Artificial Intelligence Validation

AI Indications for Use

The Eko AI software is intended to provide support to the physician in the evaluation of patients' heart sounds and ECGs. The software analyzes simultaneous ECG and heart sounds and will detect the presence of suspected murmurs in the heart sounds. The software also detects the presence of AFib and normal sinus rhythm from the ECG signal. In addition, it calculates certain cardiac time intervals such as heart rate, QRS duration and electromechanical activation time (EMAT). The software does not distinguish between different kinds of murmurs and does not identify other arrhythmias.

Eko AI is not intended as a sole means of diagnosis. The interpretations of heart sounds and ECG offered by the software are only significant when used in conjunction with physician over-read and when used on adults (> 18 years).

01 Introduction

As one of the oldest clinical evaluation methods, auscultation has faced scrutiny for its subjectivity, inability to quantify cardiovascular and pulmonary problems, and imprecision. A study (Vukanovic-Criley et al., 2006) of medical school students, residents, cardiology fellows, and physicians integrated visual and auditory (auscultation) data into a measure of cardiac examination competency. While performance increased for older students, there was no significant improvement for any group tested other than the cardiology fellows. In another study, internal medicine and family practice trainees accurately recognized only 20% of heart sounds (Mangione et al., 1997). Clinicians' inaccuracy of auscultation results in variability in Detection of common cardiovascular diseases.

Heart sound analysis software can compensate (Wen et al., 2014) for the limitations of acoustic stethoscopes. Eko's AI Software detects the presence of murmurs in heart sounds, which should prompt the physician to conduct a more complete analysis of the detected murmur to determine whether it is innocent or has a structural origin. The software does not attempt to distinguish 'pathologic' from 'innocent' murmurs. Instead, the Detection of the presence of murmurs should be combined with clinician interpretations of heart sounds, of visualizations of heart sounds, and clinical history to better determine appropriate follow-up such as a cardiologist referral, echocardiogram, or 12 lead ECG. The AI algorithm is only intended for use in adults 18 years and older.

Although auscultation yields significant cardiac health information, synchronized ECGs can improve interpretation, as the data can provide insight into the rhythm regularity. Eko provides AFib Detection using the single lead ECG rhythm in a manner similar to a number of devices on the market today. The ECG in combination with the heart sounds provides a unique picture of electrical and mechanical function of the heart.

In addition, Eko's AI reports the Heart Rate and QRS Duration. Heart rate is calculated from either heart sounds or ECG signal based on signal quality. The algorithm also flags heart rates above 100bpm as Tachycardia and heart rates below 50bpm as Bradycardia. QRS Duration is calculated from the ECG signal. QRS Duration greater than 120ms is also flagged. Prolongation of the QRS Duration can be indicative of left ventricular dysfunction such as left bundle branch block.

02   Clinical Workflow

To be useful in a clinical setting, a screening technology must be efficient and fit into a clinician's busy workflow. The Eko DUO and Eko CORE devices and the Eko's AI screening software are designed to be as complementary to a clinician's workflow as possible. The screening algorithms require only 15 seconds of recorded ECG rhythm or heart sounds to make an analysis and results will typically be returned within 5 seconds after the recording is complete. The devices are non-invasive and do not require gels or prep time and are suitable for in-office, bedside, or point-of-care screening. The Eko CORE and Eko DUO can be used as a traditional stethoscope for auscultation and are portable and accessible to most clinician skill levels. The analysis results can be imported to an EMR chart or included in a specialist referral to reduce the variability of care.
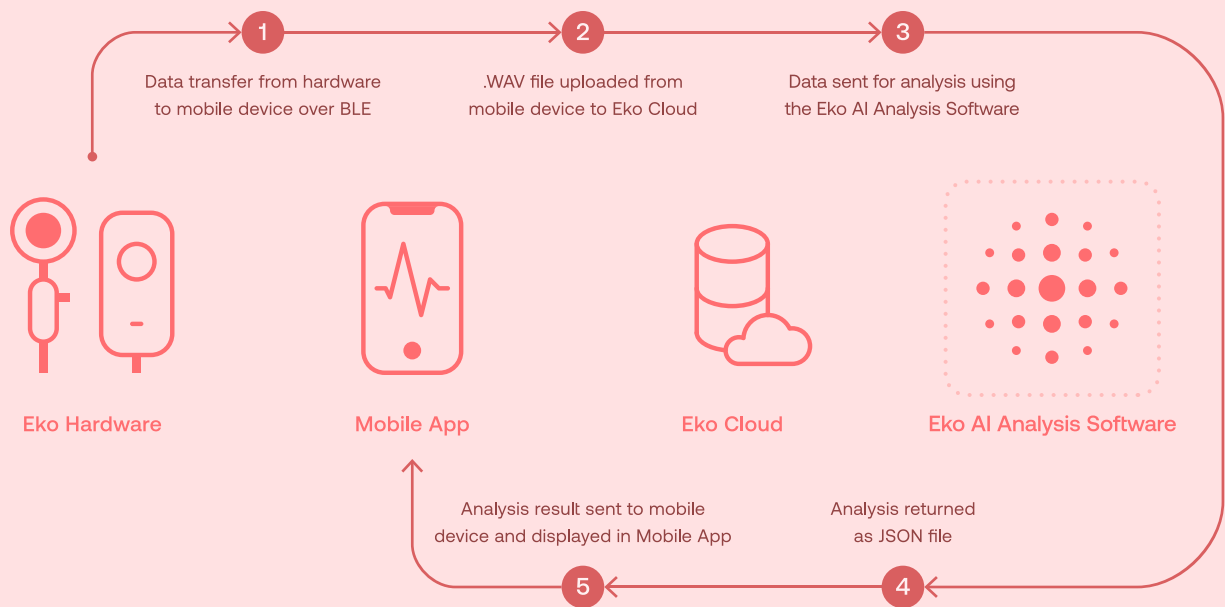
Figure 1: System Design

03 Software Description

Eko AI is a cloud-based software API that allows a user to upload synchronized ECG and heart sound/phonocardiogram (PCG) data for analysis. The software uses several methods to interpret the acquired signals including signal processing and convolutional neural networks. The API can be electronically interfaced, and perform analysis with data transferred from multiple mobile or computer based applications. The interaction between different modules is shown in **Figure 1**.

The algorithm consists of the following components:

- **Rhythm Detection algorithm:** A neural network model that uses ECG to Detect normal sinus rhythm and AFib.

- **Murmur Detection algorithm:** A neural network model that uses heart sounds to detect the presence of murmurs.

- **Heart Rate algorithm:** A signal processing algorithm that uses ECG or heart sounds as appropriate to calculate heart rate. It also provides an alert if the measured heart rate is indicative of Bradycardia or Tachycardia.

- **QRS Duration algorithm:** A signal processing algorithm that uses ECG to measure the width of the QRS pulse.

04 Performance Validation

The algorithms in Eko AI have also been validated using retrospective analysis on a combination of publicly available (MIT-BIH[1] Arrhythmia Database, MIT-BIH Arrhythmia Noise Stress Database, Physionet QT Database, and PhysioNet 2016 Database) and proprietary (Eko CORE and Eko DUO) databases. The recordings used for validation were never used to train the algorithm.

[1] Massachusetts Institute of Technology - Beth Israel Hospital

A. Rhythm Detection on Eko ECG database

The Rhythm Detection algorithm was validated using the MIT-BIH Arrhythmia and Eko DUO ECG database. The Eko DUO ECG database is a collection of recordings collected from patients visiting Northwestern Medicine Hospital and Los Alamitos Cardiovascular Clinic. This database was collected using the Eko DUO and is representative of the data quality expected in clinical practice. All recordings were automatically synced to the Eko Cloud and used for analysis.

Table 1: AFib / Normal Detection Performance in Literature

AFib Detection	Sensitivity (%)	Specificity (%)
Cardiologists (Hannun et al., 2019) reading single lead ECGs	71	94
General Practitioners (Mant et al., 2007) reading a chest lead	85	86
General Practitioners (Mant et al., 2007) reading a limb lead	69	83
Kardia Mobile (Lowres et al., 2014) using single lead ECG	99	91
Microlife WatchBP (Kearley et al., 2014) using opportunistic pulse assessment	95	90

Table 1 demonstrates that clinicians tend to have low sensitivity and higher specificity at detecting AFib from single lead ECG, while automated technologies tend to have high sensitivity and lower specificity.

Table 2: AFib Detection Performance

Performance	Sensitivity (%)	Specificity (%)
AFib Detection	98.9 (95% CI: 94.2 – 99.8)	96.9 (95% CI: 95.0 - 98.0)

The results in Table 2 show that the algorithm detects AFib with high accuracy on the Eko ECG Database.

The rhythm Detection algorithm was also validated against the MIT-BIH database and showed AFib Detection sensitivity and specificity above 95%. Collectively, these results show that Eko's AI performs AFib Detection and Normal Sinus Rhythm Detection with excellent accuracy.

B. Murmur Detection on Eko Heart Sound database

The Murmur Detection algorithm was validated using the Eko Heart Sound Database which contains recordings collected from patients visiting Northwestern Medicine Hospital and Los Alamitos Cardiovascular Clinic. The collective database is representative of the data quality expected in clinical practice. All recordings were automatically synced to the Eko Cloud and used for analysis.

The test population comprised of patients visiting Northwestern Medicine Hospital or Los Alamitos Cardiovascular Clinic for regular echocardiograms and who consented to take part in a clinical study to collect Eko data. Thus, this population has a wide distribution of age, gender and race and well represents the expected patient population for these algorithms.

Classifier Performance

Table 3 shows prior literature on the sensitivity and specificity of Murmur Detection by clinicians and comparable technologies. It demonstrates that clinicians tend to have highly variable performance in clinical auscultation.

Table 3: Murmur Detection Performance in Literature

Murmur Detection	Sensitivity (%)	Specificity (%)
General Pediatrician (Haney et al., 1999) for pediatric murmurs	82	72
General Practitioners (Gardezi et al., 2017) for significant valvular heart disease	43	69
Cardiologists (Siliste et al., 2020) for aortic stenosis	57	92
Sensicardiac (Yusuf et al., 2017) for pathologic murmurs	69	54
eMurmurID (Yusuf et al., 2017) for pathologic murmurs	84	84

Table 4: Murmur Detection Performance

Performance	Sensitivity (%)	Specificity (%)
Murmur Detection	87.6 (95% CI: 84.2 – 90.5)	87.8 (95% CI: 85.3 – 89.9)

Table 4 shows that the algorithm detects the presence of murmur with high accuracy on the Eko Heart Sounds Database, which is comparable if not better than previously published reports in literature.

C. Heart Rate

We anticipate that Eko AI heart rate calculation will be used as an aid for clinicians in a variety of healthcare settings such as primary, urgent, and emergency care centers. It allows a healthcare professional to quickly and accurately measure this vital sign. Heart rates outside of the expected range i.e. bradyarrhythmias (heart rate<50bpm) or tachyarrhythmias (heart rate >100bpm) are often a cause of concern and are flagged by the algorithm.

Algorithm Performance

Heart rate measurement performance on recordings from the MIT-BIH Arrhythmia Database is shown below:

Table 6: Heart Rate Performance

Performance	ECG (%)
Heart Rate Error	1.14 (95% CI: 0.95 – 1.34)

The sensitivity and specificity when detecting Bradycardia and Tachycardia on MIT-BIH database are shown below.

Table 7: Bradycardia and Tachycardia Detection accuracy

Performance	Sensitivity (%)	Specificity (%)
Bradycardia	94.7 (95% CI: 89.8 – 97.3)	99.7 (95% CI: 99.4 – 99.8)
Tachycardia	93.6 (95% CI: 90.9 – 95.6)	99.0 (95% CI: 98.7 – 99.3)

In addition, we show excellent agreement between the PCG based estimate and the ECG based estimate on the Eko ECG Database. These results show that the algorithm can accurately calculate heart rate and flag the presence of Bradycardia and Tachycardia and alert the clinician accordingly.

D. QRS Duration

The duration of the QRS complex, or QRS interval, is a measurement of the time interval between the beginning of the Q wave and the end of the S wave of the ECG. Prolongation of the QRS duration can be indicative of left ventricular dysfunction such as left bundle branch block.

Annotated ECG waveforms collected from the PhysioNet QT database (QTDB) were used to validate performance of the QRS Duration algorithm. The QTDB contains a wide variety of waveform morphologies, resulting in a very challenging set of recordings for QRS duration computation relative to the general population.

Algorithm Performance

A summary of the performance in calculating QRS duration over all recordings from the QT database is given below.

Table 8: QRS duration calculated on QT database

Performance	Mean (ms)
Absolute QRS Error	9.25 (95% CI: 7.93 – 10.58)

These results show that QRS duration can be accurately calculated by the algorithm.

05 Summary

In summary, the Eko AI software can prove to be a valuable clinical tool to help the clinician screen for arrhythmias and valvular heart disease by interpreting heart sounds and ECG captured from the Eko CORE and Eko DUO.

References

Gardezi et al., 2017

Gardezi, Syed Khurram Mushtaq, et al. "Cardiac auscultation in diagnosing valvular heart disease: a comparison between general practitioners and cardiologists." European Heart Journal, Vol. 38 (2017): 1155

Haney et al., 1999

Haney, Isabel, et al. "Accuracy of clinical assessment of heart murmurs by office based (general practice) paediatricians." Archives of disease in childhood 81.5 (1999): 409-412

Hannun et al., 2019

Hannun, Awni Y., et al. "Cardiologist-level arrhythmia detection and classification in ambulatory electrocardiograms using a deep neural network." Nature medicine 25.1 (2019): 65

Kearley et al., 2014

Kearley, Karen, et al. "Triage tests for identifying atrial fibrillation in primary care: a diagnostic accuracy study comparing single-lead ECG and modified BP monitors." BMJ open 4.5 (2014): e004565

Lowres et al., 2014

Lowres, Nicole, et al. "Feasibility and cost-effectiveness of stroke prevention through community screening for atrial fibrillation using iPhone ECG in pharmacies." Thrombosis and haemostasis 111.06 (2014): 1167-1176

Mangione et al., 1997

Mangione, Salvatore, and Linda Z. Nieman. "Cardiac auscultatory skills of internal medicine and family practice trainees: a comparison of diagnostic proficiency." Jama 278.9 (1997): 717-722

Mant et al., 2007

Mant, Jonathan, et al. "Accuracy of diagnosing atrial fibrillation on electrocardiogram by primary care practitioners and interpretative diagnostic software: analysis of data from screening for atrial fibrillation in the elderly (SAFE) trial." Bmj335.7616 (2007)

Siliste et al., 2020

Siliste, Roxana-Nicoleta, and Siliste, Calin. "Physical examination in aortic valve disease: do we still need it in the modern era?" EJ Cardiol Pract Vol. 18, Nº 12 (2020)

Vukanovic-Criley et al., 20061

Vukanovic-Criley, Jasminka M., et al. "Competency in cardiac examination skills in medical students, trainees, physicians, and faculty: a multicenter study." Archives of internal medicine 166.6 (2006): 610- 616.

Wen et al., 2014

Wen, Yong-Na, et al. "Beyond auscultation: Acoustic cardiography in clinical practice." International Journal of Cardiology 172.3 (2014): 548-60.

Yusuf et al., 2017

Yusuf, Warsame, et al. "Performance evaluation of two heart murmur detection applications by prospective clinical trial." Circulation 2017;136:A17004

Want to learn more?

Check out our products, case studies,
and more at **www.ekohealth.com**

Or contact us at: **1 (844) 356-3384**