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Hyperspectral imaging for the assessment and monitoring of lower limb perfusion in vascular patients

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Abstract

Acute lower-limb ischemia after abdominal aortic surgery is rare but potentially limb- threatening. Thus, prompt diagnosis and management are paramount. Only early identification and rapid correction might prevent ischemia-related complications.

Continuous postoperative monitoring of peripheral perfusion by assessing limb Colour changes, skin temperature, level of pain and acoustic Doppler readings are the main tools at the surgeon's disposal.

We describe four cases of surgical abdominal aortic repair complicated by early postoperative lower limb perfusion deficits. Diagnosis was improved and management decision aided by using hyperspectral imaging (TIVITA®).

Postoperative vascular surgery patients may present acute limb ischemia, for which they need adequate surveillance. With minimal setup time and instant diagnosis, the hyperspectral camera adds the possibility of quantifying tissue saturations and perfusion, thus refining the clinical tools already in place. The use of TIVITA® allows for the rapid diagnosis of postoperative perfusion issues. This may help direct available treatment options and reduce the time of peripheral ischaemia. Hyperspectral imaging might present an additional powerful device to further improve postoperative perfusion follow-up and ultimately improve patient outcome.

***Keywords*:** hyperspectral imaging; noninvasive monitoring; lower limb.

Introduction

Acute Lower Limb ischemia (ALI) after abdominal aortic surgery is reported in approximately 2-6% of patients and remains a serious complication, associated with higher mortality [1,2]. Swift assessment of the situation is needed in order to decide on the best course of management. In some cases, when the diagnosis is evident, no additional exam is required and an emergency surgery is carried out even before leaving the operating theatre. In other cases, we rely on angiology examinations (Doppler ultrasound) or CTA to confirm diagnosis [3].

Obtaining angiology examinations for assessment of tissue perfusion after a vascular surgery can be difficult depending on physician's availability, especially in an emergency setting. These assessments are also highly dependent on the examiner's expertise and results aren't always comparable [4,5-7].

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Hyperspectral Imaging (HSI) has been shown to be useful in assessing and monitoring tissue perfusion in a non-invasive manner [6-10]. It relies on remission spectroscopy, in which the area examined is irradiated with white light. The scattered light that is then remitted from the tissue is detected, and the characteristic resulting spectra will thus reflect the perfusion of the tissue [10]. The hyperspectral-imaging tool (TIVITA® Tissue, Diaspective Vision, Germany) assesses four parameters: Tissue Oxygenation (StO_2), Near-Infrared Perfusion (NIR), Tissue-Haemoglobin Index (THI), and Tissue-Water Index (TWI) [11]. To do so, the camera of the TIVITA® is placed about 50 cm above the area of interest, and the measurement is made in 6.4 seconds. Reconstruction is obtained from the wavelengths of visible and invisible (NIR) ranges of light reflected by the limb (500-1000 nm), and to a depth of up to 6 mm (Figure 1, left).

Values are assessed in relation to each other: a high THI and low StO_2 reflect venous congestion; low THI and low StO_2, on the other hand, reflect arterial occlusion. A low THI and high StO_2 are suggestive of adequate perfusion. Low StO_2 and high NIR reflect an adequate deep tissue supply and insufficient superficial supply, for example in the setting of an oedema. In this case, TWI will be high. A high StO_2 and low NIR show insufficient deep perfusion, which can be masked clinically by an adequate superficial perfusion [12] (Figure 1, right).

The TIVITA® Tissue was used in four cases between January and May 2020, all having had aortic surgery complicated by ALI. Here, we describe these cases and outcomes, and show how the use of HSI helped in the immediate management and follow-up.

Informed consent was obtained from all patients for this study.

Case presentations

Case 1

A 74-year old male with multiple cardiovascular risk factors (high blood pressure, diabetes mellitus, active smoking, hypercholesterolemia), underwent surgery for an abdominal aortic aneurysm measuring 55 mm. Anastomosis was performed proximally on the infrarenal aorta, and distally on the iliac bifurcation on both sides.

After declamping, no pulses were felt in the right groin. A surgical inguinal access was necessary to perform emergency femoral embolectomy, and an iliofemoral graft had to be added. The aortic graft was sectioned from the iliac bifurcation and connected via another graft to the femoral artery.

HSI was performed in the recovery suite (Figure 2, left). On these images, we observed adequate perfusion except isolated low oxygenation of the right hallux. The patient was treated with prophylactic doses of subcutaneous heparin twice daily and Aspirin 100 mg once daily

Monitoring on postoperative day 1 (Figure 2, right) showed a marked improvement of the oxygenation value of the hallux.

The patient then showed a complete clinical recovery.

The rest of the hospital stay was uneventful, and the patient was discharged on postoperative day 10 without lower limb complaints.

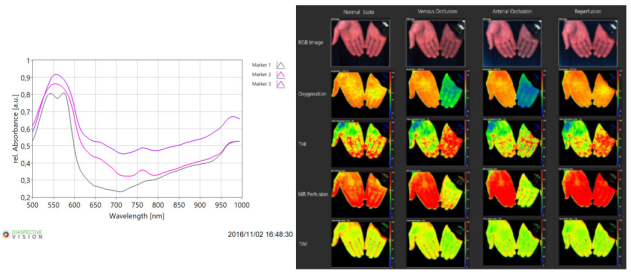

Figure 1: Spectra of human tissue. Marker1 (grey): Well-oxygenated tissue, markers 2 and 3: Poorly oxygenated tissue. Taken with permission of Diaspective Vision. Right - Occlusion test showing different states of oxygenation of the left hand. Right hand is used for comparison. A) Normal state shows good oxygenation (StO2), moderate Tissue-Haemoglobin Index (THI), Near-Infrared Perfusion (NIR) and moderate to low Tissue-Water Index (TWI). B) Venous occlusion shows low StO2 and NIR and high THI due to stasis. C) Arterial occlusion shows low oxygenation and NIR, and low THI due to absence of inflow. D) Reperfusion shows comparable images to A; higher THI attributable to sudden inflow of blood. Taken with permission of Diaspective Vision.

Case 2

A 65-year old female patient underwent elective aortic replacement surgery for a right iliofemoral occlusion and abdominal aortic aneurysm of 45 mm. Infrarenal aorto right femoral and left iliac bypass grafting was performed.

At the end of surgery, an ischaemic left foot was noted with loss of distal pulses despite pulsatile femoral and popliteal arteries. HSI was promptly obtained in the operating room. The exam showed a complete absence of foot perfusion, with a low StO_2 and NIR. (Figure 3, left).

Emergency exploration of the popliteal and crural arteries was performed through popliteal approach with embolectomy of a significant amount of material. Good inflow was obtained but backflow through distal tibial vessels was poor. Because of prolonged surgery, we decided to end the intervention. In the recovery suite, the patient didn't improve and required further thrombo-aspiration and local thrombolysis of pedal vessels.

HSI performed soon thereafter (Figure 3, right) found a slight improvement of the StO_2 as well as the NIR perfusion. However, oxygenation of the toes 1 to 3 as well as the plantar aspect of the medial forefoot remained low.

Angiology examination on postoperative day 1 correlated well with HSI, showing good revascularisation of pedal and anterior tibial artery, and a posterior tibial artery with a retrograde flow. Digital ischaemia of toes 1 to 3 remained.

HSI were performed several times over the next few days to monitor the evolution of the forefoot (Figure 4). Because of residual left hallux ischaemia, as confirmed by another angiology examination on postoperative day 10, the patient benefited from a popliteal nerve block and hyperbaric chamber therapy.

The results of these therapies were monitored with HSI. We see the improvement between day 12, soon after the nerve block (Figure 4, lower left), and day 17 (Figure 4, lower right).

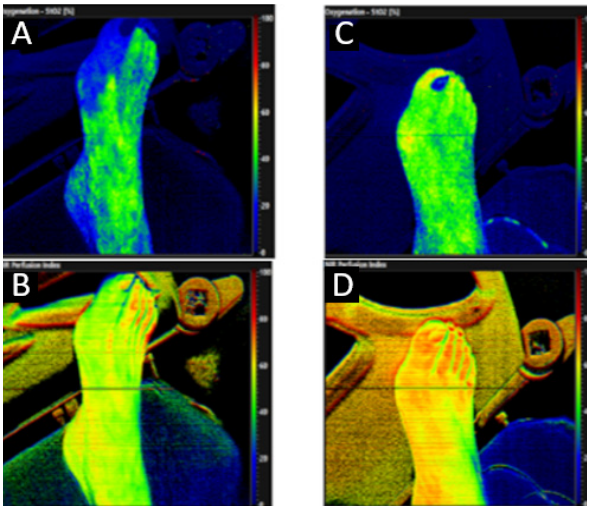

Figure 2: Left - Immediate postoperative images, showing low oxygenation (StO_2) of the hallux (A) and medium Near-Infrared (NIR) perfusion (B).
Right - Postoperative day 1. Improved StO_2 (C) and NIR (D) reflect a good perfusion of the foot.

The patient was discharged on postoperative day 24. Clinical and angiology assessment 5 weeks later showed no residual ischaemia (hallux pressure was measured at 92 mmHg, vs. 113 mmHg on the right side), except for superficial necrosis of the very distal end of the second phalanx of the hallux.

Case 3

A 51-year old male underwent an aorto-left iliac bypass and reconstruction of the left common femoral artery and presented early graft thrombosis. After multiple failed attempts to re-establish flow, the patient presented a total motor deficit of left lower limb and was referred to our centre in critical state initially for amputation. After 12 hours in the intensive care unit with therapeutic anticoagulation, he regained some mobility and sensitivity.

Duplex examination found as sole foot perfusion a slow, monophasic flow in the posterior tibial artery. Despite clinical improvement, we performed HSI to assess if conservative treatment could be a good option since five attempts of revascularisation had already failed. The HSI confirmed persistent insufficient tissue oxygenation and motivated a new attempt at revascularisation (Figure 5, row 1). A femoro-femoral right-to-left crossover bypass was performed with concomitant fasciotomies of the leg.

Postoperative images (Figure 5, row 2) showed improved foot oxygenation as surrogate indication of good foot perfusion, correlated by duplex examination, which showed patent femoral, popliteal and crural arteries.

The remaining hospital stay was uneventful and the patient was transferred for physical rehabilitation on postoperative day 34 with anticoagulant (acenocoumarol) and antiplatelet (clopidogrel) medication.

Case 4

Three months after the initial surgery, the same patient as case 3 presented an acute left lower limb ischemia, with complete occlusion of the femoro-femoral bypass graft. He underwent successful emergency embolectomy of the graft, confirmed by postoperative HSI (Figure 6).

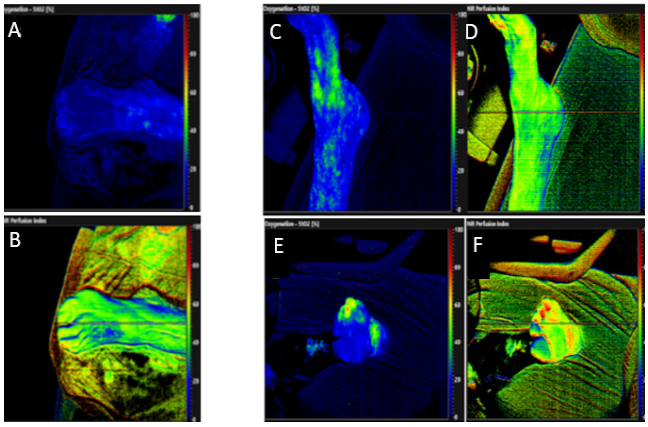

Figure 3: Left - Immediate postoperative assessment of ischaemic left foot. Low oxygenation (StO_2) (A) was associated with low near-infrared perfusion (NIR) (B).
Right - Post-thrombo-aspiration and thrombolysis. Improvement of StO_2 (C, E) and NIR perfusion (D, F). Persistent showing poor oxygenation of first 3 toes and plantar aspect (E).

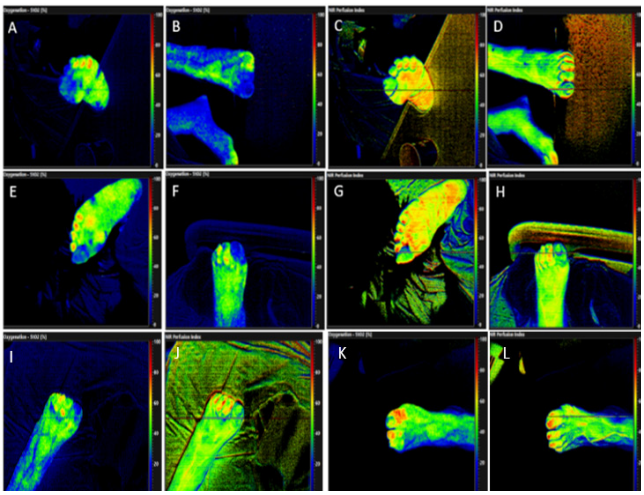

Figure 4: Monitoring during hospitalisation.
Row 1: Postoperative day 3. **Row 2:** Postoperative day 9. A-B/E-F: Oxygenation StO2. C-D/G-H: Near-Infrared perfusion index (NIR). **Row 3:** I-J: Day 12, after popliteal nerve block. K-L: Day 17, after 2 hyperbaric chamber sessions. I-K: StO2. J-L: NIR.

Suspecting a mechanical issue, the patient underwent an elective aorto-bifemoral bypass two weeks after the embolectomy.

After removing the drapes, we noted a cold left foot. HSI confirmed a complete absence of perfusion (Figure 7, row 1).

Emergency embolectomy of the crural arteries was carried out. At the end of surgery, pedal and posterior tibial pulses were palpable.

The postoperative HSI monitoring on day 2 showed a good result (Figure 7, row 2), despite early reocclusion of the posterior tibial artery at the ankle described on duplex control.

Duplex follow-up on day 10 showed spontaneous lysis of the posterior tibial artery thrombosis. Follow-up up to five months was uneventful except for confirmation of thrombophilic disease requiring lifelong anticoagulation.

Discussion

In common practice, whenever suspicion exists of ALI after a surgical or endovascular procedure, duplex examination is often the first-line examination, sometimes followed or replaced by CTA (computed tomography angiography).

In our study, we present cases in which we used HSI to assess lower limb perfusion after aortic surgeries.

The TIVITA® Tissue detects oxygenated haemoglobin and deoxygenated haemoglobin; haemoglobin tissue content; and tissue water content. These are highly specific and reproducible parameters, which make assessment and later monitoring easy and reliable [7]. HSI monitoring of free and pedicled flaps has been described [10,12], with a good correlation to the clinical signs, and was useful for confirming necessity for reintervention when arterial occlusion occurred. It is also currently under investigation for routine use in long-term monitoring of diabetic ulcers [13]. It has been suggested for use in monitoring for peripheral vascular disease, with a good intra-and inter-observer reliability [8].

In the immediate postoperative specific setting, HSI imaging was enough to justify emergent revascularisation in 2 of our 4 cases. The TIVITA® Tissue was readily available to use in the operating theatre, and the time between suspicion of ALI and confirmation using this imaging technology was under 10 minutes. This resulted in quick, limb-saving surgeries.

With this tool available in the operating room, the patient could be left under general anaesthesia, without the need for waking them or moving them. Thus, precious time was saved and surgical management could be carried out with minimal delay.

The postoperative results all show improvement compared to the first images, and the follow-up permitted to observe improvement, as in case 1 or, as in case 2, to introduce adjuvant therapies (peripheral nerve block, hyperbaric chamber).

The third patient had been transferred to our centre for primary amputation after a failed revascularisation of the left lower limb in another clinic. Despite the patient regaining some function after therapeutic anticoagulation, the angiology examination had shown very poor foot perfusion. HSI allowed to help in making the decision to operate on the patient for revascularisation instead of amputation, because despite the poor flow in one single crural artery, associated with low StO_2, NIR values were showing that the deeper tissue perfusion was somewhat maintained. Because he had had multiple failed attempts at revascularisation, and was unstable at the time, a crossover femoro-femoral bypass was the chosen surgery, with good initial results.

Conclusions

Postoperative ALI remains a challenging complication of vascular surgery and is associated with increased morbidity and mortality.

With minimal setup time and instant diagnosis, the hyperspectral camera adds the possibility of quantifying tissue saturations and perfusion, thus refining the clinical tools already in place. The use of TIVITA® allows for the rapid diagnosis of postoperative perfusion issues, and its use helped us manage this complication with a minimum delay. We believe that the use of HSI in the operating room can be a precious aid in diagnosing ALI and treating the problem in a time-effective manner in patients who undergo revascularisation surgery.

The reproducibility of the examination would make it an excellent tool to obtain an immediate postoperative tissue perfusion reference in uncomplicated revascularisations, as well as for monitoring and follow-up of all vascular patients.

More research with prospective series is needed.

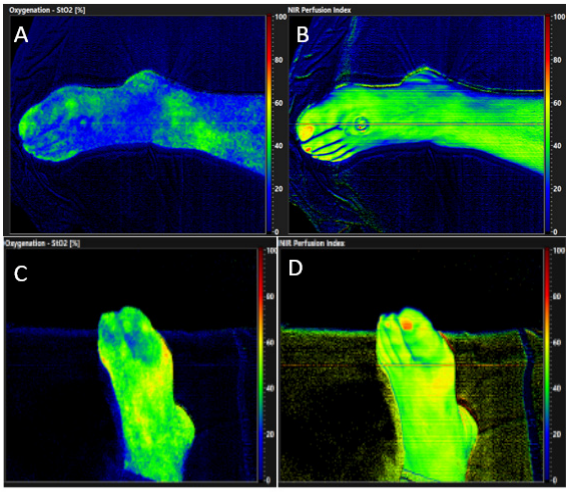

Figure 5: Pre- (row 1) and postoperative images (row 2). A, C: Oxygenation (StO_2); B, D: Near-Infrared perfusion index (NIR).

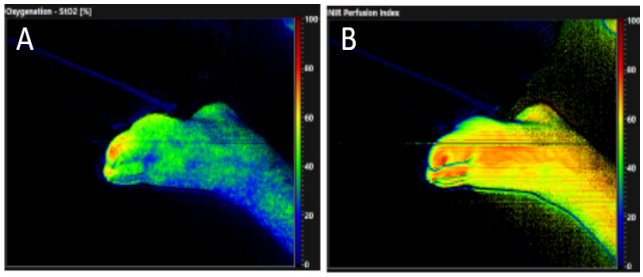

Figure 6: HSI after embolectomy. (A) Adequate oxygenation associated with good near-infrared perfusion index (B).

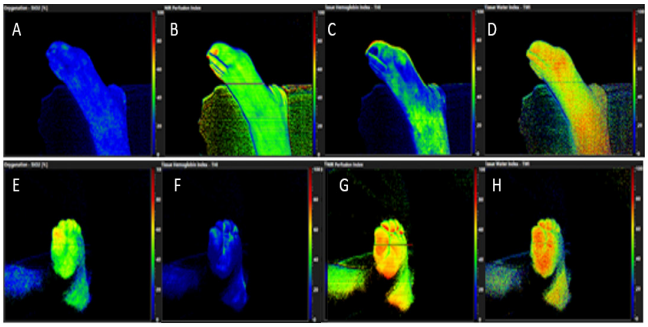

Figure 7: **Row 1** - ALI after aorto-bifemoral bypass grafting. A) Low oxygenation (StO_2) and Near-Infrared Perfusion Index (NIR) (B) are associated with a moderate Tissue Haemoglobin Index (THI) (C) and high TWI (D), likely due to stagnant blood and oedema.
Row 2 - postoperative day 2 shows good tissue perfusion. High StO_2 (A) and NIR (C) are associated with a low THI (B) Reperfusion oedema remains important at this stage (D).

Declarations

Authors' contributions: Lydia Wuarin and Nicolas Murith contributed to all steps of the manuscript; John Diaper to acquisition and interpretation of the data, Damiano Mugnai and Christoph Huber to design of the manuscript. All authors have participated to drafting the manuscript, Nicolas Murith revised it critically. All authors read and approved the final version of the manuscript.

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