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CASE REPORT

The Role of Near Infrared Spectroscopy in Diagnosing Stump Ischaemia in Patients with Below Knee Amputation: Case Reports

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Introduction: Functional near infrared spectroscopy (fNIRS) can be used to quantify stump oxygen saturation (SaO_2) as one of many possible causes of pain following major amputation. Although commonly used for cerebral perfusion monitoring during carotid or cardiac surgery, it can also be used to monitor tissue perfusion in the lower limb and predict healing following below knee amputation (BKA). The aim of this study was to measure the SaO_2 trend as there is no validated oxygen threshold to diagnose insufficient flow into the arterial collateral network currently.
Report: NIRS was used to measure SaO_2 while performing treadmill exercise. Two BKA patients with chronic stump pain were asked to perform treadmill exercise while using their prosthesis and NIRS optode applied to the posterior stump to monitor SaO_2. Cases 1 and 2 showed a decline in SaO_2 of 25% and 18%, respectively, while walking on the prosthesis. After superficial femoral artery (SFA) recanalisation and stenting, Case 1 showed improvement by maintaining SaO_2 between 54% and 60% throughout treadmill exercise. In Case 2, perfusion could not be further improved, and the patient underwent through knee amputation.
Discussion: fNIRS detected compressive ischaemia and exercise induced ischaemia as mechanisms of stump pain. Findings provided the multidisciplinary team with objective information, aiding decision making to treat stump pain.

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INTRODUCTION

Stump pain following lower limb amputation can significantly affect quality of life. The aetiologies include arterial insufficiency, neuroma and neuropathic pain, stump infection or osteomyelitis, bone spur and insufficient myoplasty coverage. Diagnosing the driving aetiology can be a dilemma. This is a report of two cases in which near infrared spectroscopy (NIRS) aided the diagnosis and management of stump pain. NIRS is commonly used for cerebral perfusion monitoring during carotid or cardiac surgery, but can also be used for tissue perfusion monitoring.[1–3] It detects tissue oxygenation by transmitting infrared light and collecting backscattered light. The information is displayed on the monitor as oxygen saturation (SaO_2). As SaO_2 was detected during treadmill exercise for this report, the term functional NIRS (fNIRS) is used.

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REPORT

The case reports are in line with the PROCESS Guideline.[4] The participants were consented to perform treadmill exercise at Sir Charles Gairdner Hospital, Western Australia.

Case 1

A 69-year-old man, with background of a left below knee amputation (BKA) due to non-healing tibiofibular fracture post-fall, presented with stump pain and paresthesia while using a prosthesis. His sole vascular risk factor was a 12-pack-year smoking history.

His left knee X ray showed mild osteoarthritis. After left common iliac artery (CIA) angioplasty, inflow velocity was 79.3 cm/s. Magnetic resonance imaging (MRI) revealed a small neuroma affecting the superficial peroneal and distal tibial nerves and ruled out osteomyelitis. However, his symptoms were persistent despite left CIA angioplasty, neuroma injection, and prosthesis adjustment. Subsequent angiogram revealed a chronically occluded superficial femoral artery (SFA) with patent profunda femoris artery (PFA).

Table 1. Oxygen saturation measurements in below knee stumps during treadmill exercise.

	Case 1	Case 2
Off treadmill		
Inflow velocity at rest — cm/s	79.3	89.0
Resting without prosthesis — %	60	71
Resting with prosthesis — %	51	61
On treadmill		
Weight bearing — %	15	52
Offloading — %	40	-
Off treadmill		
Prosthesis removal — %	60	75

Case 2

A 66-year-old man, with background of bilateral BKA due to critical limb ischaemia, presented with right stump pain while using a prosthesis. He had had a previous failed right femoral popliteal bypass for thrombosed popliteal aneurysm. His vascular risk factors included non-insulin dependent type 2 diabetes mellitus and 40-pack-year smoking history. He suffered from diabetic related complications including ischaemic heart disease, peripheral vascular disease, nephropathy, and peripheral neuropathy. He had previously had osteomyelitis and methicillin resistant *Staphylococcus aureus* (MRSA) stump infection, which had been treated with debridement and a prolonged course of antibiotics. His symptoms were persistent despite inflow disease being ruled out (velocity 89.0 cm/s) with patent PFA, absence of neuroma on MRI, prosthesis adjustment, and three stump revisions. Those revisions included necrotic tissue debridement, musculocutaneous flap refashioning, and tibia remodelling.

Stump appearance

Both cases had similar examination findings. Case 1 had a long medial scar from bypass surgery and Case 2 had multiple scars from previous stump revisions. Both stumps were hairless, pale, and cold when the prosthesis was doffed, and they had satisfactory myocutaneous coverage without bony prominences. There were no signs of infection or skin lesions. About 10 seconds later, they became warmer and hyperaemic with prolonged capillary refill time

Figure 1. Stump images demonstrating the difference in appearance immediately after the prosthesis was doffed for (A) Case 1 and (C) Case 2, and then 10 seconds later for (B) Case 1 and (D) Case 2.

of 4—5 seconds. Both femoral pulses were palpable and the popliteal pulse impalpable.

Exercise test

The NIRS optodes were placed on the posterior upper calf and secured with tape. All measurements were taken in a temperature controlled vascular laboratory using a MoorVMS-NIRS device (Moor Instruments Ltd, UK). When the prosthesis was donned, the baseline SaO_2 were 60% (Case 1) and 71% (Case 2).

During treadmill exercise, Case 1 dropped his SaO_2 from 40% to 15% with natural shift in weight on and off the prosthesis (Table 1). Each drop was associated with pain and numbness. He could walk for 4:10 minutes at 3 km/h before stopping because of pain. Case 2 dropped his SaO_2 from 70% to 52%. However, there was no saturation difference with loading and offloading during walking. He could walk for 1:00 minute at 1 km/h before stopping because of pain. After exercise, both stumps were pale after prosthesis removal (Fig. 1A and C), then becoming hyperaemic (Fig. 1B and D) before normalising after the first minute as SaO_2 returned to baseline.

Management

On inspection of Case 1's prosthesis, the posterior upper margin was not curved enough, causing stump arterial collateral network compression. Despite prosthesis revision after MDT discussion, stump pain was persistent. Furthermore, fNIRS demonstrated insufficient flow into the arterial collateral network despite satisfactory inflow velocity and patent profunda. A shared decision was made with the patient to trial SFA recanalisation and stenting for symptoms relief (Fig. 2). Iliac segment balloon angioplasty was also repeated to maximise inflow, a routine practice. The popliteal pulse became palpable post-procedure, and the patient reported marked symptom improvement. Repeat fNIRS showed maintained SaO_2 between 54% and 60% without variation during gait cycle (Table 2). The patient could walk symptom free for four minutes at 3.8 km/h. The stent was patent after six months, which demonstrated that the collaterals were providing sufficient outflow. In Case 2, fNIRS demonstrated insufficient flow into the arterial collateral network, so a shared decision was made to trial SFA recanalisation and stenting. However, the SFA could not be reconstructed, so the patient proceeded with a through

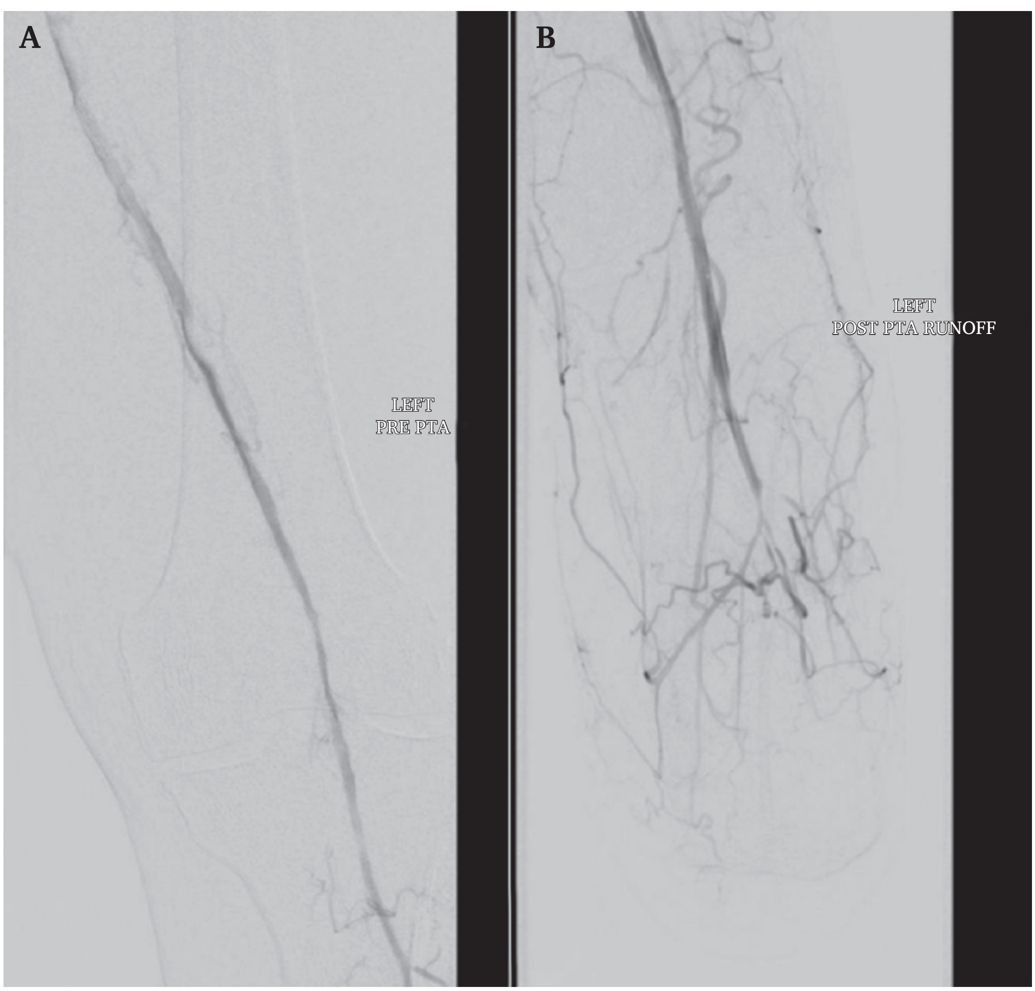

Figure 2. Case 1 angiogram post-superficial femoral artery recanalisation (A) then post-angioplasty (B).

Table 2. Improvement in Case 1 near infrared spectroscopy measurements after superficial femoral artery recanalisation and stenting.

	Case 1 Medial optode, %	Lateral optode, %	Case 2 N/A
Resting without prosthesis	55	62	
Resting with prosthesis	55	63	
On treadmill			
Walking with prosthesis 1:30	55	60	
Walking with prosthesis 2:30	55	58	
Walking with prosthesis 4:00	54	59	
Off treadmill			
Resting with prosthesis	54	59	
Resting without prosthesis	55	73	

knee amputation. At six months, the patient reported pain improvement.

DISCUSSION

The incidence of stump pain following BKA can reach up to 74% and persist for years.[5] Managing stump pain can be very challenging and MDT case discussion is key to assessing the aetiology. Many stumps have a degree of arterial insufficiency, following ligation of main arteries, which can be compounded by collateral disease and the absence of outflow.

Compression ischaemia can produce similar symptoms to neuroma; however, the latter can usually be detected by MRI. Ultrasonography can provide inflow measurements, and angiogram can demonstrate inflow disease and arterial collateral network which may contribute to insufficient flow. fNIRS is a non-invasive tool to monitor SaO_2 while the patient is in motion. Absolute values from NIRS testing vary between individuals, so widely applicable thresholds to diagnose ischaemia are difficult to apply. However, NIRS is useful as a trend instrument where subsequent readings are compared with baseline — an advantage compared with other tools such as transcutaneous oxygen tension ($tcPO_2$) and skin perfusion pressure. $tcPO_2$ and skin perfusion pressure evaluate only a few saturation points and they can easily be affected by a patient's motion.[6] Compared with tcPO2, fNIRS was as effective to predict stump healing post-BKA and tolerance to early prosthesis fitting.[3] However, $tcPO_2$ has been reported to have limited clinical applicability to establish thresholds for amputation healing.[7] Furthermore, the ability to perform an exercise test is an advantage of fNIRS over segmental pressure measurements and plethysmography. The present cases show how fNIRS demonstrates insufficient flow into the arterial collateral network as an aetiology of stump pain. fNIRS detected SaO_2 drops caused by prosthesis related compression during weight bearing, and exercise induced ischaemia in the setting of main vessel occlusion.

There are some limitations in this study. The present authors acknowledge that anterior and posterior stump supplies might be different. The NIRS optodes were placed on the posterior stump as a standard methodology in

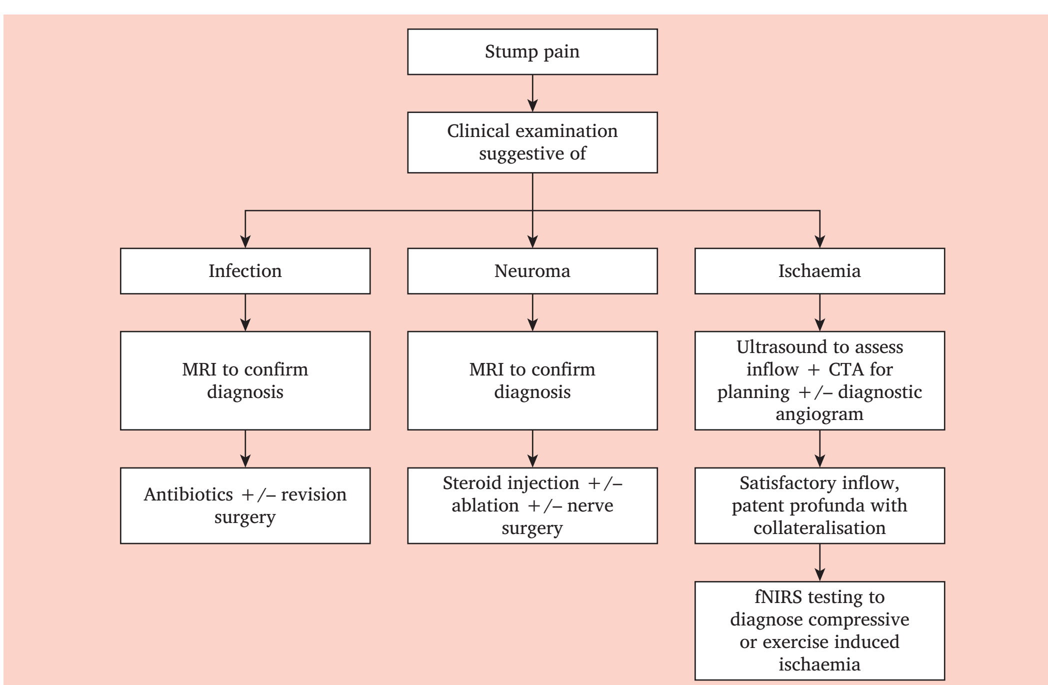

Figure 3. Diagnostic flowchart with suggested imaging and role of functional near infrared spectroscopy (fNIRS) testing to inform the multidisciplinary team treating the amputee. MRI = magnetic resonance imaging; CTA = computed tomography angiography.

measuring SaO_2 for mobilisation in peripheral arterial disease patients. Kagaya et al. demonstrated that a foot can be mapped to different areas based on arterial supply.[6] Hence, future studies could use multiple optodes for stump arterial mapping. Furthermore, comparison with other assessment tools should be baseline information collected in future studies. Wagner et al. suggested that skin temperature and $tcPO_2$ may be reliable at predicting healing following major amputation, whereas segmental pressure measurements and fluorescein angiography were not.[8] However, segmental pressure measurements, such as the profunda popliteal index, have been useful in diagnosing arterial insufficiency in the limb salvage scenario.[9] Overall, these studies will help in the process of stump pain investigation (Fig. 3).

CONFLICT OF INTEREST

None.

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