JACC: CASE REPORTS VOL. 28, 2023

CASE REPORT

CLINICAL CASE: TECHNICAL CORNER

A Novel Earbud Detects Aortic Stenosis Murmur Before and After Transcatheter Aortic Valve Replacement

Christine P. Shen, MD,[a] Jal Panchal, MS,[b] Misty Daniel, BA,[a] Christina Dimalanta, MPH,[a] Hayley Engstrom, RDCS,[a] Robert Ciesielski, PhD,[b] Anna Barnacka, PhD,[b] Steven Romero, MD,[a] Sanjeev P. Bhavnani, MD,[a] Curtiss T. Stinis, MD[a]

ABSTRACT

Noninvasive infrasonic hemodynography using the MindMics earbuds captures low-frequency acoustic vibrations throughout the cardiac cycle. In an n-of-1 analysis, we propose a new method of assessing severe aortic stenosis by using infrasonic hemodynography to detect its characteristic systolic ejection murmur before and after transcatheter aortic valve replacement. (J Am Coll Cardiol Case Rep 2023;28:102089) © 2023 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Noninvasive infrasonic hemodynography (IH) captures low-frequency acoustic vibrations in the ear canal representing fluctuating pressure throughout the cardiac cycle.[1] A novel wearable device has been developed that contains acoustic sensors embedded in an earbud configuration (**Figures 1 and 2A**) to acquire sound signals traveling from the arteries and valves in the vicinity of the ear canal.[1] We have recently demonstrated the relationship between IH and cardiac time intervals through simultaneously acquired IH, electrocardiogram (ECG), echocardiogram, and direct hemodynamic measurement catheterization datasets.[2]

LEARNING OBJECTIVES

- To understand that IH detects acoustic vibrations of heart sounds.
- To explore in-ear IH as a new method for noninvasive detection of AS through its systolic murmur.

It is well known that severe aortic stenosis (AS) produces a typical delayed peak pressure detectable on arterial pressure waveforms at catheterization, and a systolic ejection sound detectable on clinical auscultation. Our previous investigations demonstrated that the IH waveform can capture the characteristic delayed peak pressure.[3] Herein, we propose a new method of assessing severe AS through IH by detecting its characteristic systolic ejection murmur.

We report an n-of-1 analysis as a proof of concept. We identified a patient with severe aortic stenosis undergoing transcatheter aortic valve replacement (TAVR). The patient provided informed written consent and wore IH earbuds in the left and right ears, fitted for full ear canal occlusion. Data from the IH earbuds were collected simultaneously with echocardiography prior to TAVR (**Figure 2B**). The echocardiogram identified aortic stenosis measurements and calculations as well as aortic valve opening and left ventricular outflow measurements. ECG leads

From the [a]Division of Cardiology, Scripps Clinic, La Jolla, California, USA; and the [b]MindMics, Inc, Cambridge, Massachusetts, USA.

The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

Manuscript received September 26, 2023; accepted October 4, 2023.

ISSN 2666-0849 https://doi.org/10.1016/j.jaccas.2023.102089

ABBREVIATIONS AND ACRONYMS

AS = aortic stenosis

ECG = electrocardiogram

IH = infrasonic hemodynography

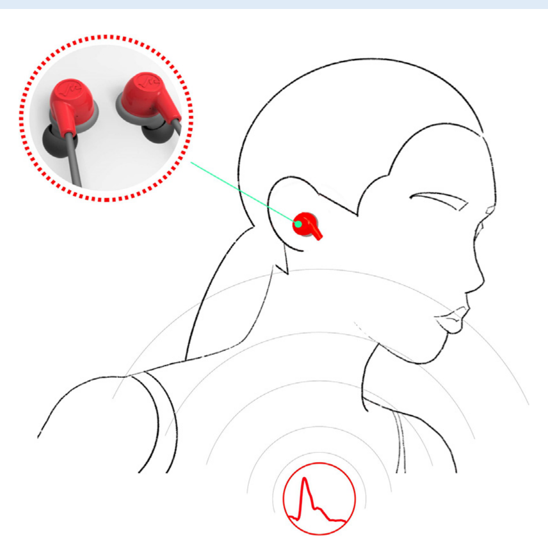
S1 = first heart sound

S2 = second heart sound

TAVR = transcatheter aortic valve replacement

were connected to the patient's left chest, right chest, and left leg to obtain reference signals. During the TAVR, simultaneous IH, ECG, and aortic catheterization waveforms were acquired at 1,000 Hz sampling rate and aggregated as a multimodal time series dataset. The data analysis was conducted based on signals from 14 cardiac cycles collected both before and after TAVR and stacked together to obtain average waveforms, with time synchronization given by the position of the QRS peaks of the ECG. The murmur detection with IH was performed after limiting the IH waveform to frequencies above 20 Hz and exploring the reduced IH signals in the region between the start and end of systole, when the first heart sound (S1) and the second heart sound (S2) were expected, respectively. S1 and S2 were recognized by studying the pressure power integral. The significance of murmur detection with IH was evaluated by conducting a paired *t* test that compared the in-ear acoustic pressure power spectrum calculated by integrating reduced IH spectra over 64-ms windows along the cardiac cycle between S1 and S2, with measurements obtained before and after valve replacement.

FIGURE 1 Mechanism of Novel Earbuds



A novel, wearable device acquires sound signals traveling from the heart.

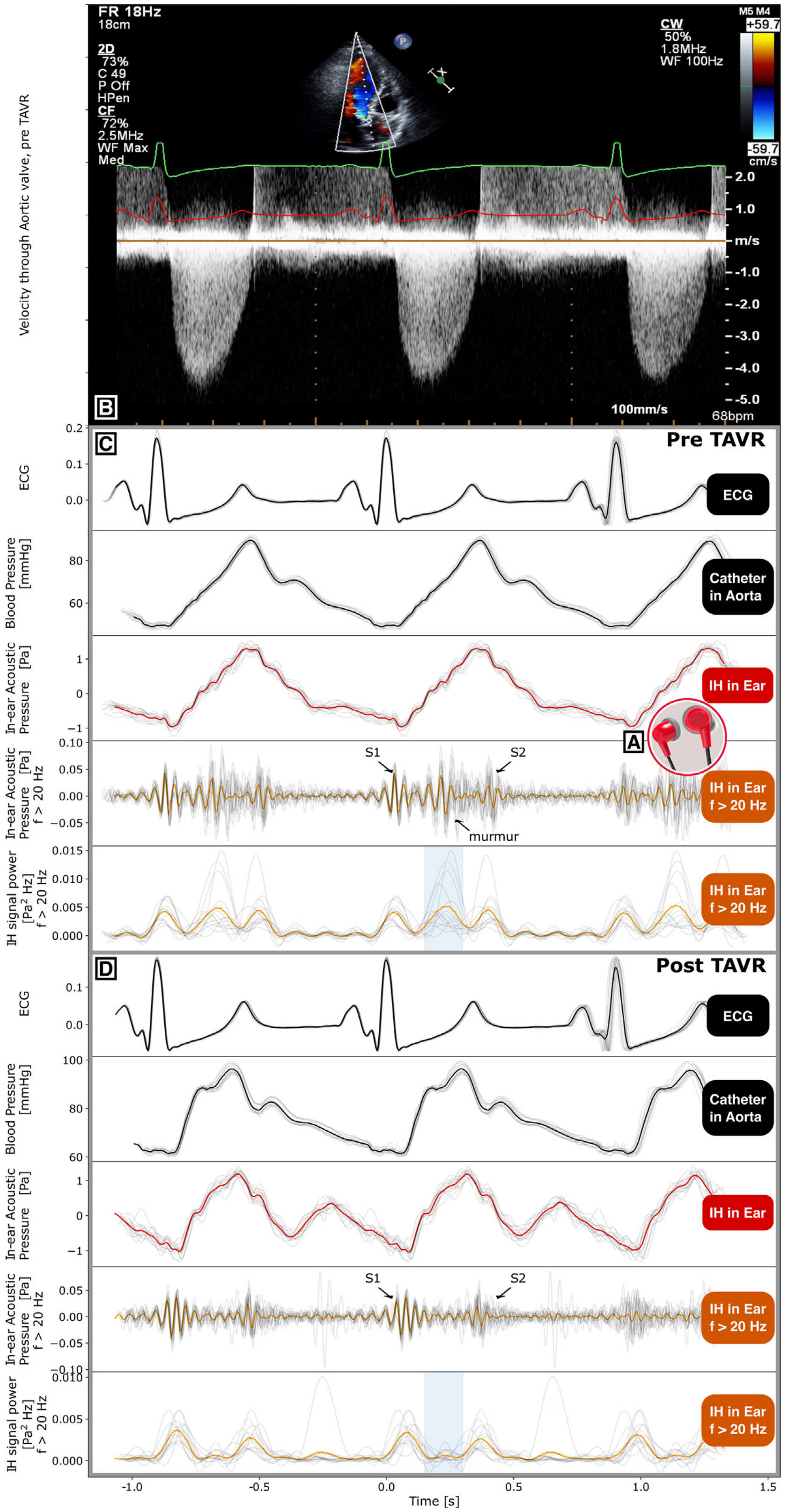
The identified patient was a 47-year-old flight instructor with a bicuspid aortic valve who presented with severe, symptomatic AS with moderate aortic insufficiency. The mean aortic pressure gradient was 52 mm Hg, the peak gradient was 83 mm Hg, the aortic valve area was 1.0 cm^2, and the dimensionless index was 0.25. After a multidisciplinary discussion with cardiothoracic surgery colleagues, a joint decision was made to proceed with TAVR based on patient preference. The patient wore the earbuds and underwent IH during the TAVR procedure with successful deployment of a 26-mm balloon-expandable valve. Prior to valve deployment (Figure 2C), there was a mid-systolic crescendo-decrescendo signal between S1 and S2, consistent with a characteristic AS murmur. Post-TAVR (Figure 2D), the S1 and S2 signals were present, but the mid-systolic signal was diminished. There was a significant reduction in signal power in the high-frequency region between S1 and S2 before (mean 0.0025 $\pm$ 0.0015 Pa^2 Hz) and after (mean 0.0006 $\pm$ 0.0003 Pa^2 Hz) TAVR ($t_{14} = 4.26$, $P = 0.0009$). Post-TAVR echocardiography showed a well-seated TAVR valve with mean gradient 13 mm Hg without paravalvular leak.

We describe in-ear IH as a new method for early, noninvasive detection of severe AS and validated this approach through synchronized multimodal cardiac testing including ECG, echocardiogram, and cardiac catheterization. We investigated the capability of IH to detect a difference in the characteristics of severe AS in the pre-TAVR and post-TAVR measurements, finding a significant reduction in the signal power during the timing of the murmur. This n-of-1 analysis is hypothesis-generating regarding the role of a convenient, wearable earbud that captures cardiac time interval and hemodynamic measurements of severe AS. Further investigation is underway to validate these findings into the use of IH to diagnose and monitor AS and other valvular diseases.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

Ms Daniel is a clinical research monitor for Edwards Lifesciences. Dr Romero has served as a consultant for Philips Image-Guided

FIGURE 2 Novel Earbud IH



Continued on the next page

Therapy Corporation. Dr Stinis has served as a proctor, speaker, and consultant for Edwards Lifesciences; a consultant for Medtronic and Boston Scientific; and speaker for Shockwave Medical. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

ADDRESS FOR CORRESPONDENCE: Dr Curtiss T. Stinis, Division of Cardiology, Scripps Clinic, 9898 Genesee Avenue, AMP 200, La Jolla, California 92037, USA. E-mail: stinis.curtiss@scrippshealth.org.

REFERENCES

1. Gilliam FR, Ciesielski R, Shahinyan K, et al. In-ear infrasonic hemodynography with a digital health device for cardiovascular monitoring using the human audiome. *NPJ Digit Med*. 2022;5:189.

2. Wheeler CM, Patel S, Waldman CE, et al. Abstract 11669: "hearing the heart" - validation of a novel digital health earbud technology to measure cardiac time intervals through infrasonic hemodynography. *Circulation*. 2021;144:A11669.

3. Waldman CE, Patel S, Wheeler CM, et al. Abstract 13654: can a novel earbud technology detect severe aortic stenosis? Modernizing the Wiggers diagram through infrasonic hemodynography synchronized with echocardiography and cardiac catheterization. *Circulation*. 2021;144:A13654.

KEY WORDS aortic stenosis, earbud, infrasonic hemodynography, murmur

FIGURE 2 Continued

(A) Earbud. (B) Echocardiography of the continuous-wave Doppler velocity profile across the aortic valve before transcatheter aortic valve replacement (TAVR). (C) Pre-TAVR tracings of electrocardiogram (ECG), catheter in the aorta, infrasonic hemodynography (IH) in the ear, IH in the ear with frequency >20 Hz, and power spectrum of IH in the ear with frequency >20 Hz (from top to bottom). (D) Post-TAVR tracings. In-ear acoustic pressure power spectrum (Pa^2 Hz) was integrated over 64-ms windows; powers of individual signals in the highlighted area between the first heart sound (S1) and second heart sound (S2) peaks were used to test significance of murmur observation in pre-TAVR relative to post-TAVR data.