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Reliability of oscillometric central blood pressure responses to lower limb resistance exercise

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Background and aims: Although it is well known that resistance training (RT) is beneficial for patients suffering from a variety of cardiovascular diseases, it remains underutilized as a rehabilitation tool as there is no reliable way to monitor the additional stress placed on the central organs. The current study aimed to determine between-day reliability of central haemodynamic indices using oscillometric pulse wave analysis (PWA) during progressive sub-maximal RT.
Methods: Nineteen healthy young males were tested on 3 different mornings in a fasted state. Central hemodynamic variables including augmentation index (AIx), AIx normalized to a heart rate of 75 beats per minute (AIx@75), central systolic blood pressure (cSBP), forwards (Pf) and backwards (Pb) wave reflection were determined at rest, as well as during leg extension RT at 10, 15 and 20% of maximal volitional contraction (MVC), and following 1 min and 5 min passive recovery.
Results: During RT at 10, 15 and 20% MVC, the intraclass correlation coefficient (ICC) values for AIx@75 (0.76–0.9), cSBP (0.74–0.78), Pf (0.75–0.82) and Pb (0.75–0.83) exceeded the criteria (0.75) for excellent reliability. During the 5 min recovery, the ICC values for AIx@75 (0.87–0.87), cSBP (0.69–0.7), Pf (0.63–0.67) and Pb (0.63–0.66) indicated good to excellent reliability.
Conclusions: Clinically meaningful changes in central hemodynamic indices can be obtained during resistance training using oscillometric PWA devices. This technology holds potential for advancing resistance training prescription guidelines for patients with overt cardiovascular diseases.

1. Introduction

The inclusion of low intensity resistance training (RT) into both primary and secondary cardiovascular disease-prevention programmes is associated with positive cardiovascular effects [1,2]. However, the American Heart Association Scientific Advisory Statement suggests that the safety of RT in moderate-high risk cardiac patients remains largely unknown, requires further studies [3], and when performed, needs close monitoring and good clinical judgement [1]. This paucity of evidence has potentially led to its limited inclusion, or exclusion, from recommended rehabilitation guidelines in many countries [4]. RT may be more widely incorporated into cardiovascular rehabilitation guidelines with the identification of a suitable method for monitoring the acute stress that RT places on the cardiovascular system. Such a method should be practical, accurate and precise (between-day reliability). Indeed, the method should have sufficient precision to enable clinical exercise physiologists and clinicians to track clinically meaningful changes.

Although it is currently recommended that heart rate and brachial blood pressure responses are recorded during RT as part of cardiac rehabilitation [1,4], these peripheral hemodynamic responses do not accurately reflect left ventricular load or overall myocardial stress [1,5,6]. Alternatively, central blood pressures and

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arterial wave reflection are of high clinical importance [5], and can be determined relatively quickly and non-invasively with acceptable accuracy [7] and precision [8] using oscillometric pulse wave analysis (PWA) [9,10]. However, while a recent study demonstrated that oscillometric PWA can be used during low intensity aerobic (cycling) exercise with acceptable precision [11], no study has examined the reliability of oscillometric PWA during RT. Therefore, the purpose of this study was to determine the between-day reliability of central haemodynamic indices determined using oscillometric PWA during progressive sub-maximal RT in a healthy population.

2. Materials and methods

This observation study was carried out in accordance with STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines [12].

2.1. Participants

To ascertain the upper limit of reliability, a relatively homogenous healthy cohort of 19 active males (age: 23.3 ± 4.2 yrs; BMI: 26.2 ± 3.1 kg/m^2) were recruited. All participants were non-smokers, asymptomatic of any illness, physically active, and were not suffering from any metabolic diseases, nor were they taking any medication known to have vascular actions. All participants provided written informed consent prior to participating in the study. Institutional ethical approval, which conformed to the Declaration of Helsinki and the standards of the journal, was obtained prior to data collection and recruitment.

2.2. Experimental procedure

Participants visited the laboratory on four separate occasions. Each session was at least 24 h apart and all sessions were completed within 10 days from the initial visit. Visit one was used to: 1) determine maximal volitional contraction (MVC) on a double leg-press resistance machine (Pulse Fitness; Congleaton, UK), and 2) familiarise participants with the exercise protocol at 10, 15 and 20% of MVC. For visits 2, 3 and 4 participants attended between the hours of 0730 and 1000 following an overnight fast, consuming only water and having refrained from caffeine for 12 h and alcohol for 24 h prior. For each session, baseline measures were collected in an upright-seated position following a minimum of 20 min of quiet rest. This was followed by progressive intensity double leg-press resistance exercise (10, 15 and 20% MVC), with each stage lasting for 5 min. Exercise intensities of 10, 15 and 20% MVC were chosen as clinical exercise physiologists and clinicians are advised to start RT at low intensities during cardiac rehabilitation [1], in part because this reduces the chance of performing a potentially dangerous valsalva manoeuvre [13]. For this initial study, the order of exercise intensity was progressive, and not randomized, to avoid a carry-over effect. At each exercise intensity, brachial blood pressure was assessed on the left arm after 3 min, with the participant continuing to perform leg extensions throughout the cuff inflation and deflation. Following the brachial blood pressure assessment a sub-diastolic recording was measured, during which the participant remained completely still with their legs, arms and head in a fixed, but relaxed position for ~10 s. After both the brachial and sub-diastolic pressures were assessed, which lasted between 60 and 90 s in total, the participant continued to exercise at the same intensity until the 5 min stage was completed. Once all three exercise intensities were completed (15 min in total), participants were asked to rest in a seated upright position on the leg-press machine while a PWA assessment was conducted at post 1 and 5 min.

2.3. Determination of one repetition maximum

Each participant's one repetition maximum was predicted from a submaximal double leg-press performance using the Brzycki equation [14]. In brief, the protocol consisted of a pulse raiser and exercise specific warm-up (6–10 repetitions at approximately 50% MVC) followed by 2 min of rest. Succeeding this, starting at a self-selected resistance, participants attempted to lift the heaviest weight possible whilst ensuring failure occurred between 7 and 10 repetitions [14,15]. The following equation was used to determine 1RM.

$$\text{One repetition maximum} = \frac{100 \text{ x LOAD}}{(102.78 - 2.78 \text{ x REPS})}$$

LOAD = amount of resistance on the machine in kg
REPS = number of repetitions performed

2.4. Exercise protocol

Once seated on the leg-press machine, participants were asked to listen to a metronome and make one complete contraction cycle (knee flexion to 90° and a near complete extension) at 0.33 Hz (one contraction every 3 s), ensuring a smooth movement during both extension and flexion occurred.

2.5. Pulse wave analysis

Following standard manufacturer guidelines [16], oscillometric pressure waveforms were recorded on the upper left arm using the SphygmoCor XCEL device (AtCor Medical, Sydney, Australia). Each measurement cycle consisted of a brachial blood pressure recording lasting approximately 60 s, followed by a 10 s sub-diastolic recording. A corresponding aortic waveform was generated using a validated transfer function [17], from which central: systolic blood pressure (cSBP), diastolic blood pressure (cDBP), pulse pressure (cPP), augmentation pressure (cAP), augmentation index (AIx), augmentation index normalized to a heart rate of 75 bpm (AIx@75), forward aortic pressure (Pf), backward aortic pressure (Pb), reflection magnitude percentage (RM%), and sub-endocardial viability ratio (SEVR) were derived. Heart rate and double product (DbPr), an index of myocardial oxygen consumption, were also determined.

2.6. Sample size

Sample size calculations were based on the primary outcome cSBP, and presuming a typical error of 6.4 mmHg derived from a previous PWA reliability study using healthy subjects [18]. Using magnitude-based inference [19] to estimate the sample size required to detect the smallest beneficial (or detrimental) in a cross-over study, with the maximum chances of a type 1 and 2 error set at 5 and 20% (i.e., very unlikely-unlikely), approximately 15 participants are required to detect a 5 mmHg change (based on the smallest change reported in previous blood pressure studies [20]). To account for the novel paradigm we oversampled (20 participants).

2.7. Statistical analysis

Statistical analyses were performed using Statistical Package for Social Sciences Version 22 (SPSS, INC., Chicago, USA). All data are