# Pulse Arrival Time Reactivity to Deep Breathing in Healthy Subjects and Vascular Multimorbid Patients

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***Abstract*—Pulse arrival time (PAT) combines the pre-ejection period and peripheral pulse transit time and may reveal cardiovascular responses to physiological challenges. This study compared PAT reactivity to a brief slow deep breathing test (DBT) in 20 young healthy adults and 21 older participants with vascular and metabolic multimorbidity. Simultaneous electrocardiography (ECG) and toe photoplethysmography (PPG) were recorded during a 5-min baseline, a 32-s DBT comprising four controlled breathing cycles, and 5-min recovery. PAT was estimated using a fiducial point-, Hilbert transform-, and the continuous wavelet transform (CWT)-based methods. The DBT induced change relative to baseline was compared between groups using Welch's t-tests with Holm correction. Exploratory receiver operating characteristic analysis for discriminating between the two groups yielded areas under the curve of 0.834, 0.835, and 0.760, respectively. In healthy participants, the peripheral pulse arrived earlier relative to the ECG during DBT, resulting in a shortening of PAT, followed by a return toward baseline during recovery. In contrast, PAT remained largely unchanged in the multimorbid group, indicating an attenuated response to the breathing challenge. All three estimation methods consistently identified a significantly greater baseline to DBT reduction in PAT in healthy participants.**

***Keywords—pulse arrival time, photoplethysmography, deep breathing, Hilbert transform, continuous wavelet transform***

## I. Introduction

Pulse arrival time (PAT) is defined as the interval between an electrical cardiac reference, typically the electrocardiographic (ECG) R wave, and a selected fiducial point of a peripheral photoplethysmography (PPG) waveform, making PAT possible for cardiovascular monitoring [1]. However, its absolute value depends on the selected PPG landmark, signal processing, and detection algorithm [2].

Deep slow-paced breathing provides a simple and repeatable physiological challenge to cardiovascular regulation. It modulates cardiac autonomic activity, respiratory sinus arrhythmia, and arterial baroreflex function [3]. Deep inspiration can also evoke changes in peripheral vascular tone that are detectable using PPG and laser Doppler flowmetry [4]. Our previous camera-based study demonstrated that paced deep breathing modifies plantar foot microcirculatory oscillations using photoplethysmography imaging (PPGI) parameters in young healthy adults [5]. Breathing challenge measurements may consequently reveal functional regulatory differences that are less apparent under resting conditions. This is particularly relevant in vascular and metabolic multimorbidity, where diabetes, autonomic neuropathy, arterial abnormalities, and microvascular dysfunction may alter cardiovascular and peripheral responses [6], [7].

Conventional PAT estimation uses discrete fiducial landmarks, such as the interval from the ECG R wave to the maximum slope of the PPG upstroke [1]. In contrast, Hilbert transform and continuous wavelet transform (CWT) approaches derive delays from waveform phase and time frequency representations. These phase derived estimates may be sensitive not only to pulse propagation but also to waveform morphology, harmonic content, and frequency selection [8]. Although phase-based analysis has demonstrated sensitivity to autonomic related changes in cutaneous perfusion dynamics [9], it remains unclear whether fiducial and phase based PAT estimators support the same group level inference during a brief breathing challenge.

The present study therefore compared fiducial-, Hilbert-, and CWT-derived PAT reactivity to paced slow deep breathing in young healthy adults and older adults with vascular/metabolic multimorbidity.

## II. Methods

The study enrolled 20 young and healthy subjects - 12 males (25.25±2.3 years old) and 8 females (24.63±1.69 years old). Healthy participants had no history of cardiovascular, chronic or metabolic disease. None reported high level athletic training or a sedentary lifestyle associated with obesity. The vascular/metabolic multimorbid group consisted of 21 older subjects with peripheral arterial disease, diabetes mellitus and other vascular/metabolic comorbidities - 10 males (63.7±15.59 years old) and 11 females (63.36±16.22 years old). The study was conducted in accordance with the Declaration of Helsinki and was approved by Ethics Committee of Comenius University (48/2021). Written informed consent was obtained from all participants before inclusion.