MULTI-CHANNEL ELECTRICAL BIOIMPEDANCE: A NON-INVASIVE METHOD TO SIMULTANEOUSLY MEASURE CARDIAC OUTPUT AND INDIVIDUAL ARTERIAL LIMB FLOW IN PATIENTS WITH CARDIOVASCULAR DISEASE

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ABSTRACT. Background. Cardiac output is the fundamental determinant of peripheral blood flow however; optimal regional tissue perfusion is ultimately dependant on the integrity of the arterial conduits that transport flow. A complete understanding of tissue perfusion requires knowledge of both cardiac and peripheral blood flow. Existing noninvasive devices do not simultaneously assess the cardiac and peripheral circulations. Multi-channel electrical bioimpedance (MEB) measures cardiac output and peripheral flow simultaneously. Objectives. Assessment of the accuracy of MEB to measure cardiac output in patients with clinical heart failure (group 1) and to measure regional arterial limb flow in patients with exertional leg pain clinically thought to have peripheral arterial disease (group 2). Methods. Cardiac output was measured by MEB in 44 patients with moderate to severe clinical heart failure (group 1) and was compared to a cardiac output measured by 2D-Echo Doppler. Peripheral blood flow (regional ankle and arm flow) was measured by MEB in another group of 25 patients with exertional leg pain clinically thought to be claudication (group 2). The MEB ankle/arm flow ratio (AAI index) was then compared to a conventional ankle/brachial pressure ratio (ABI index). Results. There was excellent correlation between the mean cardiac index by MEB (2.01 l/min/m2) and by 2D-Echo Doppler (2.06 l/min/m2) and bias and precision was 0.05 (2.4%) and ±0.48 l/min/m2 (±23%), respectively. The correlation was maintained for each measurement over a wide range of cardiac indices. There was good correlation between AAI and ABI measurements (P < 0.05). Conclusions. MEB accurately measures cardiac output in patients with moderate to severe clinical heart failure and accurately measures regional arterial limb flow in patients with peripheral arterial disease.

KEY WORDS. non-invasive cardiac output, multichannel electrical bioimpedance, non-invasive arterial limb flow, cardiac output measurement, bioimpedance.

INTRODUCTION

Cardiovascular disease (CVD) is the number one killer in the United States and is projected to be the leading cause of death and disability worldwide by 2020 [1]. Heart failure is a common outcome of CVD. Cardiac output progressively declines as clinical heart failure develops. Measurements of blood pressure and heart rate generally
Peripheral arterial disease (PAD) is another expression of CVD. The majority of patients with PAD are asymptomatic [2, 3]. Diagnosing PAD identifies those individuals at highest risk for subsequent myocardial infarction and stroke regardless of whether symptoms of PAD are present [4, 5]. PAD progression is associated with increased CVD morbidity and mortality [6]. Patients with both PAD and compromised cardiac function have a marked reduction in peripheral tissue perfusion and are at high risk.

The potential to simultaneously measure a reduced cardiac output and impaired regional arterial limb flow with a single device that distinguished between the two, or confirms the presence of both, would add a new dimension to noninvasive cardiovascular testing in patients with CVD. We have previously shown that multi–channel electrical bioimpedance (MEB), a unique application of impedance cardiography, can accurately measure both cardiac output and arterial limb flow in healthy volunteers [7]. This study was designed to test MEB’s accuracy in measuring cardiac output in a group of heart failure patients (group 1) and peripheral arterial blood flow in another group of patients (group 2) with suspected peripheral vascular disease.

**Methods**

**Study population and design**

Multi–channel electrical bioimpedance (MEB Device, Delta Segments Technology, Inc.) was used to measure central blood flow (cardiac output) and peripheral arterial blood flow (individual leg and arm flow) in two populations of patients; Group 1: 44 patients with NYHA Class II–IV HF whose clinical presentation included one or more of the following: exertional dyspnea, exertional fatigue, nocturnal dyspnea, orthopnea, peripheral edema. These patients had numerous co-morbidities: ischemic heart disease 66% (previous myocardial infarction 39%), hypertension 52%, diabetes mellitus 27%, and chronic obstructive pulmonary disease 20%. Group 2: 25 patients with exertional leg pain clinically thought to be claudication.

Measurements were performed in an outpatient Echo Doppler laboratory and a hospital noninvasive vascular laboratory, respectively. An institutional review board approved the protocols. Informed consent was obtained from all participants.

Group 1: Cardiac output was measured by MEB in 44 patients (35 males and 9 females) with clinical HF, mean age 66 years (range 39–94). The study group’s characteristics by gender are described in Table 1. The