Accepted: 26 December 2023

DOI: 10.1002/lsm.23756

CLINICAL REPORT

Hyperspectral imaging for monitoring of free flaps of the oral cavity: A feasibility study

Axelle Felicio-Briegel[1] | Matthäus Linek[2] | Ronald Sroka[2,3] | Adrian Rühm[2,3] | Christian Freymüller[2] | Magdalena Stocker[4] | Philipp Baumeister[1] | Christoph Reichel[1] | Veronika Volgger[1]

[1]Department of Otorhinolaryngology, University Hospital, LMU Munich, Munich, Germany

[2]Laser-Forschungslabor, LIFE Center, University Hospital, LMU Munich, Planegg, Germany

[3]Department of Urology, University Hospital, LMU Munich, Munich, Germany

[4]Department of Otorhinolaryngology, University Hospital Salzburg, Salzburg, Austria

Correspondence

Axelle Felicio-Briegel, Department of Otorhinolaryngology, University Hospital, LMU Munich, Marchioninistr. 15, 81377 Munich, Germany.
Email: Axelle.Felicio@med.uni-muenchen.de

Abstract

Objectives: Hyperspectral imaging (HSI) provides spectral information about hemoglobin, water and oxygen supply and has thus great potential in perfusion monitoring. The aim of the present study was to investigate the feasibility of HSI in the postoperative monitoring of intraoral free flaps.

Methods: The 14 patients receiving reconstructive head and neck surgery with a radial forearm free flap were included. HSI was performed intraoperatively (t0), on Day 1 (t1), 2 (t2), 3–6 (t3), 7–9 (t4), 10–11 (t5) and 12–15 (t6) postoperatively. Flap tissue perfusion was assessed on defined regions of interest by calculating the perfusion indices Tissue Hemoglobin Index (THI), hemoglobin oxygenation (StO_2), Near Infrared Perfusion Index (NIR Perfusion Index) and Tissue Water Index (TWI).

Results: Image quality varied depending on location of the flap and time of measurement. StO_2 was >50 intraoperatively and >40 on t1 for all patients. A significant difference was found solely for TWI between t0 and t2 and t0 and t4. No flap loss occurred.

Conclusions: The use of HSI in the monitoring of intraoral flaps is feasible and might become a valuable addition to the current clinical examination of free flaps.

KEYWORDS

flap surgery, head and neck cancer, hyperspectral imaging, monitoring, reconstruction

INTRODUCTION

Hyperspectral imaging (HSI), a technique originating in remote sensing, has recently been introduced to medicine, where it proofed to be valuable for different indications.[1–3] As HSI provides spectral information about hemoglobin, water and oxygen supply, it has great potential in perfusion monitoring. First studies showed its potential benefit in the microcirculation monitoring in critically ill patients on intensive care units,[4] for the assessment of the superficial palmary arch before radial artery harvest,[5] and in the identification of cutaneous perforators before harvesting an anterolateral thigh flap.[6] Perfusion monitoring is crucial in the postoperative surveillance of flaps. To prevent flap loss, it is of upmost importance to early detect the most common reasons for flap failure, i.e. venous congestion or arterial insufficiency.[7] The radial forearm free flap (RFF) is widely used for head and neck reconstructive surgery. Even though survival rates of flaps are high, there is still a relevant number of flap failure of 3%–5% for RFF.[8–11] Postoperative clinical monitoring of flaps is the gold standard.[12,13] As an early detection of perfusion changes is essential for flap salvage, an additional tool to detect perfusion deterioration objectively and early would be highly desirable. HSI has been successfully applied in

The study was prospectively registered in a publicly accessible database (http://cccm-studienregister.med.uni-muenchen.de/trials).

preclinical models to assess anastomoses and flaps.[14,15] Transferred to the clinic, HSI has been used in the monitoring of gastrointestinal anastomoses during open abdominal surgery and succeeded at monitoring physiological perfusion parameters.[16] Furthermore, HSI was used in the monitoring of pedicled flaps.[17] Only recently, there were first reports on the application of HSI in the postoperative monitoring of pedicled and free flaps, located at the anterior upper and lower jaw and on the external skin after reconstructive head and neck surgery. HSI proofed generally suitable for perfusion monitoring and even seemed to outperform clinical monitoring in the early detection of perfusion deterioration leading to flap revision.[18,19]

The aim of this study was to investigate the feasibility of HSI in the postoperative monitoring of intraorally placed free flaps after reconstructive head and neck surgery and to examine the relation between HSI measurements and clinical findings.

MATERIAL AND METHODS

Patients

In this prospective clinical study oncological patients ($n = 14$) scheduled for reconstructive head and neck surgery with a RFF were included. All clinical data were obtained and analyzed based on the approval by the ethics committee of the local medical faculty (IRB approval number 19–851) and in compliance with the declaration of Helsinki. Only patients with free flaps of the vestibulum oris, the oral cavity and the upper oropharynx were included.

Equipment

Imaging was performed with a CE-approved, commercially available hyperspectral camera system (TIVITA® Tissue System; Diaspective Vision GmbH; Am Salzhaff, Germany).[18,20] The system uses six halogen lamps for tissue illumination and records remission spectra in the spectral range from 500 to 1000 nm for each pixel. The data is processed in real-time and besides a red-green-blue image, the HSI system generates false color images (FCI) based on dedicated spectral features, thus representing tissue perfusion indices. The superficial tissue oxygenation (StO_2) and the near infrared (NIR) Perfusion Index represent the cutaneous and subcutaneous hemoglobin oxygenation, the Tissue Hemoglobin Index (THI) represents the relative hemoglobin content in tissue and the Tissue Water Index (TWI) the water content. According to the considered spectral ranges and the corresponding optical reachable depths in human skin, StO_2 and NIR Perfusion Index aim to assess the cutaneous hemoglobin oxygenation in superficial (<1 mm) and deeper tissue (<2 mm) layers.[19,21]

Flap assessment was performed by clinical examination (color, re-capillarization time, tissue temperature) and handheld Doppler sonography. According to the ENT-department-internal guidelines, clinical examination and Doppler ultrasound were performed every 2 h within the first 24 h after surgery and every six to 8 h the following days up to approximately 2 weeks after surgery. Flap color was categorized to pale (suspicious for arterial insufficiency), blue (suspicious for venous congestion) and rosy (considered as normal) by visual inspection, whilst tissue temperature was categorized into cold (pathologic) and warm (physiologic) by palpation. Scratch test was regularly performed once daily for approximately 1 week and additionally as needed.

HSI examination

HSI data acquisition was performed with the operating lights switched off for intraoperative imaging and in a slightly darkened room for postoperative imaging to assure similar light conditions. The camera was placed about 50 cm perpendicular to the flap focusing on the center of the flap by bringing two separate laser light points (specific camera technique) in an overlapped position on the target tissue. Intraoperatively the mouth was opened with a McIvor tongue depressor or Jennings mouth gag. Postoperatively the patient was asked to open the mouth and, if necessary, the tongue or cheek was gently pulled aside with a tongue depressor by one investigator to expose the flap as seen in Figure 1. Camera lights are only turned on during the photography process. HSI measurements were performed directly after clinical monitoring at t0 = directly after flap inset, at t1 = Day 1 postoperatively, t2 = Day 2 postoperatively, t3 = Day 3–6 postoperatively, t4 = Day 7–9 postoperatively, t5 = Day 10–11 postoperatively and t6 = Day 12–15 postoperatively. T0 was done intraoperatively during general anesthesia of the patient. T1 and t2 were done during the patients' time in the ICU, lying in the bed. Further analysis was done during the in-patient stay at the general ENT-ward. For these further measurements the patients were either lying or sitting in bed or on a chair with backrest. Two experienced clinicians - one operating the camera and one exposing the area of interest - usually performed data acquisition. For each patient during each acquisition time, two consecutive HSI scans were recorded, resulting in two data sets for each patient. Each data acquisition scan took about 15 s.

Data processing

Besides a visual interpretation of the FCIs (blue indicating low and red indicating high values), the camera-specific software package (TIVITA® Suite, version 1.6.0.1; Diaspective Vision GmbH) was used in accordance with the literature for quantification of

FIGURE 1 Example of a picture taken of the palate via HSI. On the left the camera arm can be seen (white box) with the HSI camera on the end (white circle). On the right the camera, focusing the two laser points on the palate can be seen. The tongue is gently pushed aside by a tongue depressor. Photography process has not been started yet, thus the camera lights are switched off and the palate is not yet illuminated.

perfusion indices.[22] Further analysis was performed by manually placing one circular shaped region of interest (ROI) in the center of the flap, avoiding shaded areas.[18] Each ROI was assessed separately regarding the clinically interesting indices StO_2, NIR Perfusion Index, THI and TWI. The scale for each FCI ranged from 0 to 100, with 0 corresponding to blue and 100 corresponding to red color indicating minimum and maximum index values.

Statistical analysis

Calculations were performed with TIVITA® Suite (Diaspective) and R (version 4.1.2, The R Foundation for statistical computing). Average perfusion indices and standard deviations were calculated from the considered patients and for each acquisition time. Friedman test was used to test for statistically significant differences between different acquisition times. This was followed by Friedman multiple comparison test if the Friedman test resulted significant. Wilcoxon signed rank test was performed for testing statistical differences between t0 and t1, t2, t3, t4, t5 and t6. A value of $p < 0.05$ was considered significant.

RESULTS

The 14 patients were included, of whom 13 received a reconstruction with a RFF after tumor resection. One patient had previously received a reconstruction with a RFF after resection of a tonsil carcinoma and received surgical sectioning and resection of the vascular pedicle. The median age was 62 years (range 35–75 years) and the median body mass index was 27 (range 14–34). Two patients had received previous radiotherapy of the head and neck. Further patient demographics are given in Table 1. TNM-classification 8th edition[23] has been used to stage the tumor. For pT1 the tumor is 2 cm or less in diameter and has a depth of invasion (DOI) of 5 mm or less. For pT2 the tumor is 2 to 4 cm in diameter or has a DOI of 5 to 10 mm and for pT3 the tumor is larger than 4 cm in diameter or has a DOI of more than 10 mm.

No flap loss occurred postoperatively until up to 1 year after surgery. Two patients underwent revision surgery due to wound dehiscence in the following 2 weeks after surgery. Of the 14 patients, two patients had to be excluded from further evaluation, because visibility of the free flap was poor in all pictures. One patient receiving resection of the vascular pedicle was analyzed separately as discussed later.

The further general analysis is based on HSI scans taken at t0–t6 of the remaining 11 patients. Imaging quality varied for patients and measurement times. At t0 all 11 patients underwent HSI, though the image quality of one data set was insufficient. At t1 nine patients underwent HSI leading to seven evaluable data sets. At t2 nine patients underwent HSI all being eligible to further evaluation. Seven patients underwent HSI at t3 and t4 leading to six further evaluable data sets. At t5 three patients underwent HSI with two evaluable data sets. At t6 two patients underwent HSI–further analysis

TABLE 1 Patient demographics of the 14 patients included.

TNM-classification 8th edition (23)	pT1 (≤2 cm and DOI ≤ 5 mm)	pT2 (2–4 cm or DOI 5–10 mm)	pT3 (>4 cm or DOI > 10 mm)
Number of patients	3	1	10
Gender	Male (3)	Male (1)	Male (8) Female (2)
RFF donor side	Left (3)	Left (1)	Right (1) Left (9)
Tumor location	Palate (1) Base of tongue (1) Floor of mouth (1)	Lateral tongue (1)	Tonsil (8) Lateral tongue (1) Base of tongue (1)
Tumor side	Right (1) Left (2)	Right (1)	Right (6) Left (4)
Nicotine abuse	No (1) Former smoker (2)	No (1)	No (5) Smoker (3) Former smoker (2)
Recipient artery	A. thyroidea superior (2) A. lingualis (1)	A. thyroidea superior (1)	A. thyroidea superior (8) A. lingualis (1) A. facialis (1)
Recipient vein	V. facialis (3)	V. facialis (1)	V. facialis (9) V. jugularis interna (1)
Coupler size for venous anastomosis (mm)	3.5 (1) 4.0 (2)	3.5 (1)	3.0 (2) 3.5 (2) 4.0 (5) No information (1)

Note: Brackets show number of patients.
Abbreviations: A, arteria; DOI, depth of invasion; RFF, radial forearm free flap; V, vena.

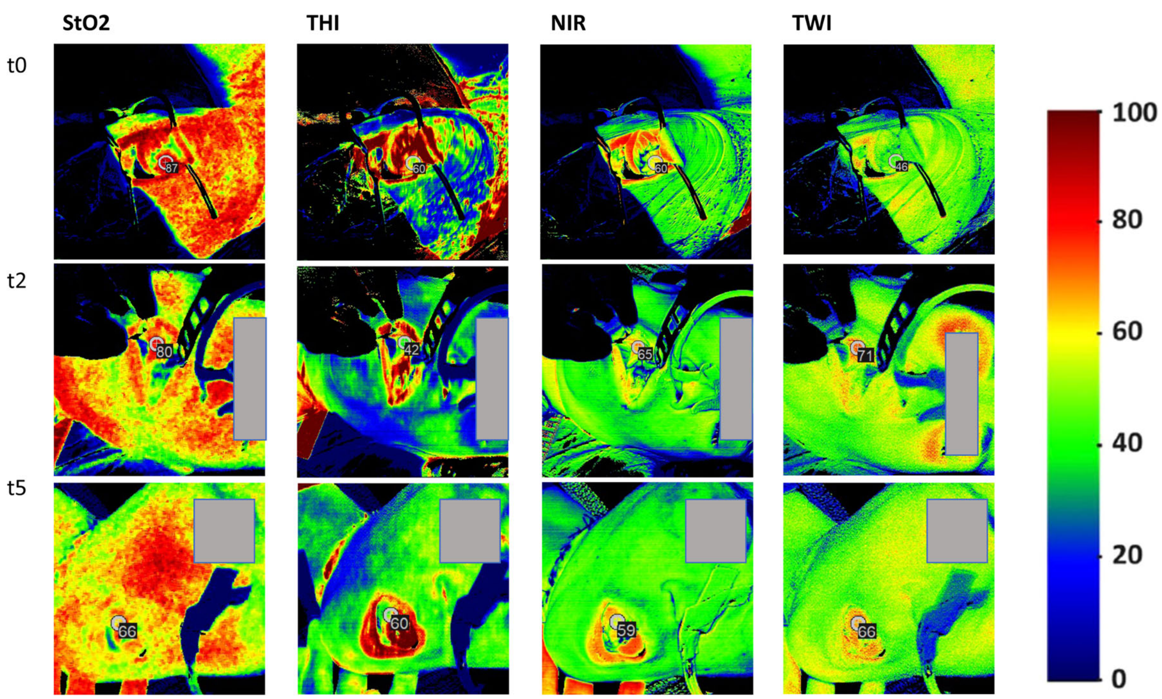

FIGURE 2 Example of perfusion monitoring with HSI in a patient with a RFF at the lateral tongue. ROI indicated by gray circle, ROI value depicted in a black box. The columns show the captured FCIs of each perfusion parameter. Each row represents a defined acquisition time. The color bar on the right side depicts the numeric range from 0 to 100 for each perfusion parameter. FCI, false-color-images; RFF, radial forearm free flap.

was possible for both data sets. Clinical examination including Doppler sonography revealed no evidence for perfusion deterioration for all patients at all measurement times.

Figure 2 exemplary shows HSI scans of a patient receiving a RFF after resection of a carcinoma of the lateral tongue. StO_2 was highest intraoperatively (StO_2 (t0) = 87) with a decrease postoperatively (StO_2 (t2) = 80), both being beyond the third quartile of the cohort and ((t5) = 66), being within the interquartile range (IQR). THI temporarily decreased postoperatively ((t0) = 60, (t2) = 42), before increasing again to the initial value ((t5) = 60), t0 and t5 lying within the IQR and t2 being within the first quartile. NIR Perfusion Index was stable at all measurement times (NIR (t0) = 60, (t2) = 65, (t5) = 59), t0 and t2 being higher than the third quartile of the cohort and t5 lying within the IQR. FCIs of TWI were green intraoperatively corresponding to middle index range ((t0) = 46) and shifted towards red postoperatively corresponding to high index range (TWI (t2) = 71, (t5) = 66), t0 and t5 lying within the IQR and t2 being higher than the third quartile. The simultaneous clinical examination showed a rosy and warm flap for all measurement moments.

Quantitative analysis of HSI scans

The results of the quantitative data analysis are given in Table 2 and Figure 3.

Wilcoxon signed rank test revealed a statistically significant difference between t0 and t2 ($p = 0.029$) as well as t0 and t4 ($p = 0.035$) regarding the TWI. There was no

TABLE 2 Median and range of StO_2, THI, NIR Perfusion Index and TWI for t0–t6 for the 11 patients evaluated.

	StO_2 median (range)	THI median (range)	NIR perfusion Index median (range)	TWI median (range)
Intraoperatively (t0)	80 (52–87)	59 (27–81)	56 (21–66)	47 (42–56)
Day 1 (t1)	66 (53–84)	77 (47–81)	44 (31–55)	53 (40–65)
Day 2 (t2)	68 (57–80)	54 (37–70)	50 (27–65)	55 (45–71)
Day 3–6 (t3)	73 (61–82)	36 (26–58)	54 (41–67)	62 (31–65)
Day 7–9 (t4)	62 (46–81)	54 (43–70)	41 (16–75)	60 (53–68)
Day 10–11 (t5)	58 (50–66)	50 (39–60)	47 (35–59)	55 (43–66)
Day 12–15 (t6)	79 (78–79)	56 (45–67)	46 (36–55)	60 (51–68)

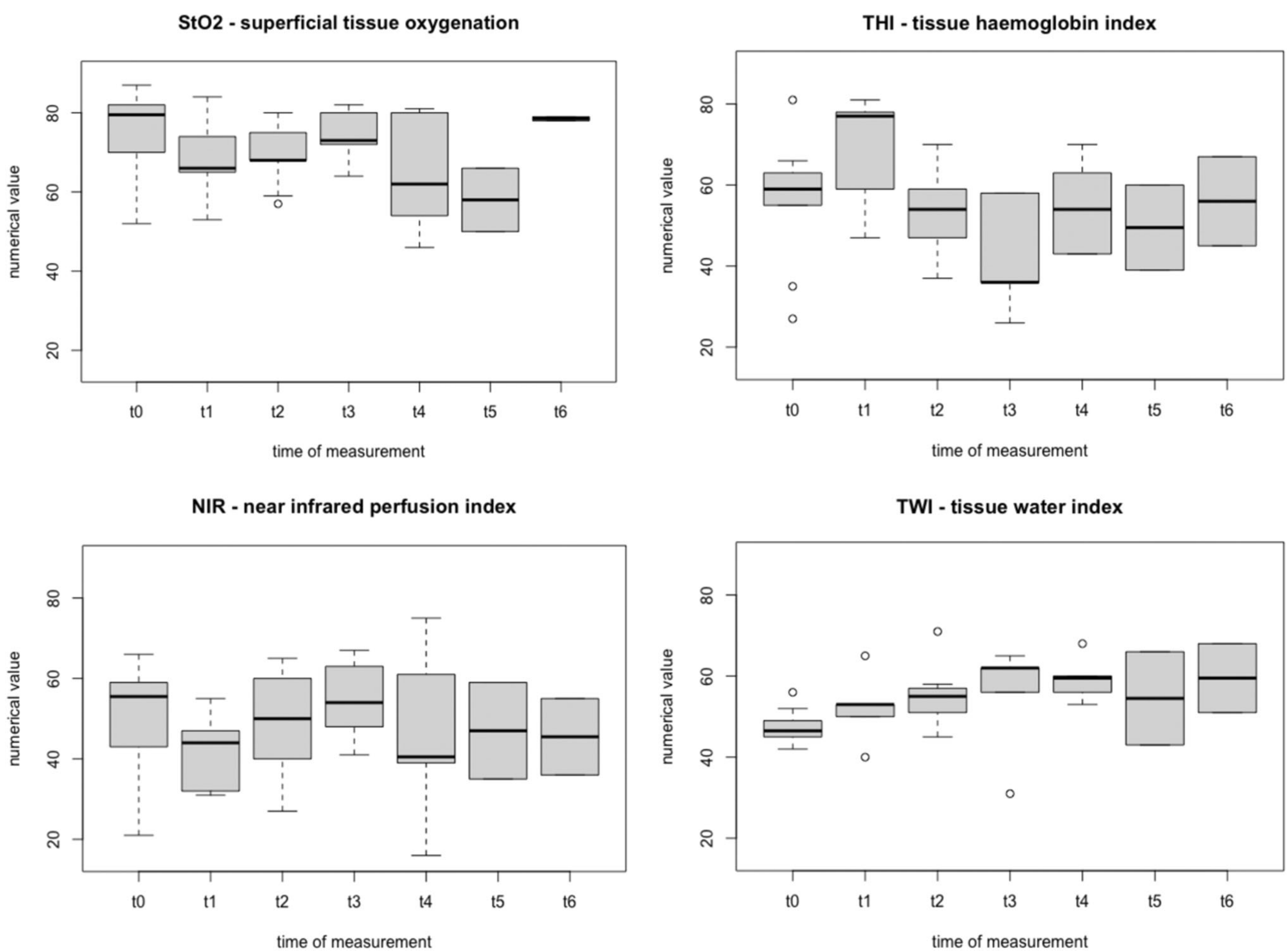

FIGURE 3 Boxplot of perfusion parameters calculated from the ROIs at the center of the flap at different acquisition times for the patients considered. Explanation of boxes: thick black line = median; box boundaries = 25% and 75%; whiskers = minimum and maximum; circles = outliers. ROI, region of interest.

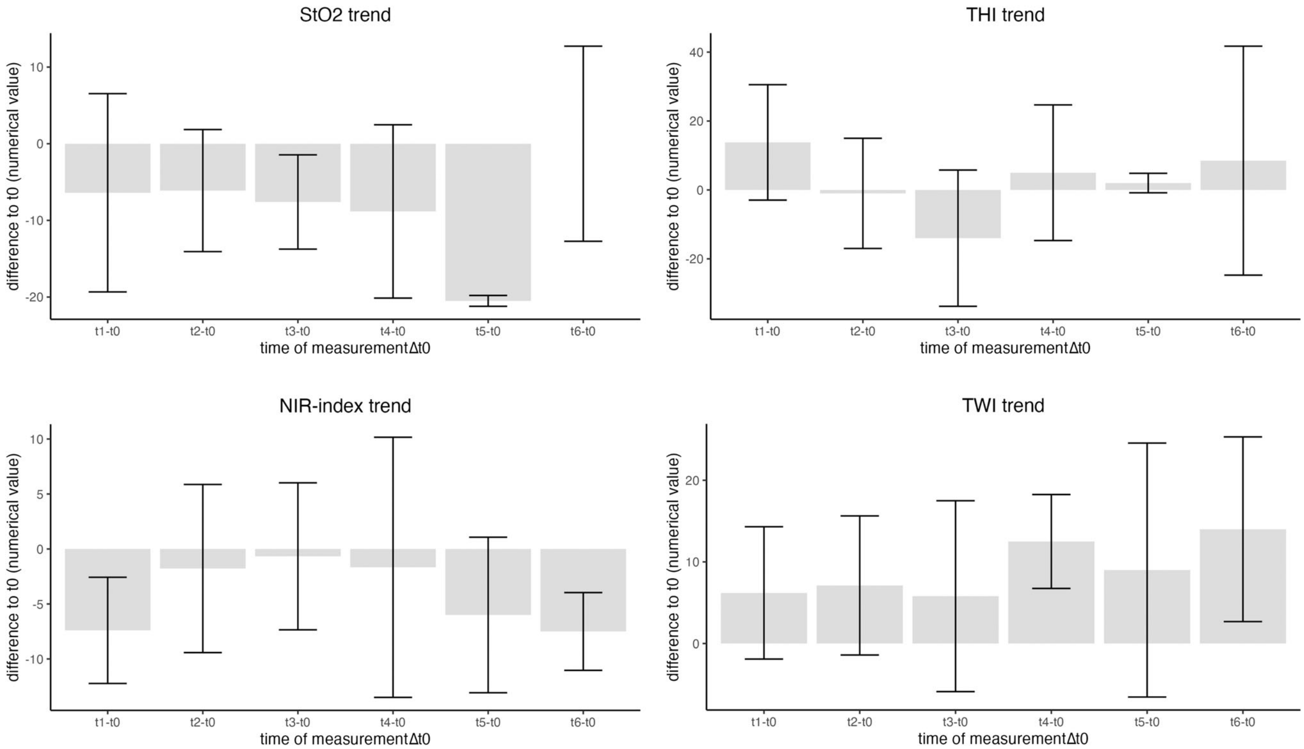

FIGURE 4 Barplot of the median drop rate (difference to baseline - t0) as well as standard deviation of the ROI for each time of measurement for StO_2, THI, NIR and TWI. Explanation of marplot: gray box = median; whiskers = standard deviation. ROI, region of interest.

statistically significant difference for other perfusion parameters and/or measurement periods. Friedman test was not significant for all values.

For each patient and time of measurement the difference to baseline (t0)–the drop rate–was calculated. The median drop rate as well as the standard deviation at each time of measurement for the patients can be found in Figure 4. Wilcoxon signed rank test revealed no statistically significant difference between the acquisition times.

Case presentation

As mentioned above, one patient, receiving a dissection and resection of the vascular pedicle of a RFF was analyzed separately. 14 months previously, the patient had received resection of a cancer of the right tonsil and free flap reconstruction with RFF from the left side. Vascular pedicle dissection and resection was performed because of an underlying unclear mass (classified as benign by postoperative histological workup), which was detected during regular tumor follow-up and for cosmetic reasons in line with the patient's wishes. Imaging of the intraoral free flap occurred intraoperatively before and after resection of the vascular pedicle as well as on the second postoperative day. As seen in Figure 5, a decrease of StO_2 (shift from red towards yellow) and increase in THI (shift from green towards red) can be observed directly after pedicle resection. The decrease of StO_2 continued with a shift from yellow towards green color on the second postoperative day. NIR Perfusion Index and TWI stayed nearly unchanged throughout the procedure. ROI placement was not possible due to the illuminated flap part being too small. Thus, solely visual evaluation was performed. Clinically the flap was rated as pale on the second postoperative day. No flap loss occurred for this patient, last seen 7 months after pedicle resection.

DISCUSSION

Until now, the gold standard in the postoperative surveillance of free flaps after reconstructive head and neck surgery is clinical monitoring and acoustic Doppler sonography.[12,13] This approach is highly subjective as both depend on the experience of the investigator. Doppler sonography only gives acoustic feedback of the arterial and venous pulse. Therefore, the aim of this study was to evaluate, whether it is possible to postoperatively monitor the perfusion of free flaps objectively via HSI and to compare the result throughout the time course. Particularity of this study is, that the investigated free flaps were located in the oral cavity and oropharynx and are thus more difficult to access when compared to externally positioned flaps. The HSI system was easy to operate. However, the exposition of the area

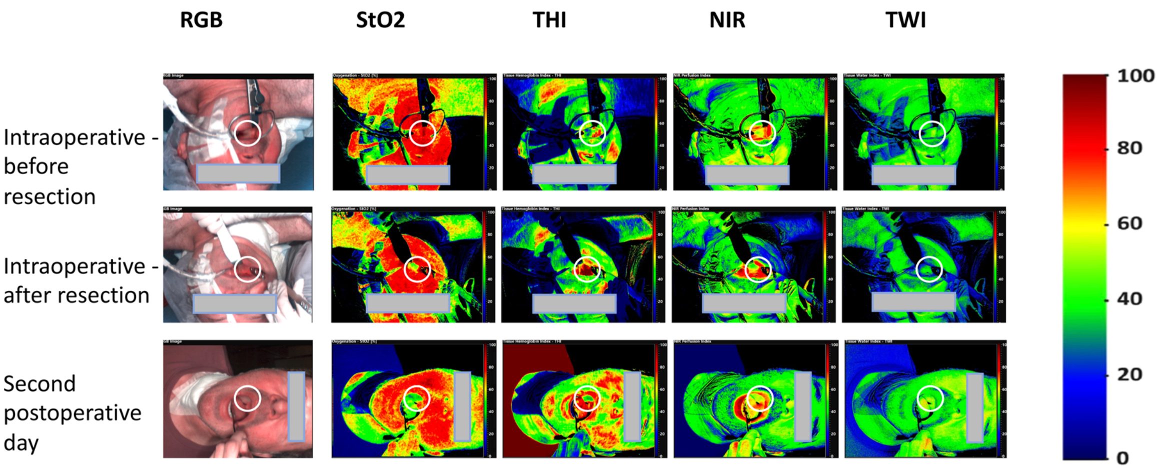

FIGURE 5 HSI scans of a RFF in a patient receiving resection of the vascular pedicle of a RFF, which was brought in 14 months before. Images were taken intraoperatively before and after resection of the vascular pedicle, as well as two days postoperatively. Free flap localization is indicated by white circle. The color bar on the right side depicts the numeric range from 0 to 100 for each perfusion parameter. RFF, radial forearm free flap.

of interest was sometimes challenging. Intraoperative photography was easily feasible. Due to general anesthesia, mouth opening using a McIvor tongue depressor or Jennings mouth gag was sufficient for HSI imaging. However, as the camera arm of this specific device is rather bulky, visualization of the RFF in the oral cavity or oropharynx was challenging, postoperatively. Problems in visualizing the flap were caused by a reduced mouth opening, intraoral swelling, excessive saliva or movement of the patients. A key challenge was to properly illuminate the area of interest and to avoid shaded areas, disallowing further data analysis. From our experience mouth opening has to be at least 3 cm, as otherwise the illumination of the flap was insufficient due to the flap being completely covered in shadows, which falsifies the indices. Efforts have been made previously to correct hyperspectral information of shaded areas. Yet, there is currently no appliable method to rule out an influence of shadow on the perfusion indices.[24] Generally, to optimize illumination, hyperspectral data acquisition was performed by two clinicians–one operating the camera and one exposing the flap with a tongue depressor. When focusing the camera on tissue, the two laser points which can be seen, have to be brought in an overlapped position at the area of interest as seen in Figure 1. Only then an acquisition of an adequate hyperspectral scan is possible. This also means, that it is important to avoid bigger movements, which was less of a problem within this study as patient cooperation was very good. If clearly visible big movement occurred during the HSI scan, it was repeated. We recommend to provide support for the patient during photography by lying in bed or sitting with a backrest to lean on and by gently holding the patients head during image acquisition. Due to swelling, swallowing of saliva was often restricted in the first days postoperatively, leading to excessive saliva in the oral cavity. Removement of the saliva is necessary before imaging. The use of HSI in the oral cavity in the awake patient is thus possible, but challenging, as two persons are needed to acquire HSI data, the exposition of the area of interest for a sufficient illumination is difficult and patient cooperation is needed. Possibly, by using an endoscopic version of HSI, reduced mouth opening and insufficient illumination would not be that problematic anymore. Altogether, by following the mentioned approach HSI data of 48 different imaging times could be acquired. ROI placement was not possible in 6 of the 48 data sets (12.5%), even though ROI size can be individually selected. In those cases, ROI placement was not possible because the illuminated area of the flap was too small to place a ROI without including shaded areas of the flap. As at least two data sets exist from each patient for each acquisition time, the image with the better quality and illumination was used.

A review of the literature showed only four other prospective studies regarding free flap monitoring using HSI technique so far, all using TIVITA®.[18,19,21,25] One study was published by Kohler et al. and included patients with soft tissue reconstruction with various pedicled and free flaps.[21] In that study none of the patients had a RFF and none of the flaps was placed intraorally, which makes a direct comparison of data and handling difficult. However, the authors noticed, that all flaps that had StO_2 and NIR Perfusion Index values below 40 on the first postoperative day had to be partly or completely revised due to flap loss. Another study from Thoenissen et al. with five RFFs and eight anterior lateral thigh flaps, all placed extraorally, showed no significant change in values, though no flap loss occurred in this study.[25] 24 h after surgery the mean drop rate was 17% for StO_2% and 9% for THI.[25] Another two studies were published by Thiem et al., reporting, amongst others, about 25 patients receiving free flaps in the oro-maxillofacial area (including 12 RFFs) in the first study[18] and 65 patients receiving free flaps (including 24 RFFs) in the second study.[19] Only flaps of the upper and lower jaw or flaps with extraoral skin islands were included, as the oral cavity was rated as not accessible via the used HSI system.[18] Thiem et al. proposed a value of $StO_2 < 40$ as critical and in combination with NIR Perfusion Index <25 and THI < 40 as suggestive for arterial occlusion.[18,19] Furthermore, the authors state, that perfusion problems can be detected earlier by means of HSI data when compared to conventional clinical monitoring and Doppler sonography.[19]

In the present study, none of the 11 patients had a StO_2 value below 40 intraoperatively or on t1. As no flap loss throughout this small case series was observed, a StO_2 value of more than 40 on the first postoperative day seems to be a reasonable marker for free flap viability. In this regards our findings align with the findings of Kohler et al. and Thiem et al. Regarding NIR Perfusion Index, two patients had a value slightly below 40 at t1. These two patients, however, had a NIR Perfusion Index value of about 40 also intraoperatively and thus did not show any relevant change when compared to baseline. This is in line with the findings of Thiem et al. who described a significant decrease in NIR Perfusion Index in comparison to baseline for the group experiencing perfusion disturbances of the flap.[19] Furthermore, one of the two patients was a skin type IV according to Fitzpatrick,[26] while the other patients showed skin types II and III. Melanin content of the skin cannot be quantified by HSI[19] but could be impacting the hyperspectral imaging with the used TIVITA® Tissue System.[27] Especially noninvasive hemoglobin and SpO_2 measurements seem to be influenced by skin type.[28,29] Threshold values can thus not easily be transferred uncritically to all patients and further analysis on to what extent the skin type influences the hyperspectral images is necessary. Summarizing, it is not possible yet to specify a cut-off for NIR Perfusion Index indicating malperfusion. Besides relying on the absolute value given, it is definitely of upmost importance to analyze the perfusion parameters over time, especially because there is a large variation already in the baseline data. Several studies have pointed out the importance of including the drop rate when evaluating indices acquired from spectral imaging,[18,19,30,31] even though a cut-off between physiologic and pathologic changes has yet to be defined. Within the present study, for NIR Perfusion Index no patient had a decrease of >35% of the baseline value (more than 20 points) at t1. For StO_2 the drop rate was below 25 points for all patients at t1. Significant differences between the drop rate of NIR Perfusion Index and StO_2 of patients with flap failure and viable flaps have been found by Thiem et al.,[19] which seems to support the drop rate as an important marker for early detection of flap necrosis.

A statistically significant difference regarding the TWI between t0 as well as t2 and t0 and t4 within this patients' cohort was found. Similarly, Thiem et al. described a significant difference in TWI postoperatively when compared to intraoperative measurements.[18] An explanation for this increase might be the postoperative saliva or a certain degree of congestion, which seems to impact the majority of the patients postoperatively receiving free flaps. Venous obstruction is thought to lead to edema and has been associated with ischemia.[14] However, it could be expected that venous obstruction would initially cause an increase of THI and only later an increase of TWI, due to the tissue edema. Further studies analyzing TWI and THI for patients with flap necrosis are needed to detect critical values or indices-changes for TWI and THI indicating venous congestion. Interestingly, Thiem et al. found a significant decrease of TWI for the patient group needing flap revision or experiencing flap loss.[19] This group included both patients with arterial insufficiency and venous congestion. A differentiation regarding the reason of malperfusion did not occur.

In this first report about meaningful perfusion data of flaps in the oral cavity and oropharynx the HSI data acquisition, however, was tricky, especially regarding proper tissue illumination. A smaller and more flexible HSI system (e.g., endoscope adaptable system) would be favorable to better access the oral cavity, pharynx, and, possibly, also larynx.

A further challenge was, that with the current HSI system it was only possible to focus the camera on the free flap. Due to the topography of the oral cavity, it was not possible to place a ROI on normal adjacent mucosa, prohibiting from comparing perfusion indices of the free flap with those from adjacent normal mucosa. An endoscope adaptable HSI technique would, most likely, overcome also this problem. Other limitations of this study include the small patient number and the lack of flap necrosis leading to revision, which is unfortunate for the study, but for the benefit of the patients.

Although this study showed the feasibility and the potential of the HSI technique, multicentric studies with greater patient numbers should be initiated to better determine cut-off values, thresholds, value-changes and thus to find out the clinical value of HSI in the postoperative monitoring of free flaps.

CONCLUSION

The application of HSI was feasible in the postoperative monitoring of free flaps of the oral cavity and anterior oropharynx. Furthermore, the results matched the clinical findings. Sufficient exposure and illumination of the area of interest remain challenging with the use of this HSI system, especially postoperatively due to reduced mouth opening leading to more shaded areas. Further miniaturization and improved handling should be envisioned for this kind of application. Larger studies are necessary to figure out reliable cut-off values between physiologic and pathologic perfusion indices for an easier data interpretation.

AUTHOR CONTRIBUTIONS

Conceptualization: Ronald Sroka and Veronika Volgger. Methodology: Veronika Volgger and Axelle Felicio-Briegel. *Validation*: Veronika Volgger and Axelle Felicio-Briegel. *Investigation*: Veronika Volgger. Magdalena Stocker., Philipp Baumeister, Christoph Reichel, Ronald Sroka, and Axelle Felicio-Briegel. *Data curation*: Axelle Felicio-Briegel. *Writing—original draft preparation*: Veronika Volgger and Axelle Felicio-Briegel. *Supervision*: Veronika Volgger, Ronald Sroka, and Matthäus Linek. Project administration, Veronika Volgger and Axelle Felicio-Briegel. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENTS

Open Access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. The authors have no relevant financial or nonfinancial interest to disclose.

ORCID

Axelle Felicio-Briegel http://orcid.org/0000-0002-6662-759X
Matthäus Linek http://orcid.org/0000-0002-9822-8956
Christian Freymüller http://orcid.org/0000-0002-3014-297X

REFERENCES

1. Daeschlein G, Langner I, Wild T, von Podewils S, Sicher C, Kiefer T, et al. Hyperspectral imaging as a novel diagnostic tool in microcirculation of wounds. Clin Hemorheol Microcirc. 2017;67(3–4):467–74.
2. Fabelo H, Ortega S, Ravi D, Kiran BR, Sosa C, Bulters D, et al. Spatio-spectral classification of hyperspectral images for brain cancer detection during surgical operations. PLoS ONE. 2018;13(3):e0193721.
3. Laffers W, Westermann S, Regeling B, Martin R, Thies B, Gerstner AOH, et al. Früherkennung kanzeröser läsionen in oropharynx und mundhöhle: automatisierte evaluation hyperspektraler bildstapel. HNO. 2016;64(1):27–33.
4. Dietrich M, Marx S, Bruckner T, Nickel F, Müller-Stich BP, Hackert T, et al. Bedside hyperspectral imaging for the evaluation of microcirculatory alterations in perioperative intensive care medicine: a study protocol for an observational clinical pilot study (HySpI-ICU). BMJ Open. 2020;10(9):e035742.
5. Linek M, Felicio-Briegel A, Freymüller C, Rühm A, Englhard AS, Sroka R, et al. Evaluation of hyperspectral imaging to quantify perfusion changes during the modified allen test. Lasers Surg Med. 2022;54(2):245–55.
6. Goetze E, Thiem DGE, Gielisch MW, Kämmerer PW. Identification of cutaneous perforators for microvascular surgery using hyperspectral technique - a feasibility study on the antero-lateral thigh. J Cranio-Maxillofac Surg. 2020;48(11):1066–73.
7. Sweeny L, Topf M, Wax MK, Rosenthal EL, Greene BJ, Heffelfinger R, et al. Shift in the timing of microvascular free tissue transfer failures in head and neck reconstruction. Laryngoscope. 2020;130(2):347–53.
8. Chang EI, Zhang H, Liu J, Yu P, Skoracki RJ, Hanasono MM. Analysis of risk factors for flap loss and salvage in free flap head and neck reconstruction. Head Neck. 2016;38(1):E771–5.
9. Oranges CM, Ling B, Tremp M, Wettstein R, Kalbermatten DF, Schaefer DJ. Comparison of anterolateral thigh and radial forearm free flaps in head and neck reconstruction. In Vivo. 2018;32(4):893–7.
10. Reiter M, Baumeister P. Reconstruction of laryngopharyngectomy defects: comparison between the supraclavicular artery island flap, the radial forearm flap, and the anterolateral thigh flap. Microsurgery. 2019;39(4):310–5.
11. Evans GRD, Schusterman MA, Kroll SS, Miller MJ, Reece GP, Robb GL, et al. The radial forearm free flap for head and neck reconstruction: a review. Am J Surg. 1994;168(5):446–50.
12. Kääriäinen M, Halme E, Laranne J. Modern postoperative monitoring of free flaps. Curr Opin Otolaryngol Head Neck Surg. 2018;26(4):248–53.
13. Kohlert S, Quimby A, Saman M, Ducic Y. Postoperative Free-Flap monitoring techniques. Semin Plast Surg. 2019;33(1):013–6.
14. Chin MS, Chappell AG, Giatsidis G, Perry DJ, Lujan-Hernandez J, Haddad A, et al. Hyperspectral imaging provides early prediction of random axial flap necrosis in a preclinical model. Plast Reconstr Surg. 2017;139(6):1285e–1290ee.
15. Grambow E, Dau M, Holmer A, Lipp V, Frerich B, Klar E, et al. Hyperspectral imaging for monitoring of perfusion failure upon microvascular anastomosis in the rat hind limb. Microvasc Res. 2018;116:64–70.
16. Jansen-Winkeln B, Maktabi M, Takoh JP, Rabe SM, Barberio M, Köhler H, et al. Hyperspektral-Imaging bei gastrointestinalen anastomosen. Der Chirurg. 2018;89(9):717–25.
17. Schulz T, Marotz J, Stukenberg A, Reumuth G, Houschyar KS, Siemers F. Hyperspektralimaging zum postoperativen lappenmonitoring von lokoregionären lappenplastiken. Handchir Mikrochir Plast Chir. 2020;52(4):316–24.
18. Thiem DGE, Frick RW, Goetze E, Gielisch M, Al-Nawas B, Kämmerer PW. Hyperspectral analysis for perioperative perfusion monitoring-a clinical feasibility study on free and pedicled flaps. Clin Oral Investig. 2021;25:933–45.
19. Thiem DGE, Römer P, Blatt S, Al-Nawas B, Kämmerer PW. New approach to the old challenge of free flap Monitoring-Hyperspectral imaging outperforms clinical assessment by earlier detection of perfusion failure. J Pers Med. 2021;11(11):1101.
20. Grambow E, Dau M, Sandkühler NA, Leuchter M, Holmer A, Klar E, et al. Evaluation of peripheral artery disease with the TIVITA® tissue hyperspectral imaging camera system. Clin Hemorheol Microcirc. 2019;73(1):3–17.
21. Kohler LH, Köhler H, Kohler S, Langer S, Nuwayhid R, Gockel I, et al. Hyperspectral imaging (HSI) as a new diagnostic tool in free flap monitoring for soft tissue reconstruction: a proof of concept study. BMC Surg. 2021;21(1):222.
22. Holmer A, Marotz J, Wahl P, Dau M, Kämmerer PW. Hyperspectral imaging in perfusion and wound diagnostics - methods and algorithms for the determination of tissue parameters. Biomed Eng Biomed Tech. 2018;63(5):547–56.
23. Huang SH, O'Sullivan B. Overview of the 8th edition TNM classification for head and neck cancer. Curr Treat Options Oncol. 2017;18(7):40.
24. Gevaux L. Three-dimensional maps of human skin properties on full face with shadows using 3-D hyperspectral imaging. J Biomed Opt. 2019;24(6):1–14.
25. Thoenissen P, Heselich A, Al-Maawi S, Sader R, Ghanaati S. Hyperspectral imaging allows evaluation of free flaps in craniomaxillofacial reconstruction. J Craniofac Surg. 2023;34(3):e212–6.
26. Fitzpatrick TB. The validity and practicality of sun-reactive skin types I through VI. Arch Dermatol. 1988;124(6):869–71.

27. Pachyn Ester, Aumiller Maximilian, Buchner Alexander, Freymüller Christian, Linek Matthäus, Volgger Veronika, et al. Investigation on the influence of the skin tone on hyperspectral imaging data interpretation for free flap surgery. Proc. SPIE 12627, Translational biophotonics: diagnostics and therapeutics III. 2023;126271U. https://doi.org/10.1117/12.2670934
28. Shah N, Osea EA, Martinez GJ. Accuracy of noninvasive hemoglobin and invasive point-of-care hemoglobin testing compared with a laboratory analyzer. Int J Lab Hematol. 2014;36(1): 56–61.
29. Nkengne A, Robic J, Seroul P, Gueheunneux S, Jomier M, Vie K. SpectraCam®: A new polarized hyperspectral imaging system for repeatable and reproducible in vivo skin quantification of melanin, total hemoglobin, and oxygen saturation. Skin Res Technol. 2018;24(1):99–107.
30. Keller A. A new diagnostic algorithm for early prediction of vascular compromise in 208 microsurgical flaps using tissue oxygen saturation measurements. Ann Plast Surg. 2009;62(5):538–43.
31. Becker P, Blatt S, Pabst A, Heimes D, Al-Nawas B, Kämmerer PW, et al. Comparison of hyperspectral imaging and microvascular Doppler for perfusion monitoring of free flaps in an in vivo rodent model. J Clin Med. 2022;11(14):4134.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Felicio-Briege A, Linek M, Sroka R, Rühm A, Freymüller C, Stocker M, et al. Hyperspectral imaging for monitoring of free flaps of the oral cavity: A feasibility study. Lasers Surg Med. 2024;56:165–174. https://doi.org/10.1002/lsm.23756