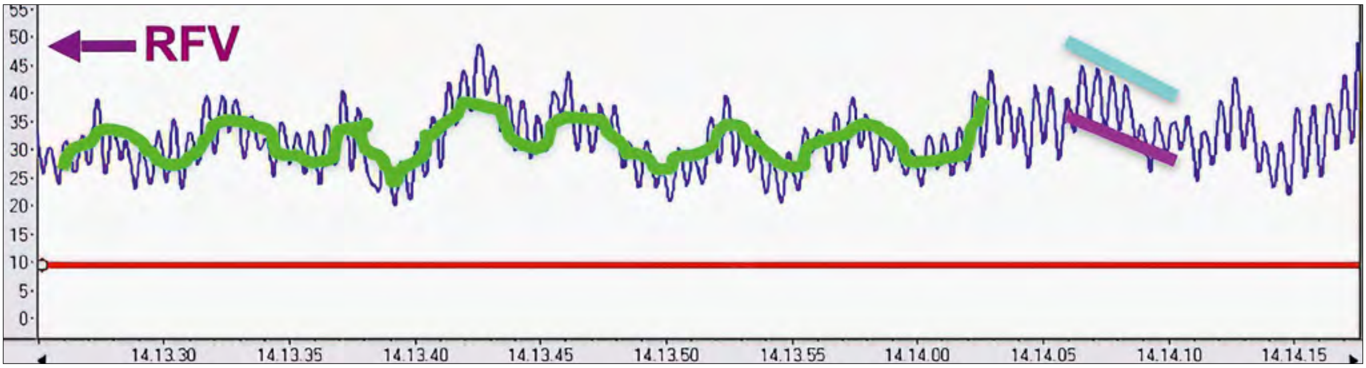

Figure 1. Relative flow values (RFV) show maximum (sky-blue, added) and minimum peaks (fuchsia, added), with a frequency similar to the cardiac one. Alarm line (red). A further wave (green, added) is also detectable: vasomotion.

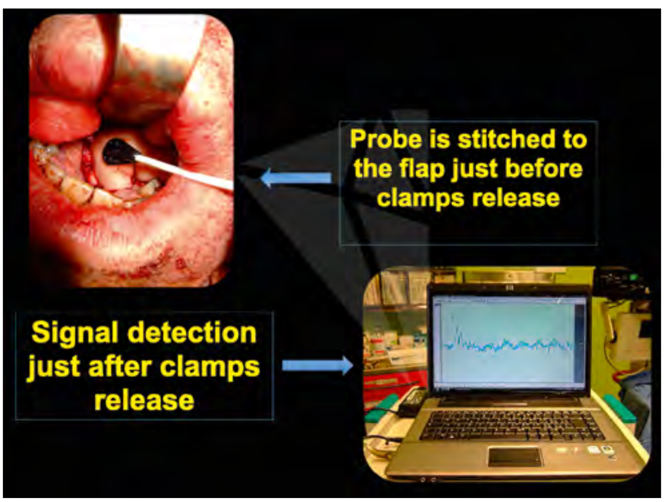

Figure 2. Probe insetting and start monitoring.

Parameters under monitoring were both RFV peak values and vasomotion sinusoid (Fig. 1). Flattening (up to vanishing) of the vasomotion wave was considered the most important sign of serious trouble affecting flap blood circulation and monitoring personnel was made aware. However, when alarmed, the responsible physician invariably pursued clinical examination including prick test to confirm or discard the suspicion. If the diagnosis was confirmed, surgical revision took place as soon as possible. The salvage protocol included thrombus removal, irrigation, intraarterial delivered fibrinolytic, a new anastomosis and assessment of the adequate pedicle setting. The salvaged flap then underwent the usual monitoring. Failure to rescue the flap was overcome by a pedicled flap whenever possible.
Antithrombotic prophylaxis (lysine acetylsalicylate 1 gr, intravenously) was routinely administered just before microanastomosis. Anticoagulant prophylaxis was never prescribed for free flap purposes.

Results

In 104/110 (94.5%) cases the post-operative course was uneventful and chart analysis revealed a near-constant increase of RFV during the first 3 post-operative days, which then became stable.
Conversely, vascular problems were detected and confirmed in 6 of 110 (5.5%) free flaps. At re-exploration, 5 pedicles were affected by venous thrombosis and 1 suffered from both arterial and venous occlusion. Analysis of the charts confirmed that – in an otherwise normal finding (Fig. 3, top) – the first sign of vascular trouble was the diminution of the vasomotion wave (Fig. 3, middle), until its disappearance, together with complete maximum/minimum peaks fall below the threshold, within minutes (Fig. 3, bottom): a slow wave was still appreciable, probably due to the push/pull movements that the still patent major vessels transmitted to the occluded micro-vessels. Both normal signals were again present after successful revision (Fig. 4). The delay between final diagnosis and revision ranged from 1 to 3.5 hours.
Interestingly, sometimes discordance between clinical features and chart parameters was detected. Some flaps "looked better" than the flow parameters that were registered.
The salvage protocol allowed 4 of 5 venous thromboses to be successfully managed and flaps were completely rescued. On the other hand – in the last case of venous thrombosis and the case of both arterial and venous occlusion – the flap salvage failed. In those cases, the problem was overcome by raising a pectoralis major myocutaneous flap. The salvage success rate was 67%, while the overall success rate reached 98%.
Minor complications included 3 partial necrosis and 2 fistulas, which were all successfully managed by conservative treatment.

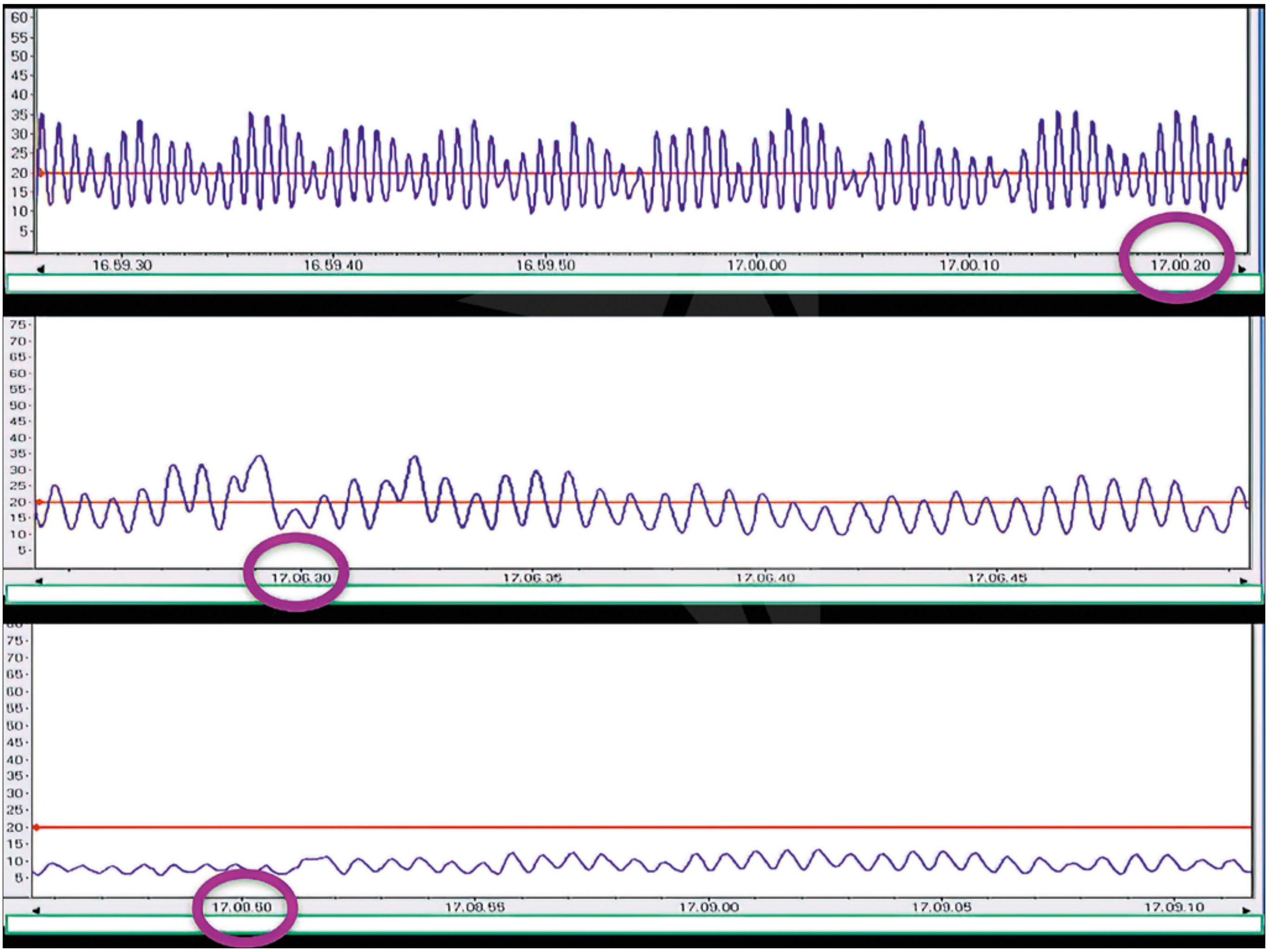

Figure 3. Top: normal perfusion. Middle: a few minutes later, the vasomotion wave begins flattening and circulation speed slows down. Bottom: RFV below the threshold and absence of vasomotion.

The positive predictive value was 100%, whereas the negative predictive value did not move beyond 0%.

Discussion

Microvascular free tissue transfer has become a popular technique for the reconstruction of challenging defects. The results are considered to be superior compared to other methods in terms of both functional and aesthetic outcomes, especially for the head and neck region. This is true when dealing with bone reconstruction, very large or composite defects, and facial reanimation. On the other hand, free flaps superiority over pedicled ones almost invariably occurs when dealing with speech and swallowing, even if not at a statistically significant level [16]. However, despite success rates being around 95% or more [3], flap failure secondary to vascular disturbances remains a major complication that can potentially invalidate the morphologic and functional success of the reconstruction, thus leading to higher patient morbidity, prolonged hospital stay and increased healthcare costs [5].

Circulation disturbances leading to flap failure may involve either the flap's arterial inflow, capillary microcirculation, or venous outflow [5]. Salvage rates of failing free flaps vary with aetiology, flap type and experience, but there is large agreement that early detection of vascular compromise and prompt surgical re-exploration significantly increases the chances of free flap salvage. Chances of flap salvage are significantly linked to the timing of detection. Yang et al. [17] showed that the salvage rate at 16 h (62.2%) was much higher than that at > 16 h (21.4%, $p = 0.0039$). Accordingly monitoring methods to aid the early recognition of disturbances in flap circulation are critical in deciding on revision, thus increasing the success of free flap reconstruction. Numerous flap monitoring strategies and technologies exist,

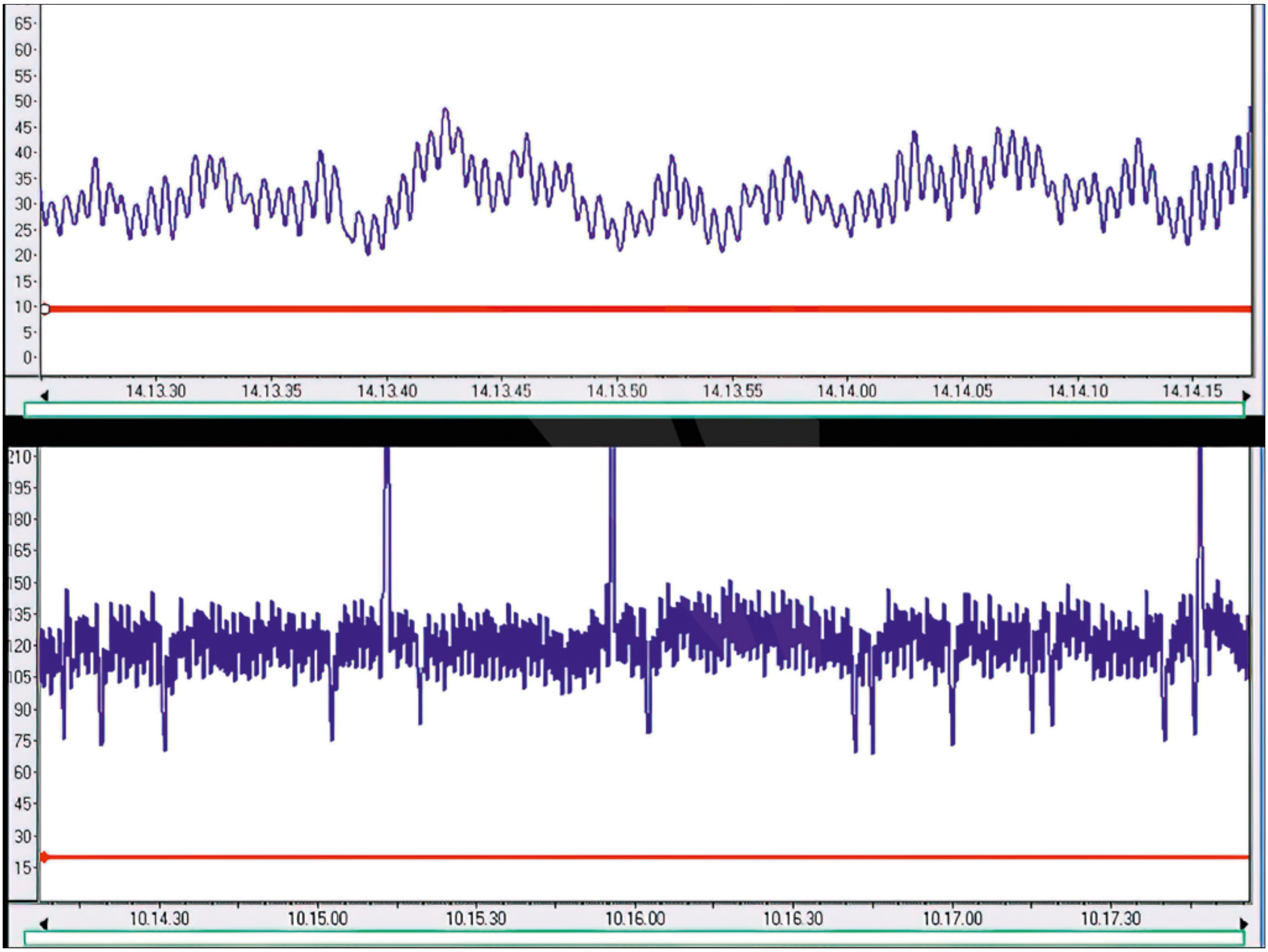

Figure 4. Charts recorded on 1st (top) and 4th (bottom) day after salvage re-exploration: high RFV and presence of vasomotion are evident.

which vary in complexity, invasiveness, efficiency and cost. Furthermore, their intrinsic value might be affected according to the flap setting: buried or non-buried. Properties of the ideal free flap monitoring technique should be: inexpensive; harmless to both patient and flap; produce rapid, reliable, and objective results; simple to interpret by relatively inexperienced personnel; and applicable to all types of free flaps [6].

Clinical evaluation is based on parameters such as the colour of the skin flap, presence or absence of oedema, presence of capillary refill (rapid or delayed) and quality of bleeding with prick test. The prick test consists of a direct puncture of the flap. Parameters to be considered are latency of bleeding and blood colour. Normal latency lasts 2-5 seconds. The immediate flowing of deep-bluish blood, together with a lack of spontaneous haemostasis, is considered highly suspicious of venous impairment. Quite often the site of puncture bears ecchymosis (Fig. 5). In contrast, the absence of any bleeding is considered a sign of arterial flow block. Direct puncture appears to be quite reliable, but needs substantial human resources and is somewhat operator-dependent. Moreover, the results are sometimes ambiguous and may lead to a dangerous delay in flap re-exploration. Nevertheless, some authors consider the prick test the gold standard for free flap monitoring [7].

Transcutaneous Doppler suffers from similar limitations to the prick test, in addition to the cost of the device.

Implantable Doppler is more reliable and needs fewer human resources, but is limited by the high cost of disposable materials. Moreover, in rare instances, removal of the probe leads to pedicle damage, requiring salvage surgery [9].

Microdialysis measures glucose, lactate, and lactate/pyruvate ratios[8] abnormally produced in the poorly perfused tissue. It is believed to be highly reliable, but local trauma and high costs hinder its widespread use.

Figure 5. Top: ecchymosis around the puncture sites in a case of venous thrombosis. Bottom: the resolution of bruising after 15 days from the successful salvage procedure. Still appreciable the typical homogeneous greyish colour of the skin affected by the previous ecchymosis.

Near-infrared spectroscopy (NIRS) relies on recording photons at 700-950 nm that have traveled through a tissue. Oxygenated haemoglobin (HbO2) and non-oxygenated haemoglobin (Hb) absorb photons differently at different wavelengths: this allows for the calculation of the oxygen saturation of the tissue (StO2). Unit and disposable costs appear to limit the use of this efficient monitoring method [5,10]. Thermal scan [12] and Macrophage Migration Inhibitory Factor [13] are still under evaluation.

LDF is a non-invasive method enabling the monitoring of microvascular blood flow [14,15]. Even though LDF measures are non-absolute, the enormous interest in microvascular perfusion has led to many clinical investigations. Indeed, it can be used in many areas and on many organs, such as the skin, brain, kidney, liver and intestines [14].

The Laser-Doppler perfusion monitoring and imaging techniques rely on the Doppler effect, first described by the Austrian scientist Johan Christian Doppler [14]. The device exploits wavelength variations of photons hitting blood red cells while flowing. In other words, the Doppler effect is applied to the light Laser instead of ultrasound.

In our series, cases with an uneventful course showed a constant RFV increase during the first 3 post-operative days. This can probably be interpreted as hyperaemia, an initial step of the progressive settling towards the steady state of the flap perfusion. By contrast, careful analysis of charts related to free flaps suffering vascular disturbances revealed that the first sign of impairment was the diminution of sinusoid expressing vasomotion. Vasomotion is a phenomenon characteristically seen under normal perfusion conditions. It is accentuated in connection with reactive hyperaemia such as in a reperfused flap and may represent a vasoregulatory mechanism in response to increased metabolic demand. As the free flap is denervated, it has been concluded that this mechanism should be under local control [15]. Vasomotion analysis potentially offers measures that are more directly related to physiological mechanisms than the measurement of microvascular perfusion alone, and have been utilised to investigate microvascular dysfunction in various disease states [15].

Therefore, we strongly recall attention to this sign as a very early indicator of vascular trouble, even if clinical appearance and prick test are negative.

Another important finding is the possible rapid evolution of the vascular disturbance: in some cases, the complete arrest of the flap perfusion may occur within a few minutes (Fig. 3).

To reduce the diagnostic delay and unnecessary surgical intervention, we adopted an expedient. A smartphone was installed to capture the screen of LDF monitoring, and – in case of alarm – paramedics were instructed to send the responsible surgeon a clip including at least 10 minutes of recording before the alert rang. In cases in which the diagnosis of serious vascular disturbance was evident, the surgeon had the possibility of immediately activating the surgical team. In dubious cases, the surgeon had the possibility of remotely monitoring the evolution of the suspected vascular disturbance. Today, this has been implemented with a streaming app. Indeed, in 2017, Yuen [18] highlighted this possibility in telemedicine. Advisable implementation of the instrument should allow the possibility of directly transmitting data from the recording device to the operator. The delay between diagnosis and actual revision is also conditioned by the immediate availability of all the required resources (i.e.: emergency team, emergency theatre, etc.).

Our findings confirm considerations about the importance of the vasomotion wave [15,19].

At present, our policy is to promptly re-explore free flaps whose monitoring shows fading of vasomotion. However, this is not intended as an automated process, as clinical evaluation maintains its value.

Perfusion disturbance (5.5%), type of vascular trouble (venous 5 of 6 cases), salvage rate (67%), and final success rate (98%) are close to those reported in larger series [17]. The case of both venous and arterial disturbance may indicate that arterial occlusion was secondary to venous thrombosis and complete occlusion of micro-vessels. Predictive positive and negative values were reassuring.

In summary, LDF appears to be a highly reliable technique with more acceptable costs (the probe is reusable) than other more sophisticated devices.

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Conflict of interest statement

The authors declare no conflict of interest.

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Author contributions

PS did conceptualization, performed the clinical work, wrote and revised the manuscript. SP and AZ did the clinical work and revised the manuscript.

Ethical consideration

Not applicable.

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