ISSN- O: 2458 - 868X, ISSN–P: 2458 – 8687
National Library of Medicine - ID: 101731606

International Journal of Medical Science and Innovative Research (IJMSIR)
IJMSIR : A Medical Publication Hub
Available Online at: www.ijmsir.com
Volume – 10, Issue – 5, September – 2025, Page No. : 18 – 32

Test Characteristics of Smart Phone-Enabled Phonoscopy with Artificial Intelligence-Enhanced Detection of Cardiovascular Disease

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Citation this Article: Oscar Maitas, Barbara A. Danek, David Elison, Christine J. Chung, James M. McCabe, "Test Characteristics of Smart Phone-Enabled Phonoscopy with Artificial Intelligence-Enhanced Detection of Cardiovascular Disease", IJMSIR - September – 2025, Vol – 10, Issue - 5, P. No. 18 – 32.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Purpose: Valvular heart disease (VHD) is a major contributor to morbidity and mortality. Auscultation has been a cornerstone of initial VHD diagnosis but requires diagnostic skill to be valuable and is often not performed at all. We therefore sought to explore the test characteristics of an AI-based software, Stethophone AI, that records, augments and visualizes bioacoustic sounds via smartphone microphone in detecting structural and rhythmic cardiac anomalies among a cohort of patients with known VHD.

Methods: A random sample of patients presenting to Structural Heart Clinic with known VHD were screened with Stethophone AI for murmur detection as part of routine clinical care, typically using a single point of auscultation

Results: Among 68 patients tested, the sensitivity for murmur detection was 95.2%. The positive predictive valve was100% and false negative rate was 4.8% for murmur detection. While the positive predictive value remained consistent across murmur types, sensitivity varied according to valve pathology. The system also demonstrated 100% sensitivity for patients in atrial fibrillation (n = 6).

Conclusions: An AI-based system, deployed as a smartphone application that utilizes the device's built in microphone can detect murmurs of valvular heart disease and atrial fibrillation with excellent discrimination

Keywords: Murmur, Artificial Intelligence, Heart Valve, Valvular Heart Disease

Introduction

Valvular heart disease (VHD) is a major contributor to morbidity and mortality. Moderate to severe VHD affects approximately 2.5% of the general population, increasing to 13.3% in individuals over 75 years[1]. Notably, women are diagnosed less frequently than men, contributing to

disparities in care and lower survival rates[1]. With increasing life expectancy and the high mortality associated with degenerative valvular disease, delayed or missed diagnosis can have severe consequences. Mortality is particularly high for aortic stenosis if diagnosed late and valve replacement therapy is not performed[1,2].

The physical exam has long been the foundation of VHD diagnosis, serving as an essential complement to history-taking. Specifically, auscultation has been a crucial, immediate, and inexpensive method for detecting VHD and other cardiac pathologies. However, studies from the US, Canada, and the UK show that internal medicine residents correctly assessed heart murmurs in only about 25% of cases, highlighting a declining emphasis on auscultation in medical education and practic[3]. Another key limitation of cardiac auscultation in general practice is the constrained time for patient-physician interactions limiting the opportunity for thorough examinations. According to a study by Neprash et al., the average primary care exam length was 18.0 minutes ± 13.5 minutes based on electronic health record data from 21,010,780 primary care visits in 2017[4]. Further, the accuracy of traditional auscultation is highly variable and often suboptimal, especially outside of cardiology specialty practice. In a subcohort of the OxValve population study, 251 patients without a prior VHD diagnosis underwent cardiac auscultation by two general practitioners, with findings compared to transthoracic echocardiography (TTE) in an investigator-blinded evaluation. Auscultation demonstrated a sensitivity of only 32% and specificity of 67% for detecting mild VHD, improving to 43% and 69% for significant VHD, respectively[5]. Additionally, a recent survey of 153 general practitioners from France, Germany, and the UK revealed that only 62% routinely performed auscultation in elderly patients. In the UK and Germany, auscultation in symptomatic elderly patients was conducted in just 38% and 40% of clinic visits, respectively, underscoring significant gaps in routine cardiac assessment[6]. Cardiologists exhibit greater accuracy in murmur detection through auscultation; however, their assessments remain imperfect. In a notable analysis by Davidsen et al. evaluating the diagnostic accuracy in detecting valvular heart disease by heart auscultation, medical doctors, including cardiologists, identified only about 50% of significant valvular lesions on physical exam, with systolic murmurs being detected more reliably than diastolic ones[7]. These findings suggest that a substantial proportion of patients may have undiagnosed valvular disease and, as a result, are not referred for echocardiography, potentially delaying critical interventions[8].

Given these challenges, there is a critical need for improved methods of murmur detection to enhance early diagnosis and patient outcomes for VHD. We therefore sought to explore the test characteristics of an AI-based software, Stethophone AI, in detecting structural and rhythmic cardiac anomalies among a cohort of patients with known VHD. The AI in this case is integrated into a stand-alone smartphone application (Stethophone Pro) that records, augments and visualizes bioacoustic sounds captured using the smartphone microphone.

Materials and Methods

Technology

The AI-based software application, developed by Sparrow Bioacoustics Inc. (Newfoundland and Labrador, Canada), enables smartphones to directly detect, record, and analyze heart sounds. The system incorporates proprietary AI and novel bioacoustic enhancement to improve the audibility of cardiac signals, along with clinical analysis and visualizations that support

interpretation. The system's AI was trained on large datasets of chest audio recordings captured at standard auscultation sites, including the carotid artery. The training datasets included a comprehensive range of cases, encompassing all types of valvular disease, congenital anomalies, pulmonary hypertension, heart failure, infective endocarditis, and pericarditis (Supplemental Data). The AI was designed to be device-independent, which enabled it to run using recordings made on ubiquitous devices such as smartphones. The system is capable of detecting the presence of heart murmurs. Notably, it also detects S1 and S2 heart sounds, enabling precise assessment, calculation, and visualization of true cardiac cycle timing and anomalies without requiring separate electrophysiology (Figure 1-2). Additionally, it identifies S3 and S4 heart sounds, which are often associated with acute cardiac dysfunction in adults (Figure 1-B).

Technology Baseline Validation

The system's AI models were validated using two distinct datasets to assess robustness and accuracy in detecting cardiac anomalies. The first, a proprietary multi-device dataset, includes 4,473 heart sound recordings from 1,072 patients, captured using a variety of handheld and commercial digital stethoscope devices. These included smartphones running iOS and Android, as well as specialized stethoscopes such as the 3M Littmann, DigiScope, Eko DUO, RNK, Thinklabs ONE, and eKuore. The second dataset comprises 3,341 recordings from 1,270 patients in the United States, representing a diverse range of real-world clinical scenarios.

Together, the datasets include 7,814 heart sound recordings from 2,342 unique patients, each paired with diagnostic confirmation via transthoracic echocardiography, expert clinical adjudication of murmur presence, and, where applicable, additional diagnostic testing. On this combined validation cohort, the AI system achieved a positive predictive value of 97.1% (95% CI: 0.964–0.973) for detecting the first heart sound (S1) and 97.5% (95% CI: 0.967–0.976) for the second heart sound (S2), with corresponding values of 91.1% and 92.4% for the third (S3) and fourth (S4) heart sounds, respectively. For murmur detection, the system demonstrated a sensitivity of 93.0% (95% CI: 0.919–0.942) and specificity of 94.4% (95% CI: 0.937–0.954). Further details regarding baseline system performance are provided in the Supplemental Reference Tables.

Study Population

The system's AI performance was tested in a clinical environment using a smartphone (iPhone 14 or later) installed with the Stethophone Pro (V3.4.1) proprietary software application, on a random sample of patients at the University of Washington Medical Center (UWMC) presenting to the structural cardiology clinic. All patients had pre-existing echocardiograms with known VHD. Examinations were conducted by placing the smartphone on the patient's chest as part of the physical examination. Data were recorded in supine or upright positions, minimizing motion and audio artifacts by instructing patients to remain silent and breathe comfortably during the recording. To evaluate the performance of the AI-based system in a typical clinical environment, the application was tested using one or two standard auscultation points only – typically the left upper sternal border and potentially the apex. This approach mirrors real-world conditions in primary care and outpatient settings, where time constraints and variability in auscultation technique may affect detection rates. Detection was performed by holding the smartphone device, face-up such that the microphone input was touching bare skin, for a 20 second recording at various

designated auscultory points (Figure 3). The number of recordings and auscultory position(s) chosen were left to the discretion of the clinical care provider in an effort to provide 'real world' results.

Results

Detection Performance Using Clinic Examinations

A total of 68 clinical examinations were performed achieving a PPV of 100% and an overall sensitivity of 95.2% for murmur detection. While the PPV remained consistent across murmur types, sensitivity varied. The sensitivity was 100% for mitral stenosis (3 examinations), 95.2% for mitral regurgitation (21 examinations), 89.5% for aortic stenosis (19 examinations), 50% for aortic insufficiency (4 examinations), and 77.8% for tricuspid regurgitation (18 examinations). Additionally, the software accurately identified 6 normal examinations, yielding a PPV of 100% and a sensitivity of 100% (Table 1). Of the 62 examinations with murmurs, the device demonstrated a false negative rate of 4.8% for murmur detection.

The system demonstrated strong diagnostic performance across all sample examinations, while also accurately detecting the first (S1) and second (S2) heart sounds, as well as calculating heart rate and identifying rhythm abnormalities. Notably, the system also achieved 100% sensitivity for the detection of atrial fibrillation in the tested cases.

Discussion

In this paper, we demonstrate that an AI-based system, deployed as a smartphone application that captures and processes heart sounds, can accurately detect murmurs in patients, achieving a PPV of 100% with a very low false negative rate of < 5%. While our sample size was modest, the software's performance aligns with the validation data showing a PPV exceeding 90%, indicating its reliability in identifying murmurs associated with significant pathologies such as aortic stenosis and mitral regurgitation.

Of the 62 abnormal examinations, 3 murmurs were not identified by the software. These missed detections were potentially influenced by reduced recording quality, which may have resulted from excessive background noise, patient body habitus, or other anatomical factors. Moreover, effective use of the device involves a learning curve, highlighting the importance of proper technique to ensure an optimal audio recording. This includes precise placement of the device in an intercostal space or a more thorough use of the device from multiple locations as one would a standard stethoscope.

In ideal practice, cardiac auscultation traditionally involves 4 to 6 auscultation points across the chest to maximize the likelihood of detecting subtle or localized abnormalities. In contrast, during our evaluation, the AI-based system was typically challenged to perform using recordings from a single auscultation point, primarily the left upper sternal border. This methodology placed significant stress on the device's ability to detect structural and rhythmic anomalies with limited input, closely reflecting everyday clinical conditions where comprehensive multi-point auscultation may not always be feasible. Despite this, the device demonstrated high diagnostic performance even under these constraints. Our findings stand in contrast to the reality that many frontline providers do not consistently perform thorough cardiac auscultation, increasing the risk of missed murmurs and delayed diagnoses. In a survey of 8,869 people aged 60 years or over in nine European countries, over half of respondents (54.2%) reported that their general practitioners rarely or never used a stethoscope to check their heart, potentially contributing to the underdiagnosis of aortic stenosis[13]. And failing to detect a murmur is not a minor clinical oversight. Heart valve

diseases, such as aortic stenosis, can remain asymptomatic for years, often presenting only as a murmur. However, once symptoms appear, the risk of adverse events increases sharply. Missing a cardiac murmur, therefore, can have significant clinical consequences, as delayed diagnosis may lead to late-stage presentation when treatment options are limited or less safe[1,2,14].

Beyond murmur detection, the system accurately determined cardiac cycle timing with precision comparable to electrophysiological methods. In our cohort, the AI-based system consistently and accurately detected S1 and S2 heart sounds during examinations, with exceptions primarily occurring in cases of missing data or recordings compromised by poor audio quality. This capability enables the precise localization of abnormal heart sound features within the cardiac cycle, all using sound alone, without the need for ECG leads. Furthermore, atrial fibrillation did not appear to affect the system's murmur detection accuracy. Among the 6 patients in atrial fibrillation during the examination, the system successfully identified all murmurs and accurately detected atrial fibrillation in each case.

The technology tested in this analysis represents a unique advancement in cardiovascular screening, as an inexpensive, distributable and simple platform capable of simultaneously detecting both acoustic and rhythm abnormalities within a unified application using acoustic signals alone without the need for dedicated hardware. By enabling a hybrid acoustic-electrical assessment through chest audio recordings alone, the system dramatically simplifies point-of-care diagnostics. It also offers the very real potential for practical and effective screening of at-risk or underserved populations, particularly those with asymptomatic or moderate valvular diseases that may otherwise go unnoticed.

By harnessing widely available smartphone technology, the platform expands access to high-quality cardiovascular assessment across diverse clinical and extra-clinical settings. It also has the capability of bridging gaps in clinical auscultation training, enhance diagnostic confidence, and significantly impact public screening programs. From a hospital management perspective, improved murmur detection represents a strategic opportunity: earlier identification can lead to increased utilization of confirmatory testing (such as echocardiograms) and timely interventions (including valve replacements), ultimately enhancing patient outcomes while contributing to hospital revenue[15]. At the same time, earlier diagnosis and treatment can help mitigate the substantial costs associated with managing advanced heart failure.

These results support the system's AI potential as a mechanism to revolutionize cardiac screening by employing widely available smartphone technology, ensuring broader access to high-quality cardiovascular assessment across diverse healthcare settings

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Legend Tables and Figures:

Table 1: Performance metric for the detection of murmurs across 62 examinations

Murmur	Precision (PPV)	Recall (Sensitivity)
All murmurs	1.0	0.95
MS	1.0	1.0
MR	1.0	0.95
AS	1.0	0.89
AI	1.0	0.5
TR	1.0	0.78

Table 2: List of heart murmurs and cardiac conditions used to train the AI

Condition	Prevalence (% of Adult Population)	Severity Rating (Clinical Impact)
Mitral regurgitation	~2% of adults (primary MR)(1) (progresses to >10% in seniors)	A frequent valve issue with potential significant impact on prognosis. Detection is important in all cases as it may be indicative of ischemic cardiomyopathy or other issues. Timing of surgical intervention is crucial for outcome. Severe MR can lead to heart failure if untreated

Condition	Prevalence (% of Adult Population)	Severity Rating (Clinical Impact)
Aortic stenosis	≈0.3–0.5% of general adults(16) (rises to ~13% in seniors)(1)	A frequent valve issue. Timing of diagnosis is crucial for the treatment outcome. High morbidity/mortality if not treated (pressure overload)
Aortic regurgitation	~5% of adults(17)	Often accompanied by other issues like aortic aneurism and dissection, infective endocarditis. Can progress to heart failure; often manageable if detected and monitored
Mitral valve prolapse	~2–3% of the population(18)	Frequently benign, but can lead to significant mitral regurgitation, arrythmias.
Mitral chordae tendineae rupture	Extremely rare (acute event; ~0.2% of myocardial infarctions)(19)	Often a result of mitral valve prolapse or infective endocarditis. Large chordae ruptures can lead to pulmonary oedema and acute severe MR with high mortality; surgical emergency
Mitral stenosis	~0.1%(20)	Nearly always rheumatic. Often progresses to atrial fibrillation, pulmonary hypertension, heart failure. Requires surgical intervention
Tricuspid regurgitation	~0.5–0.6%(21)	Often the results of other serious issues like heart failure, pulmonic emboly. Has significant impact on prognosis. Severe TR causes right heart failure
Tricuspid stenosis	<0.1%(22)	Rarely isolated, usually accompanies rheumatic mitral stenosis during advanced stage of diseased.
Ebstein's anomaly (tricuspid)	~0.005% (≈1 in 20,000 births)(23)	A congenital anomaly; variable severity; sometimes requires surgical repair.
Infective endocarditis	<0.01% at any time (annual incidence ~3–10 per 100,000)(24)	High morbidity and ~20% mortality even with treatment (requires urgent therapy). Extremely important to diagnose early. A murmur is often the only symptom
Pulmonary regurgitation	~0.1% of adults (moderate or severe PR ≈0.11%)(25)	Usually well tolerated but can lead to RV dilation in long term. Prognosis is worse when accompanied

Condition	Prevalence (% of Adult Population)	Severity Rating (Clinical Impact)
		by pulmonary hypertension.
Pulmonary stenosis	≈0.05% (congenital; ~7–10% of CHDs)(26)	Often corrected in childhood if detected. Untreated severe PS causes heart failure and death.
Hypertrophic cardiomyopathy	~0.2% of population(27)	Significant risk of malignant arrhythmias, heart failure, and sudden death.
Bicuspid aortic valve	~1–2%(28) (most common congenital valve anomaly)	Predisposes patient to early AS or AR, aortic aneurism, and dissection.
Ventricular septal defect	~0.03% (unrepaired in adults; ~0.3 per 1000)(19)l	Small VSDs are often benign but increases the risk of infective endocarditis. Large unrepaired VSDs cause HF/Eisenmenger's syndrome (often repaired in if detected childhood)
Ventricular septal rupture	0.2% of acute MIs(19)	An acute post-MI complication with very high mortality; requires emergency repair
Atrial septal defect	≈0.1% (Secundum ASD ~0.13% of births)(29)m	Often asymptomatic until mid-life. Large ASD causes RV failure if uncorrected. Frequently challenging to detect and hard to visualise.
Left atrial myxoma	<0.01% (incidence ~0.5 per million per year)(30)	Primary cardiac tumor; can cause emboli/obstruction of the mitral valve. Requires surgery.
Patent ductus arteriosus	~0.05% of births(31) (symptomatic cases; "silent" PDA up to 0.5%)	Small PDA are often benign, carrying a minor risk of endocarditis. Large PDA leads to HF if not closed (usually corrected early if detected).
Arterial-venous fistula	Rare (<0.1%) in general adult population (excluding surgical AV fistulas)	Significant AV shunts can cause high-output heart failure; typically requires intervention.
Aortic coarctation	~0.04% (≈4 per 10,000 live births)(32)	Causes secondary arterial hypertension; without repair can lead to heart failure or cerebral hemorrhage
Carotid stenosis	~3% (asymptomatic ≥50% stenosis in general population)(33)	Major risk of stroke; high morbidity if stroke occurs (often managed with endarterectomy/stenting in severe cases

Condition	Prevalence (% of Adult Population)	Severity Rating (Clinical Impact)
Pericarditis	~0.04% annual incidence (≈40 per 100k persons/year)(34)	Causes chest pain, usually self-limited or treatable; can recur or (rarely) lead to tamponade or constrictive pericarditis
Venous hum	Common in children; rare in adults	An innocent vascular noise with no pathological significance (benign)
Innocent murmur	Nearly 80% of children at some time(35) (often resolves by adulthood)	A benign murmur with no morbidity
Still's murmur	Very common in young children	An innocent murmur of childhood; no clinical consequences (typically disappears with age)

Table 3: List of rhythm abnormalities analyzed by the AI

Condition	Prevalence (% of Adult Population)	Severity Rating (Mortality Risk, Stroke Risk, Long-Term Complications)
Tachycardia (e.g. SVT – rapid heart rate arrhythmias)	~0.3%(36)	Rarely life-threatening with minimal stroke risk (not fatal unless other heart disease is present). Prolonged episodes can cause discomfort or tachycardia-induced cardiomyopathy.
Bradycardia (slow heart rate, sick sinus syndrome)	~0.4% (significant bradyarrhythmias in adults)(37)	Low stroke risk, but severe bradycardia can cause syncope and heart failure. Often requires pacemaker if symptomatic (high-degree AV block or sinus node dysfunction may necessitate pacing).
AV Blocks (2nd & 3rd Degree) (atrioventricular conduction blocks)	Mobitz I (2nd) seen in ~1–2% of healthy young adults.(38) Complete heart block (3rd) ~0.02–0.05% of the population.(39)	High mortality risk if untreated (3rd-degree AV block is a medical emergency that can be fatal without prompt pacemaker therapy). 2nd-degree (Mobitz II) can progress and cause syncope. Significant risk of sudden cardiac arrest or heart failure exists in advanced AV block, so aggressive management is required.

Condition	Prevalence (% of Adult Population)	Severity Rating (Mortality Risk, Stroke Risk, Long-Term Complications)
Atrial Flutter	<1% of adults (much less common than AF; e.g. ~200,000 new cases per year in the US(40)	Notable stroke risk (comparable to atrial fibrillation) High heart rates can cause tachycardia-induced cardiomyopathy or heart failure if untreated. Mortality risk is elevated if flutter is persistent and unmanaged.
Atrial Fibrillation (AFib)	~5% of adults(41)	High stroke risk and increased mortality. A-Fib approximately doubles the risk of death and leads to long-term complications like heart failure, myocardial infarction, kidney disease, dementia, etc.

Table 4: Performance metric for detection of S1 and S2 using combined MDD and USD dataset

Heart Sound	Precision (PPV)	Recall (Sensitivity)
S1	0.969 (95% CI: 0.976 - 0.981)	0.979 (95% CI: 0.956 - 0.963)
S2	0.971 (95% CI: 0.973 - 0.979)	0.977 (95% CI: 0.956 - 0.964)

Table 5: Performance metric for detection of S3 and S4 using combined MDD and USD dataset

Heart Sound	Precision (PPV)	Recall (Sensitivity)
S3	0.911	0.851
S4	0.919	0.822

Table 6: Performance metric for murmur detection using combined MDD and USD dataset

Metric	Test Result
Sensitivity	0.930 (95% CI: 0.919 - 0.942)
Specificity	0.944 (95% CI: 0.937 - 0.954)
Accuracy	0.938 (95% CI: 0.932 - 0.946)
ROC AUC	0.979 (95% CI: 0.975 - 0.983)

Table 7: Performance metric for heart rate detection using combined MDD and USD dataset

Mean absolute error (MAE)
0.389 bpm (95% CI: 0.346 to 0.430)

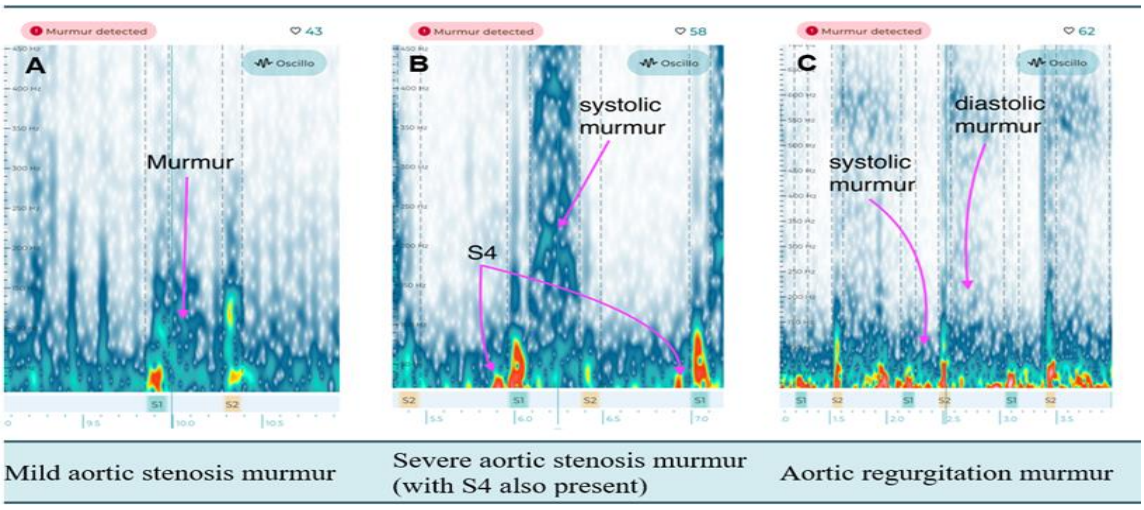
Table 8: Performance metric for the detection of bradycardia and tachycardia using combined MDD and USD dataset

Test parameter	Bradycardia	Tachycardia
Precision (PPV)	0.961 (95% CI: 0.919 - 0.991)	0.969 (95% CI: 0.945 - 0.988)
Recall (Sensitivity)	0.990 (95% CI: 0.967 - 1.000)	0.953 (95% CI: 0.925 - 0.976)
Specificity	0.999 (95% CI: 0.998 - 1.000)	0.998 (95% CI: 0.996 - 0.999)
F1	0.975	0.961

Table 9: Performance metric for the detection of atrial fibrillation using combined MDD and USD dataset

Metric	Value
Precision (PPV)	0.978
Recall (Sensitivity)	0.885
Specificity	0.980

Figure 1. Visualization of various cardiac conditions along with their associated murmurs (A-H), highlighting the precise identification of heart sounds (S1, S2). Notice the identification of an S4 in a patient with severe aortic stenosis (B).



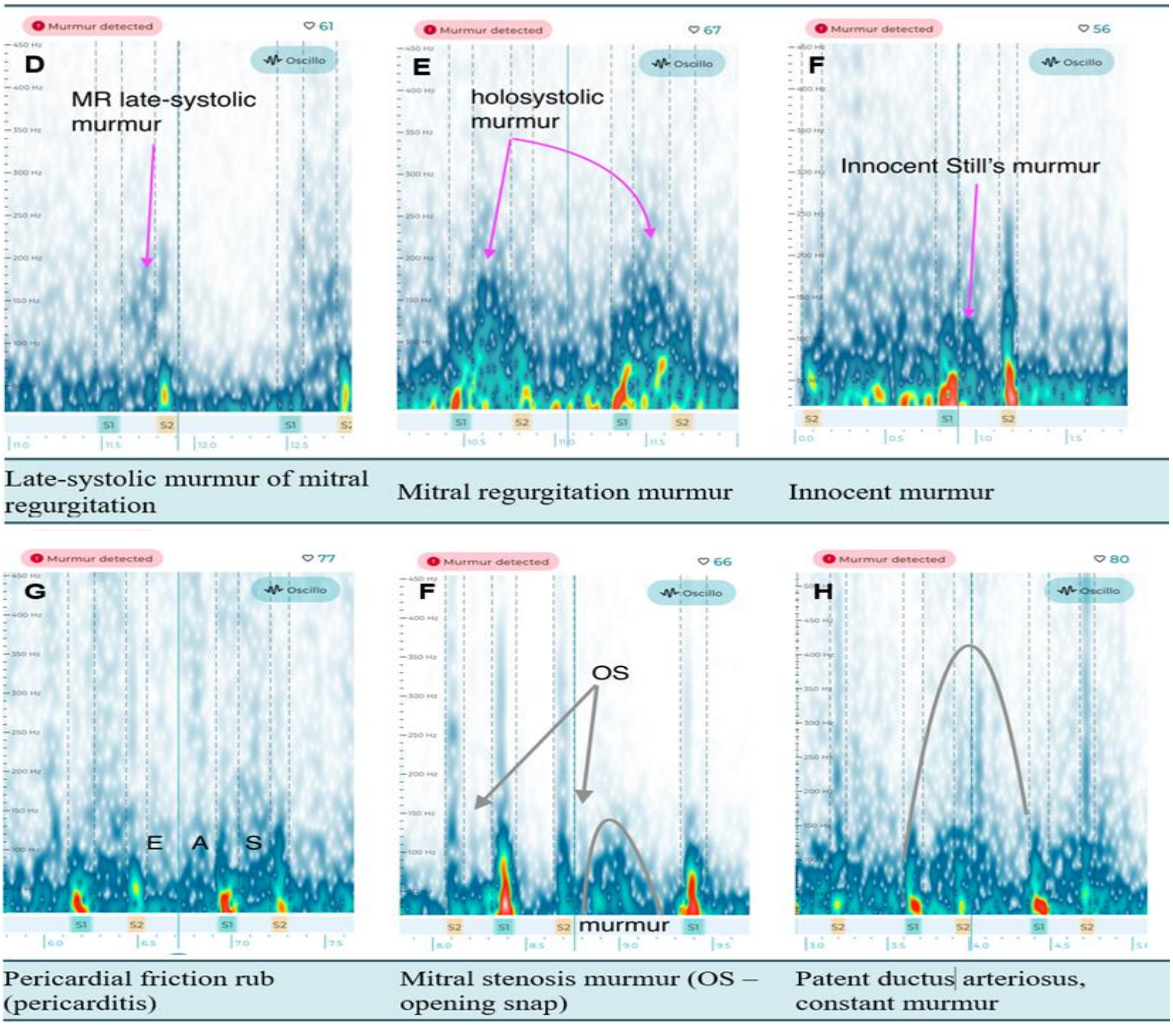
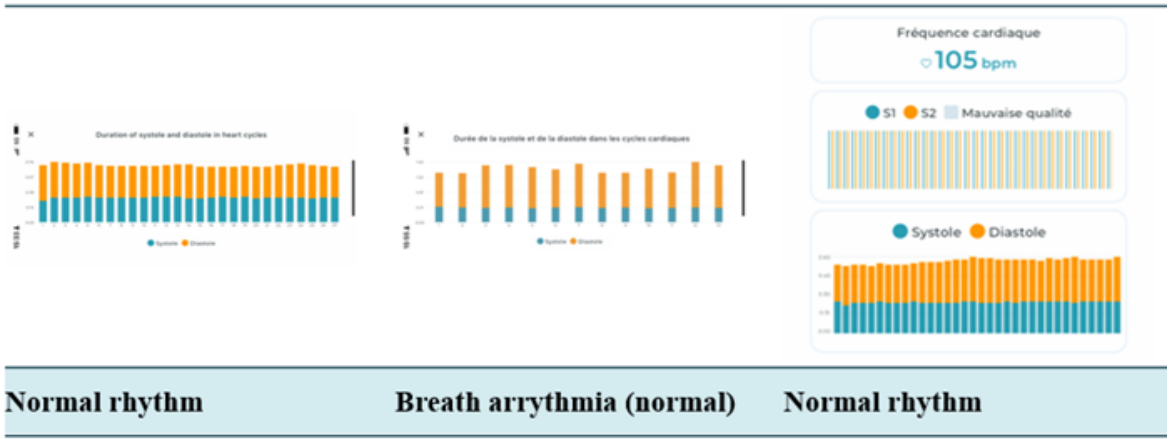


Figure 2: Heart Cycle Timing Visualizations for Various Conditions



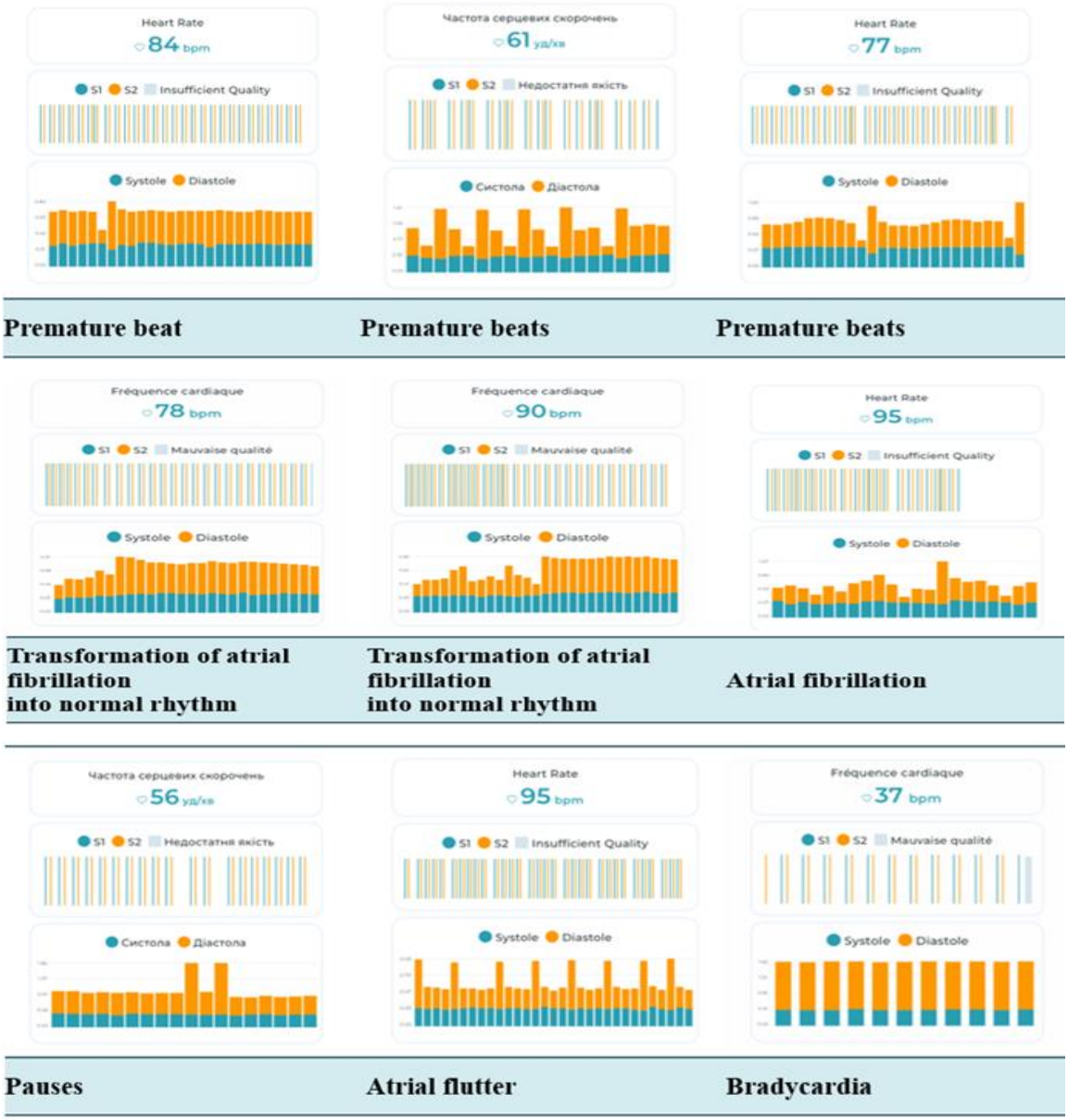


Figure 3: Smartphone with the Stethophone Pro application recording heart sounds