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Review article

Clinical application of transcutaneous oxygen pressure measurements during exercise

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ABSTRACT

Exertional lower limb pain is a frequent diagnostic issue in elderly patients. Arterial claudication results from the mismatch between the oxygen requirement of, and oxygen delivery to the exercising muscles. Non-invasive vascular investigations (ultrasound imaging, plethysmography or segmental pressure) are used in routine at rest or following exercise, but none can be used during walking or to directly monitor cutaneous oxygen delivery to the limb. Here, we review the methods, tips and traps of the transcutaneous oxygen pressure measurement technique and potential applications.

Transcutaneous oxygen pressure measurement is largely used in vascular medicine for patients with critical limb ischemia. It can also detect regional blood flow impairment at the proximal and distal limb simultaneously and bilaterally during exercise. Exercise-oximetry can also analyze systemic oxygen pressure changes on a reference area on the chest, to screen for occult pulmonary disease. As a surface technique, it does not directly measure muscle oxygen content but provides a reliable estimation of regional blood flow impairment.

With the use of a recently reported index that is independent of the unknown transcutaneous gradient for oxygen, exercise-oximetry provides some accurate information compared to classical non-invasive vascular investigations to argue for a vascular or non-vascular origin of exertional lower limb pain during exercise. Although a time consuming technique, it is a simple test and it is progressively spreading among referral vascular centers as a useful non-invasive diagnostic tool for patients suspected of arterial claudication.

1. Introduction

Peripheral artery disease (PAD) is a major public health challenge. PAD affects approximately 5% of the general population and 20% of people after the age of 70 [1]. The number of PAD patients increased by 23.5% between 2000 and 2010, and patients suffering from PAD have a three-fold increase risk of mortality and major cardiovascular events as compared to non-PAD patients [2].

Claudication is generally the first manifestation of PAD, although PAD may remain asymptomatic for years. Vascular-type claudication is defined as lower back and/or hip and/or buttock and/or thigh and/or calf pain or discomfort that is absent at rest, appears during walking, and forces the patient to stop, thereby impairing walking ability. It can be unilateral or bilateral. Not all patients with PAD report typical vascular-type claudication, and almost half of the patients with PAD have exertional leg symptoms other than intermittent claudication [3]. Apart from PAD, non-vascular disease can induce exertional limb pain that may mimic arterial claudication such as lumbar spinal stenosis [4] or hip osteoarthritis [5]. Further,

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many co-morbid conditions such as cardiac or pulmonary disease can result in walking limitation [6–8] and participate in the walking impairment of PAD patients. The prevalence of comorbidity in patients with claudication is particularly high, specifically in elderly patients. Thereby, defining the exact origin of exertional limb pain can be a challenging issue. Multiple invasive approaches and various non-invasive vascular investigations (NIVI) have been proposed to diagnose the arterial origin of exertional limb pain [4,9]. In this article, we review the methods, tips and traps of the technique and its potential applications.

2. Importance of exercise tests in arterial claudication

In claudication, as in most exercise-related diseases, exercise testing should be used to increase sensitivity and diagnostic performance of any test used. Another benefit of standardized exercise testing is to quantify walking impairment, reproduce symptoms during the medical visit (that may differ from symptoms by history) and screen for associated co-morbid conditions (dyspnea, articular pain) that may also limit exercise. There are various modalities for exercise testing in PAD, but the purpose of this review is not to discuss the strengths or limitations of each approach (constant load *vs.* progressive intensity; treadmill *vs.* corridor walking; walking, tiptoeing) [10–12].

3. Non-invasive exercise tests in arterial investigation

Advantage and limits of various NIVI are reported in Table 1. The most widely used and easiest NIVI is the measurement of resting and post-exercise lower limb arterial pressure generally measured at the ankle and expressed as ankle-brachial index (ABI). ABI, or other segmental pressure examination such as penile, toe or thigh pressure, are recommended by the American College of Cardiology Foundation/American Heart Association to investigate vascular claudication [13]. After a few minutes resting supine period, a sphygmomanometer and a hand-held Doppler are used for the recording of systolic pressures in the brachial, and ankle (i.e., at least posterior tibial, and dorsalis pedis arteries). The ABI is calculated by dividing the highest ankle pressures in each leg by the highest arm pressure [2]. Arrhythmia, intolerance to strict lying position specifically after exercise, arterial stiffness and delay in obtaining readings from the end of exercise, are some of the limits of the technique. Another limit is the heterogeneity of proposed cut-off point to analyze post-exercise ABI results [14]. Last, the diagnostic performance of segmental pressure may be of limited use for proximal claudication [15,16].

Doppler waveform recordings (Table 1, column 2) are used at rest and could be used after exercise. Using a 4–8 MHz continuous Doppler probe, Doppler waveforms can be analyzed at various levels of the arterial tree on both sides before and after exercise. To date, there is lack of consensus regarding normal vs. abnormal waveform interpretation to be found after exercise.

Multilevel resting and post-exercise plethysmography (Table 1, column 3) can be used to quantify blood flow with transient arrested venous return using a thigh cuff abruptly inflated to ~ 50 mmHg. Although the technique is extremely accurate it is mostly used as a research tool rather than use in clinical routine.

Resting and post-exercise thermography (Table 1, column 4) have been abandoned due to environmental constrains and lack of accuracy.

Resting and post-exercise near infra-red spectroscopy (NIRS) has recently been proposed as a rapid and attractive tool to measure muscle oxygen saturation during exercise and diagnose PAD patients specifically at the buttock level [17,18]. Various devices are available that calculate tissue oxygen saturation from the

Table 1
Advantage and limits of various non-invasive vascular investigations.

	Ankle to brachial arterial pressure index indices	Doppler velocity profiles	Plethysmography	Thermography	Near infrared spectroscopy	Scintigraphy	Exercise oximetry
Available in Primary care	Y	Y	Y	N	N	N	N
Simultaneous bilateral measurements	Y	N	Y	Y	Y	Y	Y
Measurement during exercise	N	N	N	Y	Y	N	Y
Differentiation of proximal *vs.* distal ischemia	Y	Y	N	Y	Y	Y	Y
Sensitivity to environmental conditions	N	N	N	Y	Y	N	N
Account for systemic exercise-induced hypoxemia	N	N	N	N	N	N	Y
Normal limits have been validated against radiological imaging	Y	N	N	N	Y	N	Y
Reproducibility	good	good	good	fair	fair	good	good
Cost of the equipment (range in K€) [a]	1–5	2–30	5–20	5–15	30–50	100–300	30–70
Cost per investigation (range in €) [a]	20–100	20–100	20–100	10–50	20–50	300–1000	60–300

[a] Costs of equipment and per investigations are highly variable from one country to another.