Instructions for Use (IFU)
for
Kardia 12L System (AC-027)

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AliveCor, Inc.
189 N. Bernardo Avenue, Ste 100
Mountain View, CA 94043, USA

Australian Sponsor:
Alive Technologies Pty Ltd.
Unit 5, 19 Expo Court,
Ashmore, QLD 4214

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℞ only

CAUTION: Federal law restricts this device to sale by or on the order of a physician.

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Kardia 12L Introduction

1. Kardia 12L is a portable electrocardiograph that records four standard diagnostic-bandwidth ECG leads from a patient (I, II, V1 or V2, V4), derives four standard diagnostic-bandwidth leads (aVL, aVR, aVF, III), and synthesizes four remaining leads (V2 or V1, V3, V5, V6) to create a 12-lead ECG recording.
    a. The device consists of the following components:
    - Kardia 12L hardware, which connects to standard gel-based ECG electrodes (off the shelf) to measure and record ECG leads.
    - KardiaStation app, which provides the user interface and ECG display functions. The KardiaStation app functions on a smart device such as a smartphone or a tablet.

Note: For the European Union, the applicable app for the Kardia 12L system will be the KardiaStation 12L App. If the instructions for use (IFU) document mentions the "KardiaStation app," it's referring to the KardiaStation 12L App for Kardia 12L System users in the European Union.

2. The Kardia 12L hardware measures and records 4 leads (‘Recorded Leads’).
    a. The device can record the following sets:
        i. Leads I, II, V2 and V4 (Default)
        ii. Leads I, II, V1 and V4 (Alternate)
    b. The KardiaStation app uses the Recorded Leads to derive the remaining limb leads (i.e. Leads III, aVR, aVL, aVF) using the standard relationships.
    c. The remaining precordial leads (i.e. Leads V1, V3, V5, V6, or Leads V2, V3, V5, V6) are synthesized using a machine learning model (“Synthesized Leads”).

3. Kardia 12L requires a compatible smartphone or tablet and the KardiaStation app.
    a. The list of compatible devices can be viewed at www.alivecor.com/compatibility/pro
    b. The KardiaStation app can be downloaded from the Apple App store.

Geographical Note: The KAI 12L v2 analysis features and certain determinations described in this manual are subject to regional regulatory approvals and may not be available in all geographical jurisdictions. Please consult your AliveCor representative to confirm feature availability in your region.

Intended Purpose

The Kardia 12L is a portable electrocardiograph intended to record, derive, and synthesize a 12-lead ECG for the assessment of cardiac rhythm and morphology. It integrates an ECG analysis algorithm to provide rhythm and morphology determinations and interval measurements.

Intended Purpose (European Union)

Kardia 12L: The Kardia 12L is a portable electrocardiograph intended to record, store, and transfer a 12- lead ECG for the assessment of cardiac rhythm and morphology.

KardiaStation 12L App: The KardiaStation 12L App displays the 12-lead ECG and provides the rhythm and morphology determinations and interval measurements using the integrated ECG analysis algorithm.

Indications For Use

Kardia 12L is intended to record, store, and transfer a 12-lead resting electrocardiogram (ECG). Kardia 12L acquires four standard diagnostic-bandwidth leads (Leads I, II, V2, V4, or Leads I, II, V1, V4). The device derives four standard diagnostic-bandwidth, Lead-III and unipolar limb leads aVR, aVF and aVL. The device also synthesizes Leads V1 or V2, V3, V5, V6, which are similar to but not identical to the same leads of a standard diagnostic 12-lead. The 4 synthesized chest leads are not intended for diagnostic use and may fail to show important findings limited to those leads. This device is not a substitute for a diagnostic 12-lead ECG and is contraindicated for use in ruling out any condition (including but not limited to certain ischemia/infarcts, Brugada syndrome) for which the diagnosis may be solely dependent on the synthesized leads.

The device also provides ECG measurements and ECG analysis (rhythm and morphological interpretation) using the acquired leads. The automated ECG analysis results are provisional and should not be used for clinical action if it has not been reviewed by a qualified physician capable of independently interpreting the ECG signal in the context of the patient's condition. The automated analysis may then be confirmed, edited, or deleted by a qualified physician. ECG analysis should be used only as an adjunct to clinical history, symptoms, and the results of other non-invasive and or invasive tests.

Indications For Use (European Union)

Kardia 12L: The Kardia 12L is indicated for the acquisition and transmission of 12-lead resting ECG data to assist in the clinical assessment and monitoring of patients with known or suspected cardiac arrhythmias and morphological abnormalities. It is indicated for use by healthcare professionals in healthcare facilities and acute settings when a patient's clinical presentation (e.g., chest pain or palpitations) requires a diagnostic-bandwidth ECG to evaluate cardiovascular health

KardiaStation 12L App: The KardiaStation 12L App (utilizing KAI 12L) is indicated for the automated analysis and interpretation of 12-lead resting ECG data to aid healthcare professionals in the diagnosis of cardiac arrhythmias and morphological abnormalities. The software is indicated for use in the general population to provide interval estimations and automated determinations that assist in the management of cardiovascular conditions in both symptomatic and asymptomatic clinical settings.

Intended patient population

Patients 18 years or older experiencing palpitations, symptoms of ischemia or infarction such as chest pain. In addition, the indications for use for the Kardia 12L System state that the devices have not been tested in and are not intended for pediatric use.

Intended users

Kardia 12L is intended for use by healthcare professionals, or trained personnel in healthcare facilities (e.g. the doctor's office or hospital) and in acute settings.

Guide to Parts

Figure 1: ECG Module and Patient Lead Wire Interface

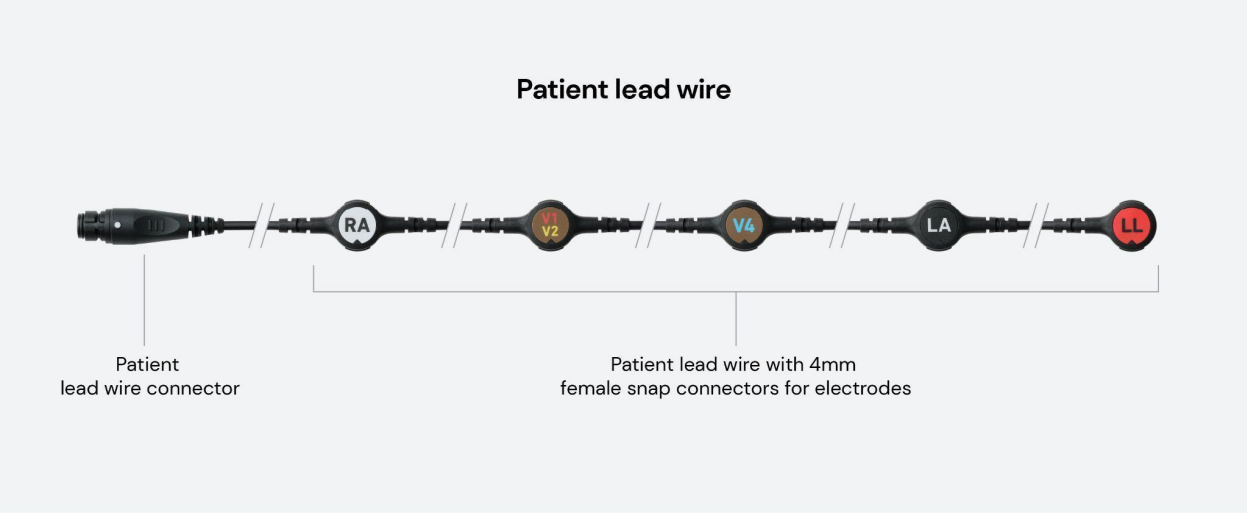


Figure 2: Patient Lead Wire

Accessories

Figure 3: Electrodes

- **Tab Electrodes** “Resting Electrodes”

Tab electrodes are small, adhesive patches that are applied directly to the skin. These electrodes have the following specifications:

Adhesion: Low to medium (typically for resting applications)
Size: Typically rectangular around 1.2" x 0.8" with 10 electrodes/card and 10 cards/pkg
Material: Silver/Silver Chloride (Ag/AgCl) usually with plastic backing
Sterilization: Alcohol wipe skin and let dry before electrode attachment

- **Snap Electrodes** “Monitoring Electrodes”

Snap electrodes are small, adhesive patches that are applied directly to the skin. These electrodes have the following specifications:

Adhesion: Medium to High (typically for active monitoring applications)
Size: Typically around 1.25” square, rectangle, or circular shaped with 3 or 5 electrodes/pkg
Material: Silver/Silver Chloride (Ag/AgCl) usually with cloth/foam backing
Sterilization: Alcohol wipe skin and let dry before electrode attachment

- **Snap to Tab Adapters**

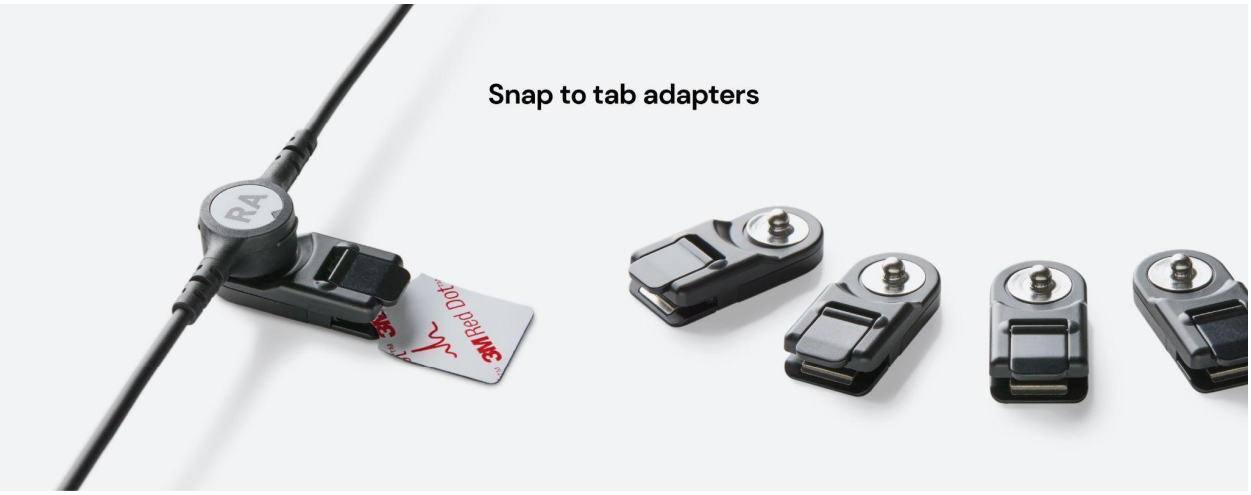


Figure 4: Snap to Tab Adapters

Snap to tab adapters have a male snap connector that mates with a female snap connection on the Patient Lead Wire. They are inserted between the ECG electrode and the ECG machine's lead wire, allowing the Tab Electrodes to be used with Kardia 12L.

Warnings

1. AliveCor does not guarantee that the patient is not experiencing an arrhythmia or other health conditions with any ECG result, including normal.
2. AliveCor makes no warranty for any data or information that is collected erroneously by the device, or misuse or malfunction as a result of abuse, accidents, alteration, misuse, neglect, or failure to maintain the products as instructed.
3. The device has not been tested for and is not intended currently for pediatric use.
4. Keep devices away from young children. Contents may be harmful if swallowed. Device contains two AAA alkaline batteries that are not accessible during normal use but, if exposed, can be a choking hazard and may cause severe tissue injury if ingested.
5. DO NOT replace the batteries when the device is in use.
6. DO NOT take a recording while driving or during physical activity.
7. DO NOT store in extremely hot, cold, humid, wet, or bright conditions.
8. DO NOT immerse the device or expose the device to excessive liquid.
9. DO NOT use while charging your smartphone or tablet
10. DO NOT drop or bump with excessive force.
11. DO NOT expose the device to strong electromagnetic fields.
12. MR-Unsafe. Do not expose the device to a magnetic resonance (MR) environment. The device may present a risk of projectile injury due to the presence of ferromagnetic materials that can be attracted by the MR magnet core
13. DO NOT place electrodes in contact with other conductive parts including earth.
14. DO NOT use un-approved accessories. Use of non-AliveCor approved accessories or transducers and cables could result in electromagnetic emissions or decreased electromagnetic immunity of this device and result in improper operation.
15. DO NOT use adjacent to or stacked with other electrical equipment because it could result in improper operation
16. DO NOT use portable RF communications equipment (including peripherals such as antenna cables and external antennas) closer than 30 cm (12 inches) to any part of the Kardia 12L System. Otherwise, degradation of system performance could result.
17. DO NOT use the KardiaStation App with a damaged smartphone, as this can cause malfunctions or errors in the device. If your smartphone is damaged, please have it repaired or replaced before using the KardiaStation App again.
18. The ECG displayed in the KardiaStation app or the PDF generated by the App should be reviewed by a qualified medical professional. Users with limited medical knowledge should not attempt to diagnose or treat any medical condition based solely on the ECG results displayed in the app. Always consult with a qualified medical professional if you have any concerns or questions about the patient's ECG results.
19. DO NOT use the system in an environment devoid of limited user vision/ limited visibility environment.
20. During use, ensure that the Patient Lead Wire is detangled and carefully routed to reduce the risk of patient strangulation or asphyxiation.
21. After use, ensure that the Kardia 12L hardware is properly stored in its designated case.

22. Despite the defibrillator-proof nature of the Kardia 12L device, it is crucial to avoid touching the defibrillation pads or paddles directly against the metal cable snap connectors during defibrillation procedures. Direct exposure to the electrical discharge may interfere with the device's performance.
23. Do not use the device without following the proper cleaning/intermediate level disinfection as mentioned in this IFU
24. DO NOT use the Kardia 12L device before carefully following the recommended operating procedures as provided in this Instructions for use
25. Synthesized leads generated by Kardia 12L are for informational purposes only. The 4 synthesized precordial leads may not be used for any clinical decision making.
26. The synthesized lead's output may be affected by external factors such as noise, interference, poor electrode contact, incorrect lead placement, etc. and may cause inaccuracies in the ECG output.
27. The Kardia 12L device is NOT intended for use in environments where electrosurgery procedures are performed. The device may not be immune to the high levels of electromagnetic disturbances typically present in such environments.
28. DO NOT use the Kardia 12L device for direct cardiac application.
29. Interpretation Hazard: Only 8 standard leads instead of 12 leads are provided and used for automated analysis. The 4 synthesized chest leads are not intended for diagnostic use and may fail to show important findings limited to those leads. This device is not a substitute for a diagnostic 12-lead ECG and is contraindicated for use in ruling out any condition (including but not limited to certain ischemia/infarcts, Brugada syndrome) for which the diagnosis may be dependent on the synthesized leads
30. Interpretation Hazard: The automated ECG analysis results are provisional and must be reviewed by a qualified physician capable of independently interpreting the ECG signal in the context of the patient condition. The provisional automated ECG analysis program may then be confirmed, edited, or deleted by a qualified physician. ECG analysis should be used only as an adjunct to clinical history, symptoms, and the results of other non-invasive and or invasive tests
31. The **provisional automated ECG analysis** should not be used for clinical action if it has not been reviewed by a qualified healthcare professional capable of independently interpreting the ECG signal.
32. Any serious incident that has occurred in relation to the device should be reported to the manufacturer and the competent authority of the Member State and/or country in which the user and/or patient is established.

Contraindications

This device is not a substitute for a diagnostic 12-lead ECG and is contraindicated for use in ruling out any condition (including but not limited to certain ischemia/infarcts, Brugada syndrome) for which the diagnosis may be solely dependent on the synthesized leads.

Cautions ⚠

Disposal instructions: To protect the environment and human health, it is important to dispose of medical devices in a responsible manner. Please do not dispose of AliveCor's products with municipal waste, as there may be hazardous substances in the electrical or electronic components.

Kardia 12L Device is intended for use by a physician or by trained professionals. Read all instructions for use and specifications provided prior to use.

The leakage current of the device is within the allowable limits; however, if multiple medical electrical devices are interconnected, there may be summation of leakage currents.

Note: There is no known safety hazard if other equipment, such as pacemakers or other stimulators, is used simultaneously with the device; however, disturbance to the signal may occur.

Features & Functionality

Kardia 12L is a 12 lead resting ECG device that measures four standard diagnostic-bandwidth leads, derives four standard diagnostic-bandwidth leads and synthesizes additional four leads, which are for informational purposes only, to create a 12-lead ECG recording for diagnostic purposes.

Kardia 12L uses Bluetooth to wirelessly transmit ECG data from the device to your smartphone or tablet.

What is an ECG?
Also known as an electrocardiogram, an ECG is a test that detects and records the strength and timing of the electrical activity in the heart. Each heartbeat is triggered by an electrical impulse. The ECG represents the timing and strength of these impulses as they travel through the patient's heart.

Getting Started

1. Remove the Kardia 12L hardware from the packaging.

2. Download the KardiaStation App (Application) to your smartphone/tablet device. Kardia 12L hardware can only be used with the KardiaStation app.

Setting up your Kardia 12L for the first time

1. Download the KardiaStation application from the Apple App Store or Google Play Store by searching for its app name within the Apple App Store or Google Play Store.
    a. Be sure to use a compatible iOS or Android device (check the compatible device list at www.alivecor.com/compatibility/pro).
    b. Do not use the Kardia 12L device with unsupported software. Verify that you have the KardiaStation App installed on your device.
    c. Login into KardiaStation App through Self-service portal generated credentials
2. Make sure **Bluetooth is turned on** in your smartphone or tablet settings.

3. Launch the app and follow the instructions on-screen.

4. You will then be taken to the home screen of the KardiaStation App.

Recording an ECG

Follow the instructions below to record an ECG.

1. Remove the Kardia 12L ECG module and the patient lead wire from the case
    - Connect the ECG module to the patient lead wire if not already connected.

2. Open the app on your smartphone/tablet
    - Ensure the Bluetooth is turned ON in your smartphone/tablet settings

3. Enter the patient information within the application and follow on-screen instructions on the KardiaStation app for connecting the Kardia 12L device to your smartphone/tablet.
    - Press the button on the ECG module to initiate Bluetooth connection. The LED should be ON

4. During ECG assessment, the patient should be supine
    - Their skin at the ankles, chest and arms below the elbows should be exposed.

5. Clean the areas where you will place electrodes with alcohol prep pads to remove dirt and oil and allow the areas to dry.

6. Place the gel electrodes in one of the following lead sets (5 total electrodes), based on the patient's symptoms as guided by the KardiaStation app. See Figure 5 below.
    - Default Lead set 1: V2, V4, RA, LA and LL
    - Alternate Lead set 2: V1, V4, RA, LA and LL

The KardiaStation app will assist in selecting the appropriate lead set by asking about the patient's symptoms, such as chest pains or palpitations, and will automatically recommend the suitable lead set for the ECG recording based on this clinical representation (see recommendations in Table 12). The user may manually select a different lead set and/or mode of operation based on their preference.

Note: Electrodes with Snap connections OR tab connections can be used. Tab electrodes require Snap-to-Tab adapters for connecting them to the wire leads.

For accurate measurements, proper electrode placement is crucial.

- V1 placement: Fourth intercostal space to the right of the sternum
- V2 placement - Fourth intercostal space to the left of the sternum
- V4 placement - Fifth intercostal space at the midclavicular line
- RA placement - Anywhere between the right elbow and right wrist
- LA placement - Anywhere between the left elbow and the left wrist
- LL placement - Anywhere below the left knee and above the left foot

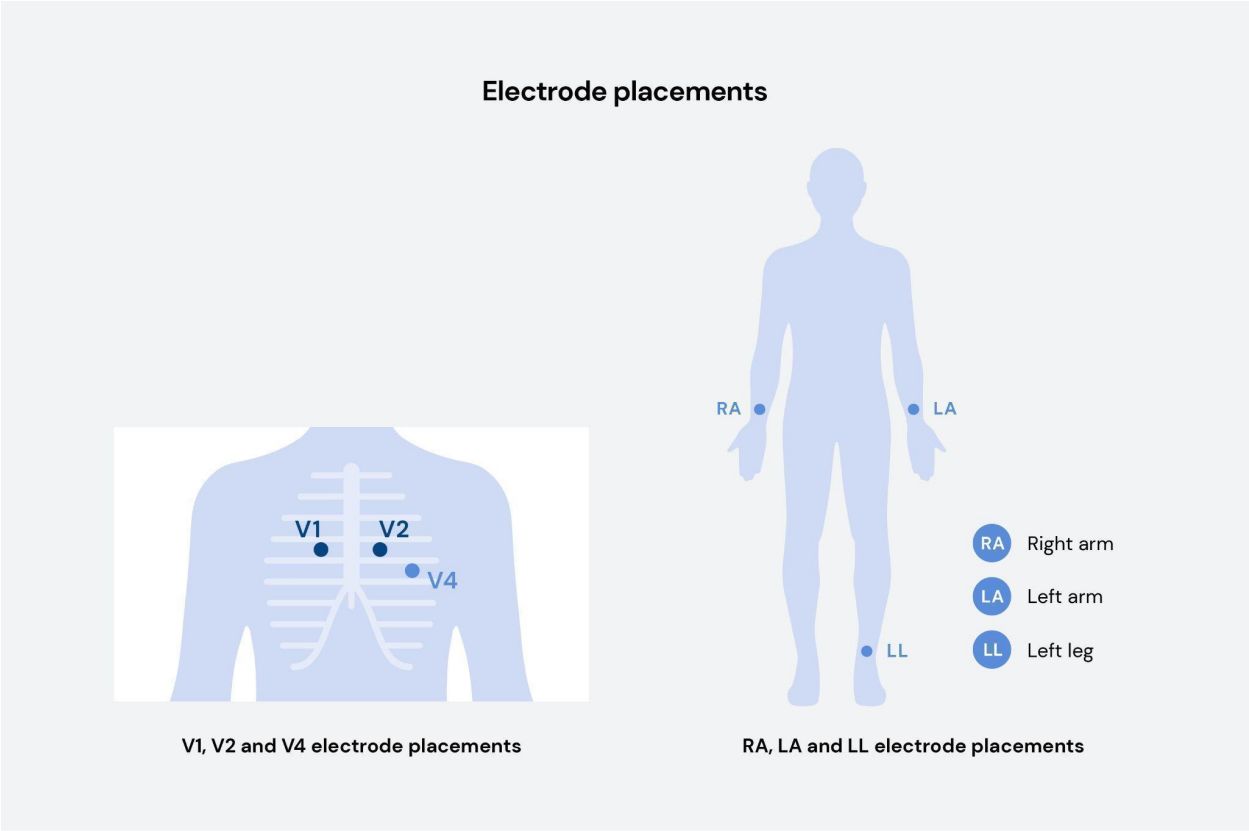


Figure 5: Electrode Placements

7. When using snap electrodes, connect the patient lead wire snap connectors to the electrodes adhered at LL, LA, RA, V2 (or V1) and V4 locations using the snap connections.
    - When using tab electrodes, connect the patient lead wire snap connectors to the snap connections on the provided Snap-to-Tab adapters then connect the adapters to the tab electrodes using the lever connectors on the adapters. Lift the lever tab, place the jaws of the adapter over the electrode's protruding tab, then press down on the lever to lock it in place.

   Note: When using the Alternate Leadset setting (V1, V4, RA, LA, and LL), you should connect the patient lead wire snap connector labeled as V1/V2 to the V1 location on the patient.

8. After connecting the electrodes, select the "**Record**" button on the KardiaStation app on your synced smartphone or tablet.
9. Activate the Kardia 12L ECG module by pressing its button, ensuring that the LED light illuminates, to start capturing the ECG data. Maintain stillness while the on-screen timer progresses from 0 to 10 seconds. Once a minimum of 10 seconds of data has been recorded, select the 'Save' button on the KardiaStation App to finalize and end the recording process.

10. Once the recording completes as indicated on the KardiaStation app, remove all connectors and electrodes.
11. The device will turn off automatically after use.

Environmental Specifications

Table 1: Environmental Specifications

Operational Temperature:	-10°C to +40°C
Transient Operational Temperature:	-18°C to +50°C Up to 20 mins usage
Operational Humidity:	0% to 95% (non-condensing)
Storage Temperature:	-18°C to +55°C
Storage Humidity:	0% to 95% (non-condensing)
Operational Pressure:	54 kPA to 101kPa Operational from sea level up to 16,404 ft / 5,000 m altitude, or any altitude above this in an aircraft with a pressurized cabin. Device has been qualified for use in both fixed wing and rotary wing aircraft.

Expected Service Life

The expected service life for Kardia 12L is 5 years.

Kardia 12L is designed to allow a minimum 3 years of battery shelf life from the date the device was manufactured and will typically record 8500 10-second ECG recordings on one set of AAA batteries. The batteries can then easily be replaced. For details regarding the battery replacement process, please refer to the 'Battery Replacement Instructions' section in this guide below.

Maintenance

No service or repair should be performed on the Kardia 12L hardware other than the maintenance listed in this section.

Cleaning Kardia 12L Device

Regular maintenance of the Kardia 12L hardware is necessary to ensure accurate and reliable performance. It is recommended to thoroughly clean and disinfect the device before and after each use using one of the approved cleaning and disinfection agents as outlined in this section below:

- Alcohol-based disinfecting wipes (Sani Wipes)
- Benzethonium Chloride-based disinfecting wipes (Cavi Wipes)

To clean and disinfect the device, follow these instructions:

- Ensure the device is turned off before cleaning and disinfecting.
- Put on a pair of disposable gloves before handling the cleaning and disinfecting agents.
- Select either a Sani Wipe or Cavi Wipe for thorough cleaning and disinfection.
- Remove a wipe from the container.
- For the ECG Module, gently wipe all surfaces, ensuring thorough coverage. Use a consistent wiping motion, such as a horizontal or vertical stroke, and apply the wipe at least 3-5 times on each surface to ensure effective disinfection.
- For the Patient lead wire, gently wipe along the entire length of the cable, including the connector and snap junctions. Pay particular attention to areas where contamination or debris might accumulate.
- For the Snap-to-Tab Adapters, carefully and thoroughly clean and disinfect the adaptor body.
- Allow all components to air dry for at least 3-5 minutes before reassembling and using the device, as per the disinfectant wipes' instructions for contact time to ensure effective disinfection.
- After cleaning, perform a visual inspection of the device. Check for any surface damage, corrosion or other forms of damage.

Store the cleaning agents according to their respective manufacturer's instructions and ensure they are within their expiration dates.

WARNING

- Always follow the manufacturer's instructions for the cleaning and disinfecting agents and ensure that the device is turned off before cleaning.
- Additionally, avoid using abrasive materials or excessive force when cleaning the device to prevent damage.
- Do not immerse the device in liquid or allow excessive moisture to enter the device during cleaning and disinfecting.

- Exterior Visual Inspection: Inspect the Device for any surface damage, or corrosion or any other form of damage. This cleaning process has been validated to ensure effective cleaning of the device.

Battery Replacement Instructions

Battery Type: AAA Alkaline

1. Gather the provided screwdriver and two AAA **Alkaline** batteries.
2. Ensure the Kardia 12L device is turned OFF.
3. Locate the battery compartment on the back side of the ECG module and note four screws located in the corners.

Figure 6: Battery Replacement

4. Use the screwdriver to remove the four screws that hold the battery compartment in place.
5. Remove the battery compartment cover and take out the old batteries.
6. Insert the new AAA batteries into the compartment, following the correct polarity (+/-).
7. Replace the battery compartment cover and use the screwdriver to reattach the four screws, being careful not to over-tighten.
8. Turn on the Kardia 12L device by pressing the power button to ensure that it is working properly.
9. If the device does not turn on, check the battery compartment and ensure that the batteries are inserted correctly.

10. Dispose of the old batteries in accordance with local regulations.

Daily Testing by Clinical Operators

Before first use each day, ensure the device powers on correctly and is able to make a recording as intended. Inspect the ECG module, patient lead wire, and snap-to-tab adapters for visible wear or damage.

Scheduled Maintenance

While daily checks and extensive scheduled maintenance are not explicitly mandated, it is advised that the device undergoes periodic verification using an ECG simulator. The frequency of these checks should be determined by your equipment quality assurance director or equivalent personnel, based on the specific needs and usage patterns of your device. For conducting these tests, there are various ECG simulators available on the market that are suitable for this purpose.

Electromagnetic & Other Interferences

- Kardia 12L has been tested and deemed in conformance with the relevant requirements in IEC 60601-1-2:2014 Class B for Electromagnetic Compatibility (EMC).

FCC Compliance

FCC ID: 2ASFFAC027

This device complies with Part 15 of the FCC Rules.

Operation is subject to the following two conditions:
1. This device may not cause harmful interference, and
2. This device must accept any interference received, including interference that may cause undesired operation.

CAUTION: Changes or modifications not expressly approved by AliveCor could void your authority to use this equipment.

To view FCC information on the KardiaStation app:

1. On the home screen, tap  on the top right of the screen to access the information screen.
2. Scroll to view the FCC ID and other applicable regulatory information.

Ingress Protection Marking

Kardia 12L is IP54 rated. Kardia 12L is protected against dust and is not affected by splashing water from any direction. Kardia 12L has been tested with relevant requirement standard 60529:1989/AMD2:2013/COR1:2019.

Essential Performance

Kardia 12L has been tested to the relevant requirements of standard IEC 60601-2-25:2011 for the basic safety and essential performance of electrocardiographs.

The essential performance of Kardia 12L ECG device is to accurately record the electrical signals from the patient's heart and provide a clear and detailed 12 Lead ECG waveform for diagnostic purposes. Kardia 12L records 4 standard diagnostic-bandwidth leads and derives standard diagnostic-bandwidth 4 leads that can be used for diagnostic purposes. Kardia 12L additionally synthesizes four precordial leads for informational purposes only so that a full 12-lead resting ECG can be displayed to the user.

In accordance with IEC 60601-2-25, the electrocardiograph equipment meets the following requirements in terms of Essential Performance:

- Protection against defibrillation (subclause 201.8.5.5.1)
- Essential performance and accuracy of ME equipment (Subclause 201.12.1.101)
- Electrostatic Discharge (Subclause 202.6.2.2.1)
- Filters (201.12.4.105.3)

In the event that noise or interference affects the quality of the recording, the device may not provide accurate results. Ensure that the environment is free from potential sources of interference, such as other electronic devices or strong electromagnetic fields, to minimize the risk of inaccurate results.

The operator should take appropriate measures to minimize the impact of the noise or interference, such as repositioning the patient or the device, before continuing with the recording.

The Kardia 12L device is powered by internal batteries and does not have a power supply cord. Therefore, subclauses 2.6.2.4.1 and 202.6.2.6.1 from IEC 60601-2-25 do not apply. Additionally, the Kardia 12L device is not intended to be used in an electrosurgery environment, and therefore, subclause 202.6.2.101 from IEC 60601-2-25 does not apply.

Applied Parts

The 5 electrodes (Right Arm Electrode, V2/V1 Electrode, V4 Electrode, Left Arm Electrode, and Left Leg Electrode) are Type CF Defibrillation Protected Applied Parts.

Operational temperature conditions for the device are -10°C to 40°C.
Transient operational temperature conditions for the device are: -18°C to 50°C for up to 20 minutes contact duration.
If ambient temperature exceeds +41°C, Applied Parts can exceed +41°C.

Troubleshooting

If you experience difficulties using your Kardia 12L, refer to the troubleshooting guide below or contact technical support at clinicalsupport@alivecor.com.

I'm having trouble getting a clear recording.

- Use new non-expired gel electrodes of the proper tab or snap variety.
- Ensure that the skin is cleaned with an alcohol swab and allowed to dry completely before electrode application.
- Disconnect any cables connected to phones (charging, headphones, etc.)
- Ensure the patient is in Supine and relaxed position during the recording
- Avoid close proximity to items that may cause electrical interference (electronic equipment, computers, chargers, routers, etc.).
- Make sure that the environment is free from potential sources of interference, such as other electronic devices or strong electromagnetic fields.
- Take appropriate measures to minimize the impact of the noise or interference, such as repositioning the patient or the device, before continuing with the recording.

My Kardia 12L hardware is not working.

- Make sure your device is compatible with the Kardia 12L ECG hardware and meets the minimum requirements listed in the IFU.
- Make sure Bluetooth is turned on in your smartphone or tablet settings and follow the steps in "Record an ECG".
- If Bluetooth is on, try to unpair and pair again to your Kardia 12L ECG .
- Ensure that the Kardia 12L device is securely attached to the electrodes and that the electrodes are properly placed on the skin.
- Check the Kardia 12L device for any physical damage or defects and contact customer support if necessary.
- Try using the Kardia 12L device with a different smartphone or tablet to see if the issue is with the hardware or the device being used.
- Check that the batteries in your Kardia 12L ECG hardware are properly inserted, oriented according to their polarity, and not expired. Replace them with fresh batteries if necessary, following the instructions in the IFU.
- If Bluetooth is on and your device is not connecting or pairing it’s possible that your battery needs to be replaced. Follow the “Maintenance” instructions to replace the battery.
- If the device still does not power on or function correctly after replacing the batteries, contact customer support for further assistance.

Electrical Safety

Table 2: Electromagnetic emissions

Guidance and manufacturer's declaration - electromagnetic emissions		
Kardia 12L is intended for use in the electromagnetic environment specified below. The customer or the user of Kardia 12L should assure that it is used in such an environment.		
Emissions test	**Compliance**	**Electromagnetic environment - guidance**
RF emissions CISPR 11	Group 1	Kardia 12L ECG hardware uses RF energy only for its internal function. RF emissions are very low and are not likely to cause any interference in nearby electronic equipment.
RF emissions CISPR 11	Class B	The device is intended for use by healthcare professionals, or trained personnel in healthcare facilities and in acute settings.
Harmonic emissions IEC 61000-3-2	N/A	Kardia 12L ECG hardware is powered from two AAA batteries and does not require AC mains power.
Voltage fluctuations / flicker emissions IEC 61000-3-3	N/A	

Table 3: Electromagnetic immunity

Guidance and manufacturer's declaration—electromagnetic immunity			
Kardia 12L is intended for use in the electromagnetic environment specified below. The customer or the user of Kardia 12L should assure that it is used in such an environment.			
Immunity test	**IEC 60601 test level**	**Compliance level**	**Electromagnetic environment - guidance**
Electrostatic Discharge (ESD) IEC 61000-4-2	±2 kV contact ±4 kV contact ±6 kV contact ±8 kV contact ±2 kV air ±4 kV air ±8 kV air ±15 kV air	±2 kV contact ±4 kV contact ±6 kV contact ±8 kV contact ±2 kV air ±4 kV air ±8 kV air ±15 kV air	Floors should be wood, concrete, or ceramic tile. If floors are covered with synthetic material, the relative humidity should be at least 30%.
Electrical fast transient/burst IEC 61000-4-4	N/A	N/A	Kardia 12L is powered from 2 Alkaline AAA batteries and does not require AC mains power.
Surge IEC 61000-4-5	N/A	N/A	
Voltage dips, short interruptions, and voltage variations on power supply input lines IEC 61000-4-11	N/A	N/A	

Power frequency (50/60 Hz) magnetic field IEC 61000-4-8	30 A/m	30 A/m	Power frequency magnetic fields should be at levels characteristic of a typical location in a typical commercial or hospital environment.

Guidance and manufacturer's declaration—electromagnetic immunity

Kardia 12L is intended for use in the electromagnetic environment specified below. The customer or the user of Kardia 12L should assure that it is used in such an environment.

Immunity test	IEC 60601 test level	Compliance level	Electromagnetic environment - guidance
Radiated RF IEC 61000-4-3	10 V/m 80 MHz to 2.7 GHz	10 V/m	Portable and mobile RF communications equipment should be used no closer to any part of the Kardia 12L ECG hardware, including cables, than the recommended separation distance calculated from the equation applicable to the frequency of the transmitter. **Recommended separation distance** $d = [\frac{3.5}{V_1}]\sqrt{P}$ < 80MHz $d = [\frac{3.5}{E_1}]\sqrt{P}$ 80 MHz to 800 MHz $d = [\frac{7}{E_1}]\sqrt{P}$ 800 MHz to 2.7 GHz where *P* is the maximum output power rating of the transmitter in watts (W) according to the transmitter manufacturer and *d* is the recommended separation distance in meters (m). Field strengths from fixed RF transmitters, as determined by an electromagnetic site survey, [a] should be less than the compliance level in each frequency range. [b] Interference may occur in the vicinity of equipment marked with the following symbol: 

NOTE 1—At 80 MHz and 800 MHz, the higher frequency range applies.
NOTE 2—These guidelines may not apply in all situations. Electromagnetic propagation is affected by absorption and reflection from structures, objects, and people

[a] Field strength from fixed transmitters, such as base stations for radio (cellular/cordless) telephones and land mobile radios, amateur radio, AM and FM radio broadcast, and TV broadcast cannot be predicted theoretically with accuracy. To assess the electromagnetic environment due to fixed RF transmitters, an electromagnetic site survey should be considered. If the measured field strength in the location in which Kardia 12L is used exceeds the applicable RF compliance level above, Kardia 12L

should be observed to verify normal operation. If abnormal performance is observed, additional measures may be necessary, such as re-orienting or relocating Kardia 12L.

[b] Over the frequency range 150 kHz to 80 MHz, field strengths should be less than 3 V/m.

Table 4: Recommended separation distances between portable and mobile RF communications equipment and Kardia 12L

Recommended separation distances between portable and mobile RF communications equipment and Kardia 12L			
Kardia 12L is intended for use in an electromagnetic environment in which radiated RF disturbances are controlled. The customer or the user of Kardia 12L can help prevent electromagnetic interference by maintaining a minimum distance between portable and mobile RF communications equipment (transmitters) and Kardia 12L as recommended below, according to the maximum output power of the communications equipment.			
Rated maximum output power of transmitter W	**Separation distance according to frequency of transmitter m**		
	150 kHz to 80 MHz	**80 MHz to 800 MHz**	**800 MHz to 2.5 GHz**
	$d = [\frac{3.5}{V_1}]\sqrt{P}$	$d = [\frac{3.5}{E_1}]\sqrt{P}$	$d = [\frac{7}{E_1}]\sqrt{P}$
0.01	0.12	0.12	0.23
0.1	0.38	0.38	0.73
1	1.2	1.2	2.3
10	3.8	3.8	7.3
100	12	12	23
For transmitters rated at a maximum output power not listed above, the recommended separation distance *d* in meters (m) can be determined using the equation applicable to the frequency of the transmitter, where *P* is the maximum output power rating of the transmitter in watts (W) according to the transmitter manufacturer. NOTE 1—At 80 MHz and 800 MHz, the separation distance for the higher frequency range applies. NOTE 2—These guidelines may not apply in all situations. Electromagnetic propagation is affected by absorption and reflection from structures, objects, and people.			

Privacy and Security

Cybersecurity is crucial to the safe and effective operation of your Kardia 12L device. It's integral to the protection of patient privacy and the integrity of the system and associated information. The security of your smart device, which serves as a primary interface with your device, must be maintained diligently. The KardiaStation App, which is essential for the operation of the device, is distributed with a digital signature. This signature serves as a guarantee that it originates from a trusted source and hasn't been tampered with.

The Kardia 12L device operates within a secured environment, designed with features that limit access to only approved users. The device is configured to be accessible only through secure pathways, ensuring the confidentiality, integrity, and availability of your information.

It is assumed that the Kardia 12L device and the corresponding KardiaStation App are being used within a secured environment. It's essential that this environment is well-protected, using a firewall or router protections, to ensure that only authorized external hosts have secure network access.

Security Responsibility

Regular upgrades and security patching are part of the ongoing cybersecurity protocols for the Kardia 12L device and the KardiaStation App. These updates are integral to maintain the device and the app's security and to ensure the latest and most secure software is applied.

Malicious Software Protection

The computing environment is increasingly hostile, with threats arising from malicious software, including viruses, worms, Trojan horses, denial of service attacks, and other malware. A vigilant defense on multiple levels is required to keep the Kardia 12L device and the KardiaStation App free from compromise.
To protect against these threats please adhere to the following instructions:

For iOS Devices:

- Protect your Apple ID account with a unique and strong password. Follow the instructions at Apple ID Security.
- Set a passcode for your device. Follow the instructions at Set a Passcode.
- Enable automatic updates for your Kardia 12L device OS. By default, these updates are turned on. Follow the instructions at Update OS.
- Enable automatic updates for the Kardia 12L device's apps. These updates are also enabled by default. Follow the instructions at Enable Automatic App Updates.
- Ensure that your Kardia 12L device has WiFi or cellular connectivity so that updates can be downloaded and installed. Follow the instructions at WiFi Connectivity and Cellular Connectivity.

- Enable automatic backups for your Kardia 12L device. Follow the instructions at Automatic Backups.

For Android Devices:

- Protect your Google ID account with a unique and strong password. Follow the instructions at Google ID Security.
- Set a passcode for your device. Follow the instructions at Set a Passcode.
- Enable automatic updates for the Kardia 12L device's apps. These updates are also enabled by default. Follow the instructions at Enable Automatic App Updates.
- Ensure that your Kardia 12L device has WiFi or cellular connectivity so that updates can be downloaded and installed. Follow the instructions at WiFi Connectivity and Cellular Connectivity.
- Enable automatic backups for your Kardia 12L device. Follow the instructions at Automatic Backups.

Please also refer to resources provided to protect a device from cybersecurity threats: FDA Cybersecurity

Once the above steps are completed, launch your KardiaStation App and enter the unique username and strong password provided to you.

Please remember that cybersecurity is an ongoing process, not a one-time setup. Continuous maintenance of your smart device's security and the KardiaStation App is paramount to protecting against unauthorized access, ensuring the functionality of the device, and safeguarding your personal and patient data.

Software Decommissioning and Secure Data Disposal

This section provides critical information for the safe removal (decommissioning) of the KardiaStation software and the proper disposal of associated patient data

The professional user is responsible for the secure management and disposal of all Patient Identifiable Health Information stored by the KardiaStation application, in line with institutional data retention and privacy policies.

On both iOS/iPadOS and Android, the deletion of the KardiaStation application is the primary method for securely removing the locally stored PHI and ECG recordings.

Application Decommissioning Procedures

- iOS / iPadOS Delete App: Touch and hold the KardiaStation icon until the menu appears. Select "Delete App". Do NOT select "Remove from Home Screen" as this keeps the data.

- Android - Clear Storage/Data: Navigate to Settings → Apps → KardiaStation → Storage & Cache. Tap "Clear Storage" (or "Clear Data") to delete all local PIHI. Uninstall App: Immediately after clearing data, tap "Uninstall" to complete the decommissioning.

Before permanently disposing of the host device (phone or tablet), the user must ensure all remaining data, including data remnants and other apps' PHI, is irreversibly destroyed.

Secure Wipe/Factory Reset: The only way to guarantee the removal of all PIHI from a host device is to perform a complete factory reset (data wipe) of the device. This process is irreversible and should only be performed after all necessary data has been archived.

- iOS/iPadOS: Settings → General → Transfer or Reset iPad/iPhone → Erase All Content and Settings.
- Android: Settings → System → Reset Options → Erase all data (factory reset).

Failure to perform a secure wipe may constitute a breach of data privacy regulations

Equipment Symbols

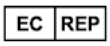
These symbols will be used in the packaging and other labeling of the Kardia 12L hardware.

Table 5: Equipment Symbols

Symbol	Interpretation		Symbol	Interpretation
	Manufacturer			Refer to instruction manual/booklet
	Importer (EU)			Authorized Representative in the European Community (EU)
	CE Mark (0123=TUV SUD)			Unique Device Identifier
	Read instructions before use			Do not dispose with household waste
	Temperature range			Do not cut, shred or attempt to destroy device
	Humidity range			Model number
	Atmospheric pressure range			Serial number
	Type CF Applied Part (Defibrillation-Proof)		IP54	Protected from water spray from any direction

	MR unsafe			Medical Device

AliveCor, Inc.
189 N. Bernardo Avenue, Suite 100
Mountain View, CA 94043, USA



Obelis s.a.
Bd General Wahis 53
Brussels, 1030, Belgium

MedEnvoy
Prinses Margrietplantsoen 33,Suite 123
2595 AM The Hague Netherlands

Kardia 12L Specifications

Table 6: Kardia 12L Specifications

ECG Module Weight	81.5 g
ECG Module Size (Dimensions)	Length: 102.0 mm Width: 43.0 mm Height: 23.85 mm with Silicone Button
ECG Module Materials	Top and Bottom Case: ABS Button: Silicone Light Guide: Polycarbonate
Patient Lead Wire Length	2736.0 mm
Patient Lead Wire Leads	Kardia 12L system ECG cable with 5 electrode (RA, V1/V2, V4, LA, LL)
Patient Lead Wire Materials	Jacket and Strain Reliefs: Thermoplastic Polyurethane Snaps: Brass RoHS3 with Nickel Plating Electrode Labels: Polyethylene Terephthalate with reverse screen printing
Snap to Tab Adaptors	5x adapters are included, enabling the Patient Lead Wire to connect with tab electrodes.
Carrying Case Material	Polypropylene
Electrode Labeling	Abbreviations and colors to comply with either IEC or AAMI standards
Electrode Compatibility	Compatible with a wide range of tab and snap electrodes, including but not limited to the following: - 3M™ Red Dot™ Resting EKG Electrode 2360 Radiolucent - 3M™ Red Dot™ Resting EKG Electrode 2330 Radiolucent - 3M™ Red Dot™ ECG Monitoring Electrodes, 2570-5, Radiolucent, Foam, Diaphoretic, with Abrader - 3M™ Red Dot™ Monitoring Electrode, 2560-5 - Kendall™ 5400 Diagnostic Tab Electrodes - Kendall™ 530 Series Foam Electrodes
Operating Conditions	Temp: -10°C to +40°C Humidity: 0% to 95% (non-condensing) Pressure: 54 kPA to 101kPa

Storage Conditions	-18°C to +55°C 0% to 95% (non-condensing)
Power Requirements	2x AAA Alkaline Batteries (1.5V) - Replaceable
Device Lifetime	5 Years
Connectivity	Bluetooth 5.1
Wireless Range	10m
Input Channels	Simultaneous acquisition of 4 ECG channels (8 standard leads)
Input Dynamic range	+/- 400mV
ADC	24bit, 192kHz/channel
Data Resolution	22bits, 1uV LSB
Measured Leads	8 standard leads I, II, III, aVR, aVL, aVF, V1, V4 or I, II, III, aVR, aVL, aVF, V2, V4
Performance Specifications	
Acquisition Sampling Rate	750Hz/channel for recording and analysis
Frequency Response	DC to 150Hz
Defibrillator Protection	ECG Module and Patient Lead Wire are isolated from system and operator
Leads Off Indicator	The status of the connection is displayed on the recording screen of the KardiaStation App. If there is no contact, the leads will appear faded. Conversely, when a connection is established, the leads will turn prominent.
Permanent Filters	Digital 3 stage 5th order SINC filter
Common Mode Rejection	100dB
Battery Life	3 years shelf life
Algorithmic Determinations	KAI 12L & KAI 12L v2* - Determinations Algorithm

*KAI 12L v2 determination algorithm is subject to regional regulatory approvals and may not be available in all geographical jurisdictions.

Clinical Benefits of Kardia 12L System

Table 7: Clinical Benefits of Kardia 12L System

The KardiaStation 12L app will assist in selecting the appropriate lead set by asking about the patient's symptoms, such as chest pains or palpitations, and will automatically recommend the suitable lead set for the ECG recording based on this clinical representation
The combination of I, II, V2, V4 was found to be particularly effective in detecting abnormal ECG morphology, especially in the anterior location, one of the most clinically significant sites.
Asymptomatic mode can reduce false positive determinations (page 57) especially for acute MI and Ischemia.
Symptomatic mode can be chosen to increase detection of MI and ischemia.
14 rhythms and 21 morphology determinations

The following tables show the acceptance criteria thresholds for KAI 12L algorithm morphology, rhythms, and interval analysis.

Table 8a: Emory DB – Validation

KAI 12L analysis performance of each morphology subtype.
Mode: Asymptomatic

Morphology Group	***Morphology***	**Lead-set: {I, II, V1, V4}**			**Lead-set: {I, II, V2, V4}**		
		Sens.	**Spec.**	**PPV**	**Sens.**	**Spec.**	**PPV**
Intraventricular blocks	*RBBB*	88.2	99.0	89.0	85.7	99.2	90.9
	LBBB	78.0	99.3	78.1	78.4	99.2	75.1
	Other blocks	39.5	96.3	47.3	35.7	96.6	47.1
Hypertrophy	*LVH*	43.9	99.0	76.9	46.3	98.9	76.4
	RVH	34.1	99.4	28.8	40.6	99.3	30.4
Atrial Enlargement	*RAE*	68.4	99.3	60.9	65.9	99.6	72.5
	LAE	78.9	96.0	66.2	36.6	98.3	67.5
Old / Previous MI	*Anterior Old MI*	31.3	97.4	55.0	29.8	97.2	52.3
	Inferior Old MI	27.4	99.2	76.3	32.2	99.1	76.4
	Lateral Old MI	39.8	97.4	30.6	40.2	97.6	32.0
Recent / Acute MI	*Anterior Acute MI*	32.8	99.5	10.7	47.1	99.6	17.6
	Inferior Acute MI	26.2	99.8	24.6	35.1	99.7	27.2
	Lateral Acute MI	38.0	99.8	29.4	54.2	99.7	27.6
Ischemia	*Anterior Ischemia*	56.1	98.1	59.9	60.3	97.9	59.3
	Inferior Ischemia	49.7	98.0	58.1	48.5	98.2	60.1
	Lateral Ischemia	45.6	97.9	66.9	47.1	98.1	68.8
Prolonged QT		55.9	95.0	53.1	55.8	95.2	54.2
Paced ECG		68.5	99.4	84.1	76.6	99.2	80.8
Normal or otherwise normal		88.8	74.4	67.3	88.8	76.0	68.7
Other	*Early repolarization*	57.3	97.4	19.7	53.6	98.4	26.9
	Wolff-Parkinson-White (WPW)	46.0	99.8	19.3	60.1	99.7	13.8

Table 8b: Mayo DB – Validation

KAI 12L analysis performance of each morphology subtype.
Mode: Asymptomatic

Morphology Group	***Morphology***	**Lead-set: {I, II, V1, V4}**			**Lead-set: {I, II, V2, V4}**		
		Sens.	**Spec.**	**PPV**	**Sens.**	**Spec.**	**PPV**
Intraventricular blocks	*RBBB*	91.2	99.3	91.6	89.3	99.5	93.7
	LBBB	81.3	99.4	86.2	82.3	99.2	84.0
	Other blocks	45.1	97.2	63.9	41.2	97.5	64.5
Hypertrophy	*LVH*	41.3	99.2	69.3	48.7	99.0	66.4
	RVH	57.7	99.5	23.1	62.8	99.4	21.3
Atrial Enlargement	*RAE*	66.8	99.6	61.5	62.0	99.8	72.5
	LAE	73.6	97.0	58.1	35.3	98.6	58.9
Old / Previous MI	*Anterior Old MI*	53.7	97.9	47.1	59.5	97.6	46.8
	Inferior Old MI	36.2	99.0	80.9	40.6	98.8	80.1
	Lateral Old MI	41.4	98.2	28.9	44.6	98.0	29.1
Recent / Acute MI	*Anterior Acute MI*	56.7	99.6	16.9	66.1	99.6	20.3
	Inferior Acute MI	64.3	99.6	27.1	71.6	99.6	26.8
	Lateral Acute MI	46.2	99.8	27.9	57.6	99.7	22.2
Ischemia	*Anterior Ischemia*	53.5	99.1	79.3	59.9	99.1	82.3
	Inferior Ischemia	58.2	98.7	68.5	56.2	98.9	71.8
	Lateral Ischemia	46.3	98.6	76.3	47.3	98.8	79.6
Prolonged QT		50.4	95.5	45.1	50.1	95.6	45.4
Paced ECG		66.9	99.7	92.6	70.3	99.6	90.2
Normal or otherwise normal		88.5	80.3	78.4	88.5	81.8	79.7
Other	*Early repolarization*	43.0	98.6	33.4	35.3	99.4	47.3
	Wolff-Parkinson-White (WPW)	53.7	99.9	28.1	60.4	99.8	17.1

Table 8c: Emory DB – Validation

KAI 12L analysis performance of each morphology subtype.
Mode: Symptomatic

Morphology Group	***Morphology***	**Lead-set: {I, II, V1, V4}**			**Lead-set: {I, II, V2, V4}**		
		Sens.	**Spec.**	**PPV**	**Sens.**	**Spec.**	**PPV**
Intraventricular blocks	*RBBB*	91.3	98.8	86.6	89.2	99.0	88.3
	LBBB	85.7	98.9	70.5	85.0	98.7	67.6
	Other blocks	41.1	95.2	41.9	36.4	96.0	43.4
Hypertrophy	*LVH*	56.1	97.9	67.1	57.6	97.9	67.7
	RVH	48.0	98.8	23.3	55.7	98.5	21.7
Atrial Enlargement	*RAE*	78.4	98.8	50.2	76.0	99.2	60.5
	LAE	84.9	94.0	58.5	47.3	96.8	59.8
Old / Previous MI	*Anterior Old MI*	37.3	96.5	52.2	33.5	96.5	49.5
	Inferior Old MI	31.3	99.0	74.9	35.5	98.9	75.3
	Lateral Old MI	40.1	97.3	29.8	40.2	97.5	31.0
Recent / Acute MI	*Anterior Acute MI*	58.1	98.8	8.6	62.2	99.2	12.7
	Inferior Acute MI	43.1	99.4	18.7	46.0	99.4	20.1
	Lateral Acute MI	51.4	99.7	24.7	64.2	99.6	23.8
Ischemia	*Anterior Ischemia*	60.9	97.7	57.1	64.8	97.5	56.2
	Inferior Ischemia	52.6	97.6	55.4	51.8	97.9	58.5
	Lateral Ischemia	48.7	97.5	64.2	49.9	97.7	66.6
Prolonged QT		72.2	91.5	46.4	72.1	91.8	47.2
Paced ECG		70.0	99.4	83.8	78.4	99.2	80.2
Normal or otherwise normal		77.6	82.3	72.3	77.9	83.4	73.6
Other	*Early repolarization*	51.8	96.9	15.8	48.8	97.9	20.9
	Wolff-Parkinson-White (WPW)	52.8	99.6	11.6	62.0	99.4	8.5

Table 8d: Mayo DB – Validation

KAI 12L analysis performance of each morphology subtype.
Mode: Symptomatic

Morphology Group	***Morphology***	**Lead-set: {I, II, V1, V4}**			**Lead-set: {I, II, V2, V4}**		
		Sens.	**Spec.**	**PPV**	**Sens.**	**Spec.**	**PPV**
Intraventricular blocks	*RBBB*	93.9	99.0	89.1	92.4	99.2	90.8
	LBBB	88.8	98.8	78.9	89.0	98.6	76.2
	Other blocks	46.4	96.2	56.9	41.8	97.0	59.9
Hypertrophy	*LVH*	53.6	98.3	57.0	60.1	98.0	55.6
	RVH	69.6	99.0	15.6	77.0	98.7	13.8
Atrial Enlargement	*RAE*	76.8	99.3	50.6	72.5	99.6	61.5
	LAE	80.1	95.5	50.2	46.4	97.4	50.3
Old / Previous MI	*Anterior Old MI*	58.9	97.2	42.6	63.1	97.1	42.8
	Inferior Old MI	40.4	98.7	78.9	44.4	98.6	78.6
	Lateral Old MI	42.5	98.0	28.1	45.2	97.9	28.1
Recent / Acute MI	*Anterior Acute MI*	65.8	99.1	10.3	74.8	99.4	15.3
	Inferior Acute MI	76.4	99.3	19.8	81.0	99.3	21.3
	Lateral Acute MI	54.6	99.7	22.0	63.2	99.6	18.7
Ischemia	*Anterior Ischemia*	57.2	98.7	74.9	64.1	98.8	78.0
	Inferior Ischemia	61.0	98.2	63.1	58.8	98.5	67.1
	Lateral Ischemia	49.6	98.1	72.4	50.6	98.4	75.9
Prolonged QT		60.6	92.2	36.1	60.1	92.3	36.3
Paced ECG		68.3	99.7	92.2	71.9	99.6	89.9
Normal or otherwise normal		76.0	87.3	82.8	76.5	88.3	84.0
Other	*Early repolarization*	38.7	98.3	26.4	35.8	99.1	39.3
	Wolff-Parkinson-White (WPW)	56.7	99.8	16.0	63.3	99.6	9.9

Table 9a: Emory DB – Validation

KAI 12L rhythm analysis performance:
Mode: Asymptomatic, Lead-set: {I, II, V1, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	91.1	88.5	91.3	Pass
Sinus Rhythm	*80*	*85*	83.9	90.1	81.1	Pass
Atrial Fibrillation	*80*	*95*	86.0	99.5	93.6	Pass
Atrial Flutter Leadset:{I, II, V1 V4}	*60*	*95*	70.5	99.3	58.2	Pass
Paced rhythm	*55*	*95*	62.0	99.6	71.0	Pass
Junctional rhythm	*40*	*95*	32.0	99.9	21.6	Pass*
Bigeminy	*80*	*95*	88.5	99.0	23.8	Pass
1st degree AV Block.	*80*	*90*	88.4	96.5	69.3	Pass
High degree AV Block	-	*95*	23.1	99.4	3.0	Pass
Sinus arrhythmia	*50*	*95*	45.7	98.9	67.8	Pass*
Marked sinus arrhythmia	*55*	*90*	64.7	98.1	29.4	Pass
Sinus Rhythm with marked bradycardia	*30*	*95*	94.9	97.7	42.8	Pass
Sinus tachycardia	*85*	*95*	93.5	99.2	92.3	Pass
PVCs	*70*	*90*	81.7	94.5	12.9	Pass

Table 9b: Mayo DB – Validation

KAI 12L rhythm analysis performance:
Mode: Asymptomatic, Lead-set: {I, II, V1, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	82.4	96.2	97.4	Pass*
Sinus Rhythm	*80*	*85*	88.8	86.1	71.8	Pass
Atrial Fibrillation	*80*	*95*	87.3	99.4	94.0	Pass
Atrial Flutter Leadset:{I, II, V1 V4}	*60*	*95*	62.1	99.4	67.4	Pass
Paced rhythm	*55*	*95*	63.4	99.8	90.8	Pass
Junctional rhythm	*40*	*95*	45.6	99.9	26.8	Pass
Bigeminy	*80*	*95*	94.4	99.0	26.2	Pass
1st degree AV Block.	*80*	*90*	80.3	97.9	84.6	Pass
High degree AV Block	-	*95*	49.3	99.4	18.2	Pass
Sinus arrhythmia	*50*	*95*	41.9	99.2	70.8	Pass*
Marked sinus arrhythmia	*55*	*90*	84.1	98.0	18.9	Pass
Sinus Rhythm with marked bradycardia	*30*	*95*	97.2	97.4	54.2	Pass
Sinus tachycardia	*85*	*95*	93.9	99.1	89.8	Pass
PVCs	*70*	*90*	88.7	98.2	79.6	Pass

Table 9c: Emory DB – Validation

KAI 12L rhythm analysis performance:
Mode: Asymptomatic, Lead-set: {I, II, V2, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	89.7	86.4	89.7	Pass
Sinus Rhythm	*80*	*85*	83.0	88.8	78.9	Pass
Atrial Fibrillation	*80*	*95*	85.4	99.3	90.7	Pass
Atrial Flutter Leadset:{I, II, V2 V4}	*35*	*95*	43.7	99.2	41.3	Pass
Paced rhythm	*55*	*95*	59.6	99.6	65.8	Pass
Junctional rhythm	*40*	*95*	35.9	99.8	11.9	Pass*
Bigeminy	*80*	*95*	88.2	98.9	22.0	Pass
1st degree AV Block.	*80*	*90*	81.2	96.5	67.2	Pass
High degree AV Block	-	*95*	8.9	99.0	0.7	Pass
Sinus arrhythmia	*50*	*95*	44.2	98.9	66.7	Pass*
Marked sinus arrhythmia	*55*	*90*	66.6	97.4	23.7	Pass
Sinus Rhythm with marked bradycardia	*30*	*95*	95.1	97.7	42.9	Pass
Sinus tachycardia	*85*	*95*	93.2	99.2	92.7	Pass
PVCs	*70*	*90*	77.5	94.1	11.6	Pass

Table 9d: Mayo DB – Validation

KAI 12L rhythm analysis performance:
Mode: Asymptomatic, Lead-set: {I, II, V2, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	82.0	93.9	95.9	Pass*
Sinus Rhythm	*80*	*85*	87.0	85.2	70.1	Pass
Atrial Fibrillation	*80*	*95*	85.1	99.0	90.0	Pass
Atrial Flutter Leadset:{I, II, V2 V4}	*35*	*95*	39.6	99.2	47.3	Pass
Paced rhythm	*55*	*95*	61.4	99.7	87.5	Pass
Junctional rhythm	*40*	*95*	47.7	99.8	17.0	Pass
Bigeminy	*80*	*95*	93.3	98.9	24.1	Pass
1st degree AV Block.	*80*	*90*	71.7	97.8	81.9	Pass*
High degree AV Block	-	*95*	37.4	99.2	10.3	Pass
Sinus arrhythmia	*50*	*95*	40.2	99.2	69.3	Pass*
Marked sinus arrhythmia	*55*	*90*	84.1	97.3	14.8	Pass
Sinus Rhythm with marked bradycardia	*30*	*95*	97.3	97.4	54.3	Pass
Sinus tachycardia	*85*	*95*	93.6	99.1	90.1	Pass
PVCs	*70*	*90*	82.5	97.7	73.5	Pass

Table 10a: Emory DB – Validation

KAI 12L rhythm analysis performance:
Mode: Symptomatic, Lead-set: {I, II, V1, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	94.2	88.2	91.4	Pass
Sinus Rhythm	*80*	*80*	85.8	86.5	76.3	Pass
Atrial Fibrillation	*85*	*95*	88.5	99.3	91.9	Pass
Atrial Flutter Leadset:{I, II, V1 V4}	*60*	*95*	63.5	99.2	53.0	Pass
Paced rhythm	*65*	*95*	70.4	99.1	53.5	Pass
Junctional rhythm	*45*	*95*	28.1	99.9	15.9	Pass*
Bigeminy	*80*	*95*	90.5	98.7	18.9	Pass
1st degree AV Block.	*80*	*90*	85.8	95.7	63.9	Pass
High degree AV Block	*-*	*95*	24.3	99.2	2.5	Pass
Sinus arrhythmia	*50*	*90*	56.9	97.5	53.2	Pass
Marked sinus arrhythmia	*65*	*90*	76.1	97.2	24.8	Pass
Sinus Rhythm with marked bradycardia	*80*	*95*	92.0	96.5	32.0	Pass
Sinus tachycardia	*85*	*85*	94.8	97.7	81.4	Pass
PVCs	*75*	*85*	85.1	93.7	11.8	Pass

Table 10b: Mayo DB – Validation

KAI 12L rhythm analysis performance:
Mode: Symptomatic, Lead-set: {I, II, V1, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	84.6	96.2	97.4	Pass*
Sinus Rhythm	*80*	*80*	89.9	83.2	68.1	Pass
Atrial Fibrillation	*85*	*95*	87.6	99.2	91.5	Pass
Atrial Flutter Leadset:{I, II, V1 V4}	*60*	*95*	55.6	99.3	58.1	Pass*
Paced rhythm	*65*	*95*	73.0	99.0	73.2	Pass
Junctional rhythm	*45*	*95*	38.1	99.9	19.9	Pass*
Bigeminy	*80*	*95*	95.3	98.7	21.1	Pass
1st degree AV Block.	*80*	*90*	79.3	97.2	80.2	Pass*
High degree AV Block	*-*	*95*	64.4	99.3	19.0	Pass
Sinus arrhythmia	*50*	*90*	52.2	98.1	55.0	Pass
Marked sinus arrhythmia	*65*	*90*	92.8	97.1	15.0	Pass
Sinus Rhythm with marked bradycardia	*80*	*95*	93.9	96.0	42.5	Pass
Sinus tachycardia	*85*	*85*	95.4	97.7	78.3	Pass
PVCs	*75*	*85*	91.7	97.5	73.9	Pass

Table 10c: Emory DB – Validation

KAI 12L rhythm analysis performance:
Mode: Symptomatic, Lead-set: {I, II, V2, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	92.5	86.1	89.8	Pass
Sinus Rhythm	*80*	*80*	84.9	85.0	74.1	Pass
Atrial Fibrillation	*85*	*95*	88.8	99.0	88.2	Pass
Atrial Flutter Leadset:{I, II, V2 V4}	*35*	*95*	38.5	99.0	33.4	Pass
Paced rhythm	*65*	*95*	68.6	99.0	50.3	Pass
Junctional rhythm	*45*	*95*	31.3	99.8	9.9	Pass*
Bigeminy	*80*	*95*	90.2	98.6	17.5	Pass
1st degree AV Block.	*80*	*90*	80.3	95.3	60.4	Pass
High degree AV Block	-	*95*	12.4	98.8	0.8	Pass
Sinus arrhythmia	*50*	*90*	53.4	97.5	50.8	Pass
Marked sinus arrhythmia	*65*	*90*	76.9	96.4	20.4	Pass
Sinus Rhythm with marked bradycardia	*80*	*95*	93.1	96.5	32.2	Pass
Sinus tachycardia	*85*	*85*	94.3	97.8	81.9	Pass
PVCs	*75*	*85*	81.4	92.7	10.0	Pass

Table 10d: Mayo DB – Validation

KAI 12L rhythm analysis performance:
Mode: Symptomatic, Lead-set: {I, II, V2, V4}

Rhythm	***Acceptance Criteria***		**KAI 12L**			**Result**
	Sens.	***Spec.***	**Sens.**	**Spec.**	**PPV**	
Normal Sinus Rhythm	*90*	*80*	84.0	94.1	96.1	Pass*
Sinus Rhythm	*80*	*80*	88.3	82.2	66.4	Pass
Atrial Fibrillation	*85*	*95*	87.1	98.7	87.4	Pass
Atrial Flutter Leadset:{I, II, V2 V4}	*35*	*95*	34.9	99.0	38.2	Pass*
Paced rhythm	*65*	*95*	71.2	99.0	71.8	Pass
Junctional rhythm	*45*	*95*	39.1	99.8	13.6	Pass*
Bigeminy	*80*	*95*	94.4	98.5	19.1	Pass
1st degree AV Block.	*80*	*90*	72.6	96.8	76.4	Pass*
High degree AV Block	*-*	*95*	50.4	99.0	11.2	Pass
Sinus arrhythmia	*50*	*90*	49.7	98.1	53.3	Pass*
Marked sinus arrhythmia	*65*	*90*	90.7	96.3	11.8	Pass
Sinus Rhythm with marked bradycardia	*80*	*95*	94.6	95.9	42.4	Pass
Sinus tachycardia	85	85	94.9	97.7	78.6	Pass
PVCs	75	85	87.6	96.4	65.5	Pass

Table 11: KAI 12L Interval Estimation Performance (all in milliseconds, except HR in bpm)

Database	Interval	Metric	*Acceptance Criteria*	KAI 12L {I, II, V1, V4}	KAI 12L {I, II, V2, V4}	Result
CSE DB	PR	Mean interval difference	*≤ ± 10*	1.4	1.1	Pass
		Std. Dev. of difference	*≤ 10*	6.7	6.8	Pass
	QRS	Mean interval difference	*≤ ± 10*	-5.6	-5.1	Pass
		Std. Dev. of difference	*≤ 10*	5.6	5.6	Pass
	QT	Mean interval difference	*≤ ± 20*	1.2	1.6	Pass
		Std. Dev. of difference	*≤ 25*	9.7	10.2	Pass
QT Clinic DB	PR	Mean interval difference	*≤ ± 10*	0.7	0.0	Pass
		Std. Dev. of difference	*≤ 10*	8.8	8.6	Pass
	QRS	Mean interval difference	*≤ ± 10*	-1.5	-0.1	Pass
		Std. Dev. of difference	*≤ 10*	7.2	7.2	Pass
	QT	Mean interval difference	*≤ ± 20*	8.3	8.6	Pass
		Std. Dev. of difference	*≤ 25*	14.5	14.0	Pass
	QTcB	Mean interval difference	*≤ ± 20*	8.3	8.6	Pass
		Std. Dev. of difference	*≤ 25*	20.1	19.7	Pass
	QTcF	Mean interval difference	*≤ ± 20*	8.3	8.6	Pass
		Std. Dev. of difference	*≤ 25*	16.8	16.4	Pass
	HR	Mean Absolute Difference (in beats per minute=bpm)	*≤ 3 bpm*	2.0 bpm	2.0 bpm	Pass
Emory Validation DB	PR	Mean interval difference	*≤ ± 10*	-1.7	-1.8	Pass
		Std. Dev. of difference	*≤ 10*	8.5	8.4	Pass
	QRS	Mean interval difference	*≤ ± 10*	1.2	1.1	Pass
		Std. Dev. of difference	*≤ 10*	5.3	5.3	Pass
	QT	Mean interval difference	*≤ ± 20*	1.9	2.0	Pass
		Std. Dev. of difference	*≤ 25*	10.5	10.4	Pass

Physician's Guide

Introduction

Kardia 12L is a portable 12-Lead resting electrocardiograph (ECG) device that acquires 4 ECG leads from a patient, and using software generates the remaining leads to create a 12-lead ECG recording. The device can be used by healthcare professionals (HCPs) to record a resting ECG, where traditional 10 electrode 12 lead ECG recorders are not practical to administer due to size, time, or need for specialized clinicians to administer. Examples may include physician offices, and remote and field locations.

Figure 7: Kardia 12L Hardware

The Kardia 12L hardware consists of the Kardia 12L ECG Module that connects to the Patient Lead Wire. The Patient Lead Wire is a single cable that includes five snap-on electrodes. These hardware elements are further discussed below. Kardia 12L also consists of a mobile software application, the KardiaStation App that executes on a mobile computing platform (MCP), such as an Apple® iPhone® smartphone. To use Kardia 12L, a compatible smartphone or tablet is required along with the KardiaStation app. You can view the list of compatible devices at www.alivecor.com/compatibility/pro. To record an ECG, the user positions standard off-the-shelf

(OTS) ECG gel electrodes on the patient and snaps the connectors in the Patient Lead Wire onto the electrodes.

Kardia 12L allows for two options for which set of reduced leads are acquired:

1. Lead Set 1: Leads {I, II, V2, and V4}, with electrodes on RA, LA, LL, V2, V4; and
2. Lead Set 2: Leads {I, II, V1, and V4} with electrodes on RA, LA, LL, V1, and V4.

All leads are acquired using standard diagnostic ECG electrode positions, i.e., with RA on the right arm, LA on the left arm, LL on the left leg, V1 precordial lead on the 4th intercostal space (ICS), right margin of the sternum, V2 precordial lead on the 4th ICS left margin of the sternum, V4 precordial lead on the 5th ICS at the midclavicular line.

The Lead Set option is selected by the HCP in the KardiaStation App. During a recording, the Electronics Module simultaneously acquires a 10-second ECG for the Lead Set selected by the user and transmits the recorded ECG to the KardiaStation App. Using Leads I and II provided in the input, Kardia 12L computes Leads III, aVL, aVR, and aVF using standard math for such lead computation. The remaining precordial leads are synthesized using an AliveCor proprietary lead synthesis algorithm. The complete 12-lead ECG is then displayed to the user.

> **WARNING**: Synthesized leads generated by Kardia 12L are for informational purposes only. The 4 synthesized precordial leads may not be used for any clinical decision making.
>
> **Warning: Interpretation Hazard:** Only 8 standard leads instead of 12 leads are provided and used for automated analysis. The 4 synthesized chest leads are not intended for diagnostic use and may fail to show important findings limited to those leads. This device is not a substitute for a diagnostic 12-lead ECG and is contraindicated for use in ruling out any condition (including but not limited to certain ischemia/infarcts, Brugada syndrome) for which the diagnosis may be dependent on the synthesized leads
>
> **Warning: Interpretation Hazard:** The automated ECG analysis results are provisional and must be reviewed by a qualified physician capable of independently interpreting the ECG signal in the context of the patient condition. The provisional automated ECG analysis program may then be confirmed, edited, or deleted by a qualified physician. ECG analysis should be used only as an adjunct to clinical history, symptoms, and the results of other non-invasive and or invasive tests
>
> **Warning:** The **provisional automated ECG analysis** should not be used for clinical action if it has not been reviewed by a qualified healthcare professional capable of independently interpreting the ECG signal.

The KardiaStation App also integrates a 12-lead ECG analysis software called KAI 12L to provide rhythm and morphology determinations, and interval measurements. KAI 12L is

intended for use by HCPs to analyze a diagnostic-bandwidth ECG and only requires 4 ECG leads for analysis, specifically, either Leads {I, II, V2, and V4}, or Leads {I, II, V1, and V4}.

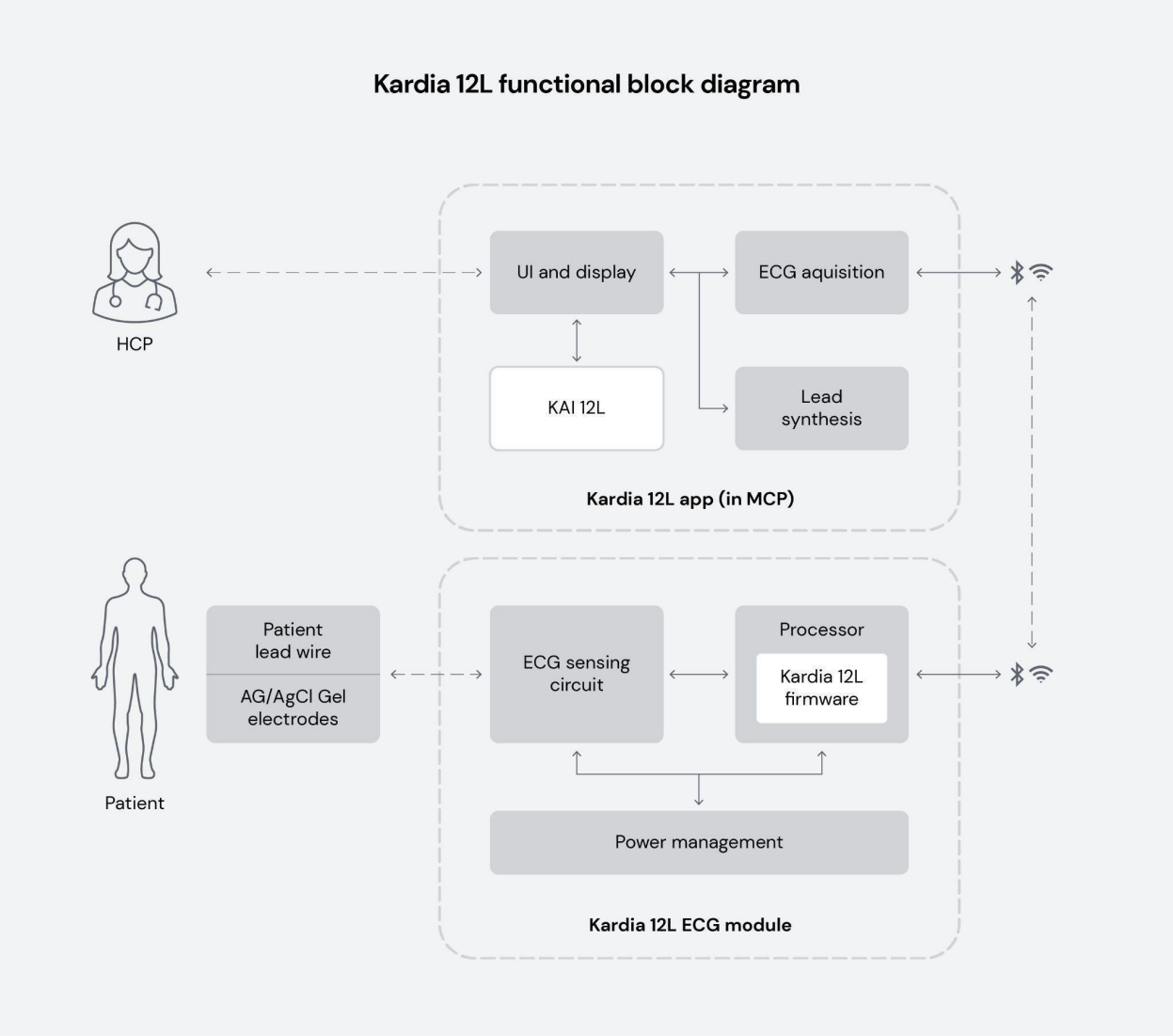


Figure 8: Kardia 12L Functional Block Diagram

Kardia 12L is intended to record, store, and transfer a reduced 12-lead resting electrocardiogram (ECG). The device acquires four leads (Leads I, II, V2, V4, or Leads I, II, V1, V4), derives Lead-III and Augmented Limb leads aVR, aVF and aVL, and synthesizes Leads V1,V3, V5, V6 or V2, V3, V5, V6. It is suitable for use with patients aged 18 years and older.

This device is intended for use by healthcare professionals, or trained personnel in healthcare facilities (e.g. the doctor's office or hospital) and in acute settings, particularly in scenarios where traditional 12 Lead ECG machines may not be accessible or practical. Kardia 12L is a prescription

use device that must be used under the guidance of a physician. Be sure to ensure that the ECG and any analysis results are reviewed by a cardiologist or other expert ECG clinician.

Using the Kardia 12L ECG Device

To start using your Kardia 12L ECG device, unpack the hardware, generate KardiaPro practice, set credentials and download the associated KardiaStation App on your compatible iOS or Android device. Once installed, enable Bluetooth to connect your device to the Kardia 12L hardware and launch the application.

When ready to record an ECG, connect the ECG module to the patient lead wire and ensure the patient is suitably prepared with exposed skin at the ankles, chest, and arms below the elbows. After cleansing these areas, place the gel electrodes at specific locations depending on whether you are using default Lead set 1 (V2, V4, RA, LA, and LL) or alternate Lead set 2 (V1, V4, RA, LA, and LL). A simplified summary to decide the choice of Lead Set and Analysis Mode is shown in the **Table 12** below.

Table 12: Choosing the Lead Set and Analysis Mode based on clinical presentation

	Analysis Mode	
Lead Set	**Asymptomatic**	**Symptomatic**
Lead Set 1 {I, II, V2, V4}	Standard physical exams	Patient presenting with symptoms of ischemia or infarction such as chest pain
Lead Set 2 {I, II, V1, V4}	Standard rhythm screening	Patient presenting with palpitations

The modes are intended to be user selectable. **Figure 9** shows the flow of the Kardia 12L user interface that helps the user select these modes using the clinical presentation. Note that the user can also manually select the Analysis Mode and/or the Lead Set (not shown in the figure). Please also refer to the Section “Choosing Between Leadset 1 [I, II, V1, V4] and Leadset 2 [I, II, V2, V4]” for additional details.

In essence, choose Lead Set 1 as the default option but use Lead Set 2 if the focus is on rhythm. Choose to record both Lead Sets one after another to get a more complete picture of the patient. Based on the clinical presentation, choose the Symptomatic Analysis Mode if the patient presents with palpitations, or symptoms of ischemia or infarction such as chest pain. Choose Asymptomatic Mode for standard screening and exams.

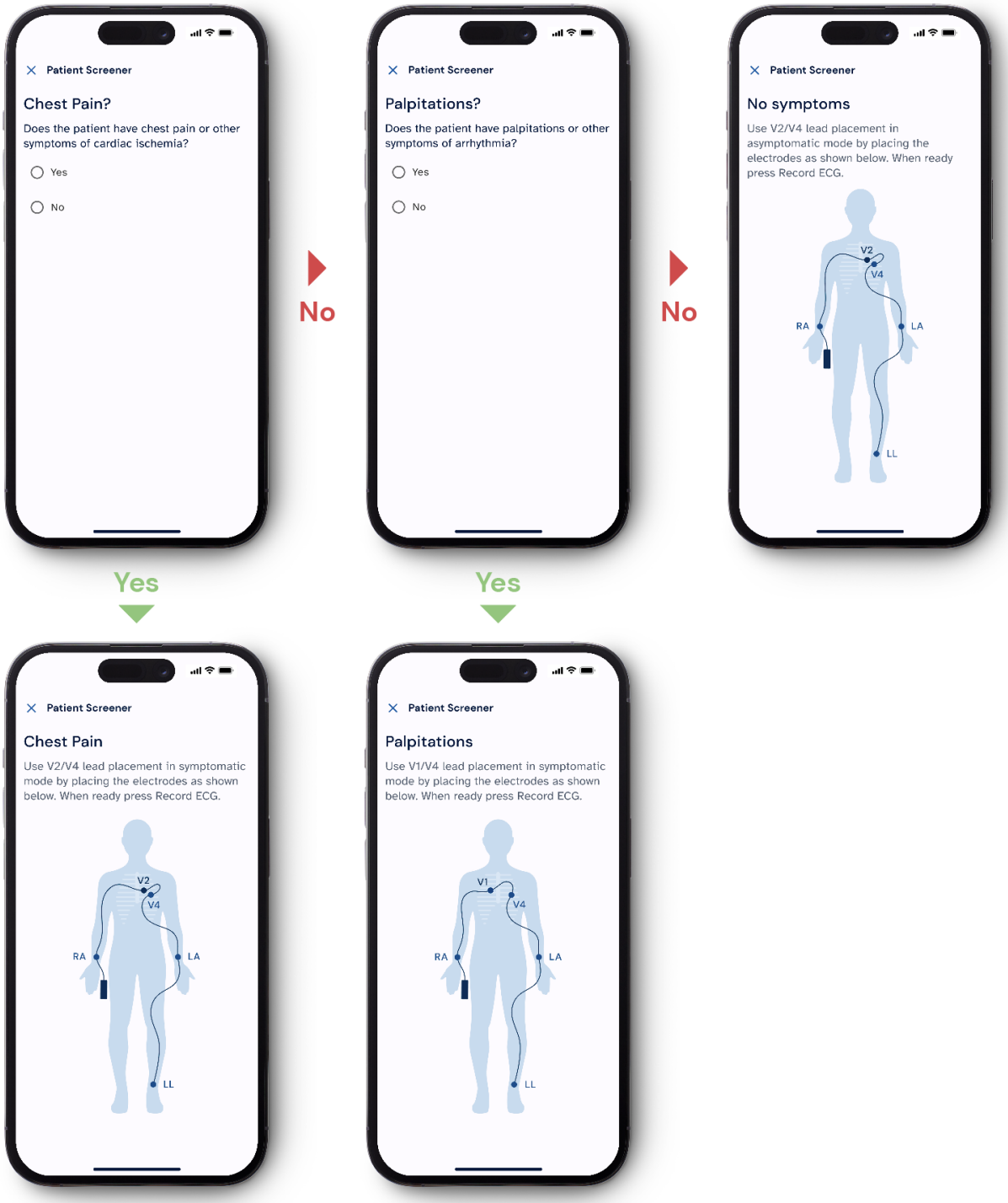


Figure 9: Flow of analysis and lead selection in Kardia 12L based on clinical presentation

Once the electrodes are placed and connected, activate the Kardia 12L ECG module and begin recording by selecting the "Record" button on the KardiaStation App. A minimum of 10 seconds of data is required for a complete recording,

During the live recording, pay attention to the ECG signal quality ring. This ring is your guide to understanding the quality of the ECG signal being captured. A low-quality signal typically results from noise interference, which could impact the accuracy of the ECG recording.

- **Green** Ring signifies a good quality signal. This indicates that all 10 seconds of the current ECG recording are of high-quality.

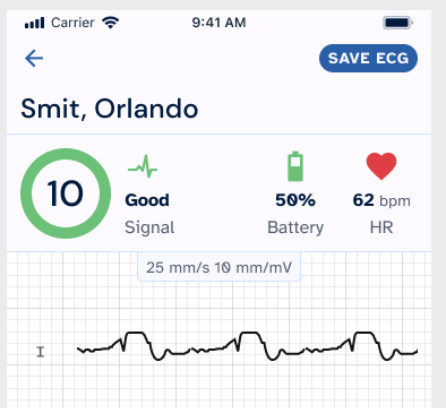


Figure 10: Green Ring signifying High quality signal

- The ring indicates the signal quality over the last 10 seconds. If any part of the last 10 seconds had a low-quality signal, that segment of the ring will be yellow, and the overall status will indicate "Low Signal Quality". Once the ring is fully green, the status will change to "Good Signal Quality". Poor quality signal may result from noise interference.

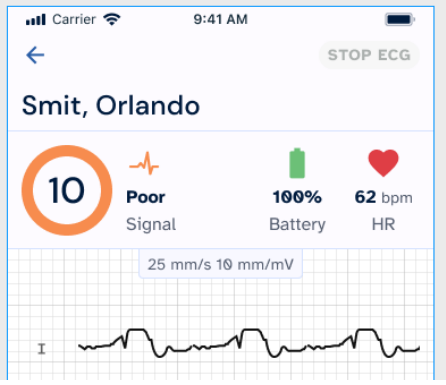


Figure 11: Yellow Ring signifying Low quality signal

Once you have a recording of at least 10 seconds, you can select the 'Save' button on the app to conclude the process. While it is recommended that you save when the entire 10 seconds have good signal quality, the software does not restrict you from saving a 10 second ECG even if the signal quality is low.

Remove the connectors and electrodes from the patient once the recording is completed. The device will automatically switch off after use. Please be sure to clean and disinfect the device before and after every use.

For a more detailed step-by-step guide on using the Kardia 12L ECG device, please refer to the instructions provided in the Sections above within this document.

Configuration of Standard and Reduced ECG Lead Sets

The standard 12-lead ECG employs 10 electrodes, with four limb leads and six chest or precordial leads. Eight leads acquire signals directly (I, II, and V1-V6), and four are computed from leads I and II in the following manner:

III = II – I
aVR = -(I + II) / 2
aVL = I – II/2
aVF = II – I/2

An artificial reference signal, called the Wilson Central Terminal (WCT), is created to produce the reference unipolar signals for all six chest leads. These chest leads are initially measured directly as a vector using their corresponding chest electrode and the reference electrode of RA. Subsequently, WCT is subtracted to yield the final chest leads V1 through V6.

For many years, researchers have investigated reduced ECG lead sets as an alternative to standard 12-lead ECGs. These studies aim to simplify the 12-lead ECG acquisition process while maintaining diagnostic performance equivalent to the original 12-lead ECG. These reduced lead sets can generally be classified into two types:

- The first uses a subset of the 12-lead ECG, such as the set comprising leads (I, II, V1, V5), as studied by Drew et al. (2002), or the set composed of leads (I, II, V2, V5) as examined by Nelwan et al. (2004).
- The second employs non-standard electrode positions, which typically results in a total of four chest leads and one reference lead, as proposed by Dower et al. (1988).

Kardia 12L ECG Device's approach to Reduced Lead Set

Inspired by these previous studies, our team chose to employ a subset of the standard 12-lead ECG in the Kardia 12L ECG device. More specifically, we retained the same limb leads I, II, and added two additional precordial leads (V leads). To determine the best precordial leads to use, AliveCor's internal research team performed an analysis of various combinations of acquired precordial leads. This research showed that the recorded I/II/V1/V4 and I/II/V2/V4 leads were the best combination to be able to review a wide range of ECG rhythm and morphological issues. Notably, the combination of I, II, V2, V4 was found to be particularly effective in detecting abnormal ECG morphology, especially in the anterior location, one of the most clinically significant sites. The lead V1 is also the best lead for detecting P waves.

Taking these results into account, the Kardia 12L system offers the option to use two lead sets. Lead Set 1 consists of I, II, V1, and V4, while Lead Set 2 comprises I, II, V2, and V4. The precordial leads V1, V2, and V4 have clear landmarks that are relatively easier to identify than leads V3, V5, and V6. Thus, the use of these specific lead sets not only provides a reliable measure of ECG signals in the reduced lead set approach, but also makes the Kardia 12L ECG device highly efficient and adept at capturing a broad range of heart signal information.

Warning: The 4 synthesized chest leads are not intended for diagnostic use and may fail to show important findings limited to those leads. This device is not a substitute for a diagnostic 12-lead ECG and is contraindicated for use in ruling out any condition (including but not limited to certain ischemia/infarcts, Brugada syndrome) for which the diagnosis may be solely dependent on the synthesized leads.

Synthesized Leads on the ECG Report

Synthesized leads are provided so that physicians can view Kardia 12L ECGs in the familiar standard resting ECG format (Figure 12). However, the 4 synthesized chest leads are for informational purposes only and are not intended for diagnostic use.

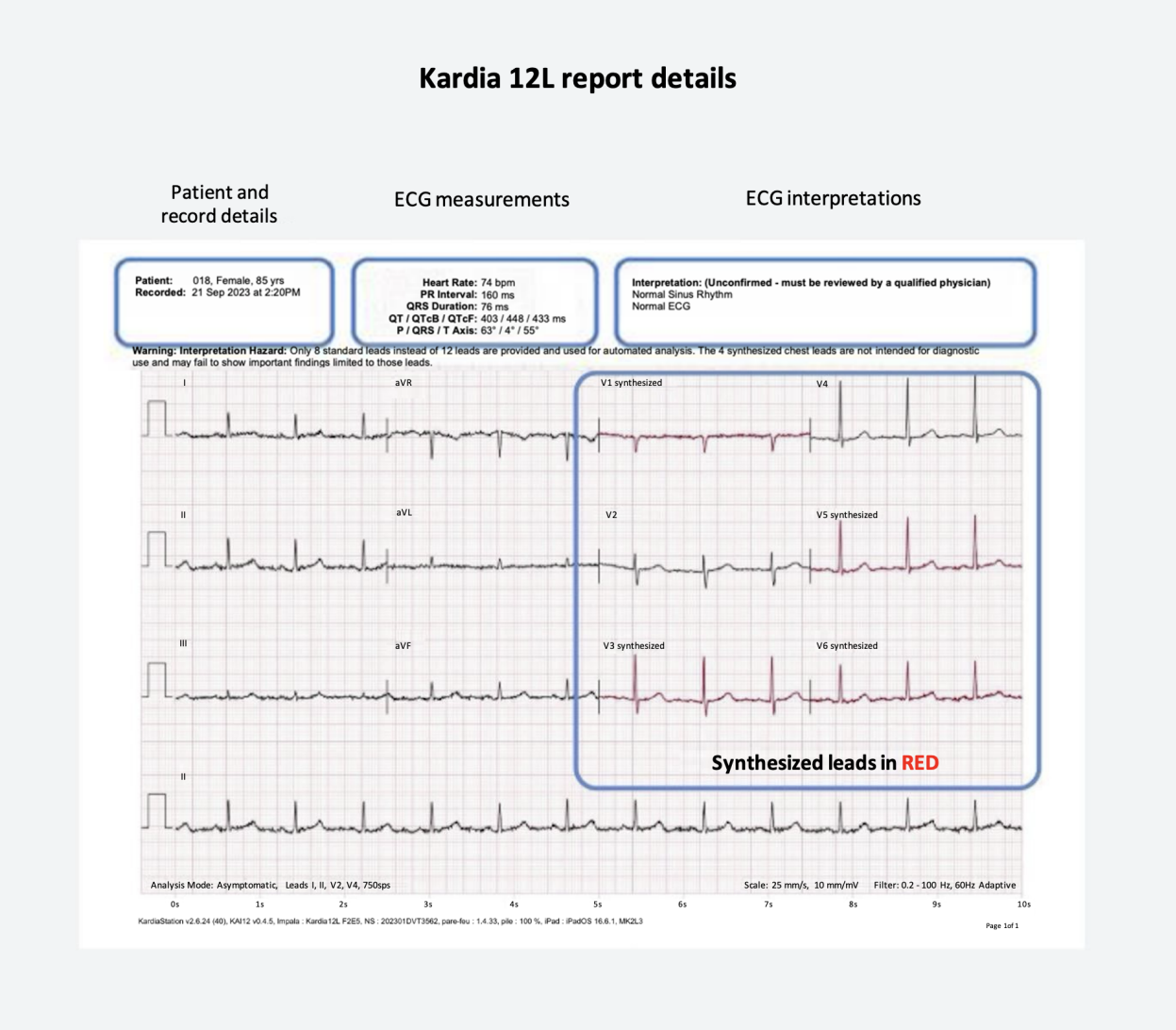


Figure 12: A reduced 12-lead Resting ECG report from Kardia 12L. For ease of identification in the figure above, synthesized leads are displayed in Red

In Figure 12, which illustrates a reduced 12-lead resting ECG report, the precordial leads marked by red are synthesized from other measured leads. The actual measured leads include all limb leads and two precordial leads, namely V1 and V4.

Choosing Between Leadset 1 [I, II, V1, V4] and Leadset 2 [I, II, V2, V4]

In the context of reduced lead ECG interpretation, we focus on two primary leadsets: Leadset 1 and Leadset 2.

Leadset 1 includes limb leads I, II, and precordial leads V1 and V4. Lead V1, positioned in the fourth intercostal space to the right of the sternum, delivers detailed insights into the right atrium and right ventricle. This lead is particularly valuable for its capacity to detect P waves, making it excellent for diagnosing possible arrhythmias (J. Lee et al., 2018). Lead V4, situated in the fifth intercostal space in line with the middle of the clavicle, provides pivotal data about the anterior wall of the left ventricle, often considered the best lead for detecting anterior ischemia and infarction.

In contrast, Leadset 2 consists of limb leads I, II, and precordial leads V2 and V4. Lead V2, located in the fourth intercostal space to the left of the sternum, provides valuable information about the septal region of the heart. This lead is particularly useful for diagnosing possible infarctions and ischemias, as it's often considered the best lead for detecting both septal and anterior ischemia and infarction (L. Wang et al., 2017). The inclusion of lead V4 in this set, similar to Leadset 1, ensures comprehensive coverage of the anterior wall of the heart, and some information for lateral location due to its closeness to v5, the lateral lead.

Both leadsets, through Kardia 12L's patient lead wires and electrode combination, utilize a minimum lead set to provide maximum information on the heart's inferior (lead II, III, aVF), anterior (V2, V4), and frontal plane’s lateral wall (lead I, aVL) activities. The selection of the precordial lead set combination V1/V4 or V2/V4 is facilitated by the same patient lead wire, with the electrode placement on the patient's chest being the only variable. This feature provides the clinician with an easy option to perform both a Lead Set 1 and a Lead Set 2 recording relatively quickly to get an enhanced evaluation of the patient’s heart activity in the anterior and septal regions.

Thus, the decision between Leadset 1 and Leadset 2 should be guided by specific diagnostic needs, the patient's specific conditions, and the healthcare setting. In summary, lead set [I, II, v1, v4] is optimized for certain arrhythmia determinations, like atrial flutter, while lead set [I, II, v2, v4] is optimized for morphology determinations. By offering these two leadsets, Kardia 12L empowers healthcare professionals to make more informed diagnostic decisions.

References:

J. Lee, G. McManus, et al. (2018). "The Right Ventricular Leads: Importance in Electrocardiography". Journal of Electrocardiology.

L. Wang, H. Zhang, et al. (2017). "Septal and Anterior Wall Ischemia on Electrocardiography". Cardiology Journal.

Integration of KAI 12L within Kardia 12L and Reference Guide

KAI 12L, a Software as a Medical Device (SaMD), is designed to be used by healthcare professionals for the analysis of diagnostic-bandwidth Electrocardiograms (ECGs). KAI 12L has been seamlessly integrated into Kardia 12L to enhance our ability to provide high-quality, reliable ECG analysis.

The KAI 12L software interfaces with Kardia 12L, contributing its comprehensive analysis capabilities to our existing technology. With this integration, Kardia 12L is capable of capturing and analyzing a 10-second ECG, offering robust rhythm, morphological analysis, and ECG interval estimation.

KAI 12L requires only four ECG leads for analysis - either leads {I, II, V2, V4} or leads {I, II, V1, V4}, i.e. the same leads directly acquired by Kardia 12L. Despite this, it provides a full suite of rhythm, morphological, and interval determinations, tailored to meet varying clinical requirements. With KAI 12L's two operational modes, Symptomatic and Asymptomatic, Kardia 12L can optimize for either sensitivity or positive predictive value (PPV), according to the needs of the specific clinical situation.

For more comprehensive information on how KAI 12L works within Kardia 12L, and to understand the full potential of this integration, we will be providing a detailed KAI 12L Physician's Guide. The guide, serving as an annex to this document, will offer an in-depth look at KAI 12L's features and instructions for use including warnings, making it an invaluable resource for healthcare professionals seeking to make the most out of the Kardia 12L system.

User Manual for KAI 12L

Rx Only

Note: This section contains supplementary information for technical implementers and may be primarily relevant for use outside the European Union (EU) or where KAI 12L is treated as a separate component. Within the EU, the KAI 12L library is an inseparable, integrated component of the KardiaStation 12L App.

Introduction

KAI 12L is Software as a Medical Device (SaMD) intended for use by healthcare professionals to analyze a diagnostic-bandwidth ECG. KAI 12L analyzes a 10-second ECG and provides rhythm analysis, morphological analysis, and ECG interval estimation. Rhythm and morphology determinations are overlapping, i.e., an ECG could receive multiple rhythm and morphology determinations (e.g., Sinus Rhythm, Acute MI). No beat-level analysis is provided by the device.

This SaMD provides these capabilities in the form of an Application Program Interface (API) library. Any software or device (“target device”) with the correct lead set and ECG recording specifications can incorporate the KAI 12L API library into its device software to provide users with diagnostic ECG analytics. The input ECG is provided by the target device to KAI 12L, to which the various KAI 12L algorithms are applied, and outputs generated accordingly. KAI 12L has a C++ interface and a distributed binary (library), which is used by the target device to statically link to KAI 12L. Viewing of KAI 12L’s ECG analysis is handled by the target device.

KAI 12L is intended to be used with standard diagnostic, resting ECG recordings. KAI 12L only requires 4 ECG leads for analysis, specifically, either Leads {I, II, V2, and V4}, or Leads {I, II, V1, and V4}. Regardless of the lead configuration, KAI 12L provides the same set of rhythm, morphological, and interval determinations. KAI 12L has two modes of operation, Symptomatic Mode, that optimizes the sensitivity to detect the various rhythms and morphologies, and Asymptomatic Mode, that optimizes the PPV, by optimizing the Specificity, to detect the various rhythms and morphologies. The user can choose which lead set and which mode of determinations to utilize based on the target clinical application.

Geographical Note: The KAI 12L v2 analysis features and certain determinations described in this manual are subject to regional regulatory approvals and may not be available in all geographical jurisdictions. Please consult your AliveCor representative to confirm feature availability in your region.

How to use the Manual

This manual is intended for qualified health care professionals, or trained personnel using KAI 12L, a diagnostic resting ECG analysis program, in healthcare facilities (e.g. the doctor's office or hospital) and in acute settings. This manual is also intended for software developers who want to incorporate KAI 12L into their software.

There are two parts to the manual. The first part includes the physicians' guide which is intended to help the health care professionals understand the intended use of the device, explain how the device works, and how to use the output. The second part of the manual includes the implementer's guide and it explains how to integrate the KAI 12L SaMD API into the host platform.

KAI 12L Indications for Use

AliveCor's KAI 12L ECG analysis system assists the healthcare professional (HCP) in measuring and interpreting resting diagnostic ECGs for rhythm and morphological information by providing an initial automated interpretation. The interpretation by the analysis program may then be confirmed, edited, or deleted by the HCP. The analysis program is intended for use in the general population ranging from healthy subjects to patients with cardiac and/or non-cardiac abnormalities. KAI 12L is intended for use by healthcare professionals, or trained personnel in healthcare facilities (e.g. the doctor's office or hospital) and in acute settings.

KAI 12L analyses should be used only as an adjunct to clinical history, symptoms, and the results of other non-invasive and/or invasive tests. KAI 12L analyses are considered unconfirmed and must be reviewed by a qualified physician. The provisional automated ECG analysis should not be used for clinical action if it has not been reviewed by a qualified healthcare professional capable of independently interpreting the ECG signal.

Type of Use – Rx Only

KAI 12L is a prescription-use ECG analysis software as a medical device. It may be integrated into other prescription use devices and the output of KAI 12L is intended for review by a healthcare professional.

CAUTION: Federal law restricts this device to sale to or on the order of a physician.

Use Model

The KAI 12L SaMD is a software library written in C++. It is distributed as a precompiled library for POSIX compliant platforms. This library can be used by implementers to build devices on any platform, local or cloud based, that is running a compatible operating system platform. Manufacturers can incorporate KAI 12L in their devices by statically linking the KAI 12L library to the manufacturer's ECG target device software. This linking is performed by the ECG manufacturer per standard methods used to link software with API libraries. KAI 12L can be integrated in a medical device system to display the results of the ECG analysis on the system's physical or remote display. In operation, such medical devices call the primary analysis method in the KAI 12L library as needed for the device application to process and analyze ECGs. The KAI 12L library provides the result of the requested analysis by subsequently responding to the caller of the method. These medical devices also provide the user interface and display for KAI 12L's analysis. KAI 12L does not have its own user interface and cannot be called or otherwise accessed by an end user directly.

Hazard Information

The terms Danger, Warning, and Caution are used throughout this manual to point out hazards, and to designate a degree or level of seriousness. Familiarize yourself with their definitions and significance.
Hazard is defined as a source of potential injury to a person.
DANGER indicates an imminent hazard which, if not avoided, will result in death or serious injury.
WARNING indicates a potential hazard or unsafe practice which, if not avoided, could result in death or serious injury.

CAUTION indicates a potential hazard or unsafe practice which, if not avoided, could result in minor personal injury or product/property damage.
NOTE provides application tips or other useful information to assure that you get the most from your equipment.
Additional safety messages that provide appropriate safe operation information may be found throughout this manual.

Warning
KAI 12L analysis program may occasionally not correctly interpret an ECG. The ECG tracing is significant only when interpreted in conjunction with clinical findings. Thus, it is critical that a physician utilizes their best clinical judgment when reviewing the ECG interpretation

Warning
INTERPRETATION HAZARD: The automated ECG analysis results are provisional and must be reviewed by a qualified physician capable of independently interpreting the ECG signal in the context of the patient condition. The provisional automated ECG analysis program may then be

confirmed, edited, or deleted by a qualified physician. ECG analysis should be used only as an adjunct to clinical history, symptoms, and the results of other non-invasive and or invasive tests

Warning
The **provisional automated ECG analysis** should not be used for clinical action if it has not been reviewed by a qualified healthcare professional capable of independently interpreting the ECG signal.

Warning
INTERPRETATION HAZARD: KAI 12L may fail to detect or misidentify conduction pacing and demand pacing. Always review and interpret ECG results in conjunction with clinical presentation, patient history, and other available diagnostic information. If a paced rhythm is suspected clinically, consider additional evaluation irrespective of the KAI 12L result

Warning
INTERPRETATION HAZARD: KAI 12L does not detect sinus pause nor does it provide a determination of an abnormally short PR interval. Always review and interpret ECG results in conjunction with clinical presentation, patient history, and other available diagnostic information. If a sinus pause or short PR interval is suspected clinically, consider additional evaluation irrespective of the KAI 12L interpretation result (including using KAI 12L's ECG measurements as appropriate).

ECG Input Requirements

KAI 12L is compatible with a standard diagnostic bandwidth ECG that utilizes standard 'wet' Ag/AgCl electrodes with conductive gel/paste to record an ECG. This ECG may be a full 12-lead or a reduced lead ECG but regardless of what was originally recorded, KAI 12L only requires one of the two lead-sets, either Lead Set 1 {I, II, V2, and V4}, or Lead Set 2{I, II, V1, and V4}. The Lead Set 1 {I, II, v2, v4} is the default and has the best balance of performance across all determinations. In specific situations where the user requires a focus on atrial and right ventricle related determinations (e.g., atrial fibrillation (AFIB), atrial flutter (AFLUT), right ventricle hypertrophy (RVH), right atrial enlargement (RAE)), the Lead Set 2 {I, II, v1, v4} provides slightly improved performance as compared to Lead Set 1. Please refer to the Physician's Guide for additional discussion on the choice of the Lead Set and Analysis Mode.

Compatible ECG devices

Based on validation data, KAI 12L is compatible with resting ECGs from GE Medical Systems® (e.g., MAC1200, MAC 1600, MAC 5500, MAC5500HD, MACVU, MAC VU360, MAC-PC, etc.) and AliveCor's Kardia 12L ECG devices.

Physician's Guide for KAI 12L

KAI 12L Operating principle and detailed design

KAI 12L is a software library written in C++ that provides various ECG analysis capabilities. The KAI 12L is distributed as a precompiled library for Posix-compatible platforms. AliveCor incorporates KAI 12L into compatible devices by statically linking the KAI 12L library to the target device software. This linking is performed per standard software methods used to link with API libraries. In operation, the target devices call methods in the KAI 12L library as needed to process and analyze ECGs. The KAI 12L library provides the result of the requested analysis by subsequently responding to the called API method. The target devices also provide the user interface and display for KAI 12L's analysis. KAI 12L does not have its own user interface and cannot be called or otherwise accessed by an end user directly.

KAI 12L analyzes ECG data recorded using 'wet' Ag/AgCl electrodes with conductive gel/paste from diagnostic bandwidth ECG acquisition units that can provide 4-leads of ECG data from either of two lead sets: lead set 1 {I, II, v2, v4} or lead set 2 {I, II, v1, v4}. For all the algorithm determinations, only measured leads and derived standard limb leads {III, aVR, aVL, aVF} are used and the synthesized leads are not used. The data is processed through various internal algorithms that are developed using machine learning principles. For each lead set, KAI 12L produces the rhythm and morphological determinations as well as ECG interval estimates as noted below. For the rhythm and morphological determinations, KAI 12L provides two modes of results, one with determinations optimized for specificity ("Asymptomatic Mode"), and another optimized for sensitivity ("Symptomatic Mode").

Note that the device provides Symptomatic and Asymptomatic output for each ECG and it is up to the target software to define which mode is shown to the healthcare professional. However, AliveCor recommends that the choice of Lead Set and Analysis Mode utilize the patient clinical presentation, as shown in **Table 13** below.

Table 13: Choosing the Lead Set and Analysis Mode based on clinical presentation

	Analysis Mode	
Lead Set	**Asymptomatic**	**Symptomatic**
Lead Set 1 {I, II, V2, V4}	Standard physical exams	Patient presenting with symptoms of ischemia or infarction such as chest pain
Lead Set 2 {I, II, V1, V4}	Standard rhythm screening	Patient presenting with palpitations

In essence, choose Lead Set 1 as the default option since it is most balanced for both morphology and rhythm determinations. However, use Lead Set 2 if the focus is on rhythm since lead V1 usually carries more P wave information than lead V2. Choose to record both Lead Sets one after another to get a more complete picture of the patient. Based on the clinical presentation, choose

the Symptomatic Analysis Mode if the patient presents with palpitations, or symptoms of ischemia or infarction such as chest pain. Choose Asymptomatic Mode for standard screening and exams.

Physicians and other healthcare professionals access KAI 12L through the target software. This may be within the ECG recording device itself or as an independent analysis software program that aggregates ECGs from various devices. This guide is intended to help the health care professionals understand the intended use of the device, explain how the device works, and how to use the output. Please refer to the target device user manual for user interface instructions.

All outputs of the subject device must be overread by a qualified physician capable of independently interpreting the ECG signal in the context of the patient's condition. The automated analysis may then be confirmed, edited, or deleted by a qualified physician. ECG analysis should be used only as an adjunct to clinical history, symptoms, and the results of other non-invasive and/or invasive tests.

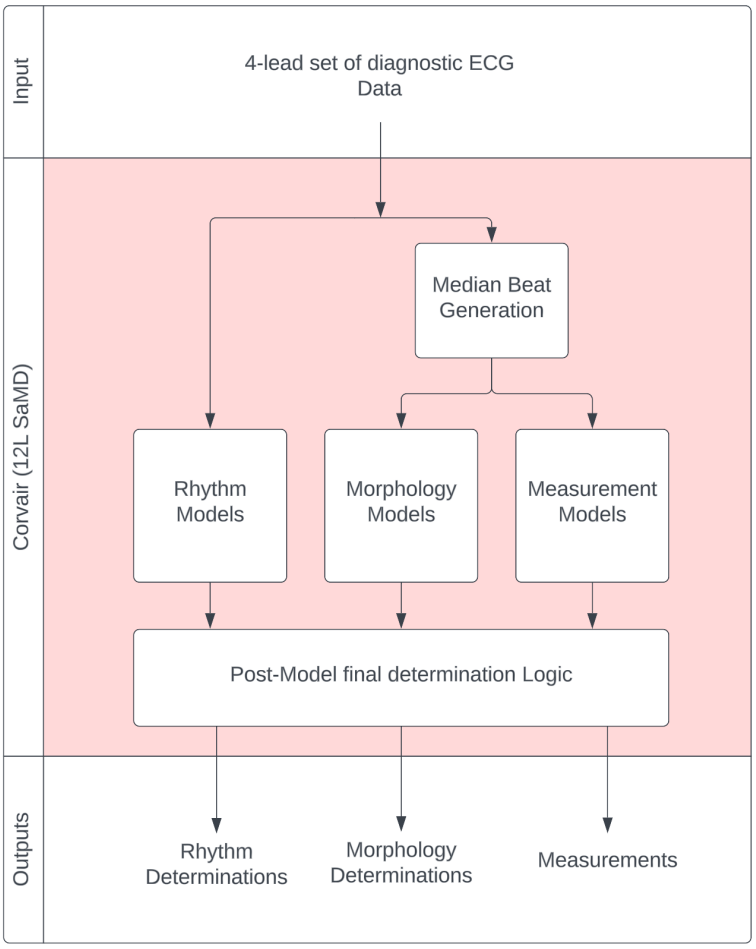


Figure 13: KAI 12L's internal structure

The figure above shows KAI 12L's internal structure and a brief summary of the analysis sequence is provided below:

- Lead computation: Using Leads I and II provided in the input, KAI 12L computes Leads III, aVL, aVR, and aVF using standard formula for such lead computation.
- Rhythm analysis: Determination of rhythm proceeds in two steps, one an analysis by the Rhythm DNN, a neural network that makes an initial determination of the 15 rhythms that KAI 12L provides. These determinations are optimized using the information from the post analysis in the final determinations step (below).
- Median beat generation: The median beat is computed by detecting all the QRS locations in the ECG and computes the median of all the dominant types of beats in the ECG. This type of median beat is traditionally used in ECG signal analysis to reduce noise.
- Morphology analysis: Morphological analysis is performed on the median beat using a deep neural network (DNN). It is designed to classify the 21 morphology determinations noted in the table below. The DNN uses 8 median beat signals, i.e., the 4 leads from the input and 4 computed leads. The final morphology determinations are generated from the morphology post analysis (below).
- Interval measurements: For interval analysis, a DNN similar to the morphological analysis is used. The final output classification is optimized for the three intervals, PR, QRS, and QT. Note that the interval analysis is intended to provide an interval based on all leads, i.e., KAI 12L produces a global interval by incorporating all measured and derived leads.
- Axis measurements: Frontal plane axes are calculated for the: P, QRS, and T waves using leads I, II, and derived leads: III, aVR, aVL, aVF.
- Final determinations: The final determinations/interpretations of KAI 12L are based on the results of all the DNN analyses and the interval and axis measurements noted above. The final determinations use several logical corrections or exclusions based on cardiology science and clinical practice. For example, if a pacing is detected, then a sinus rhythm determination is skipped. Additionally, thresholds developed during training are applied to output of the DNNs to define the Asymptomatic Mode and Symptomatic Mode determinations. Note that the device provides both output modes for each ECG input. It is up to the calling device to decide which modes should be displayed to the HCP based on the clinical context of use.

Each of the DNNs used for rhythm, morphology, and interval analysis is described further in the following section.

Table 14: Summary of KAI 12L Output Information

#	Output Information	Description
1	Rhythm determinations	Major rhythm types · Normal Sinus Rhythm · Sinus rhythm · Atrial fibrillation · Atrial flutter · Paced rhythm · Junctional rhythm · Bigeminy Rhythm modifiers · 1st degree AV block · High degree AV block (including 2nd and 3rd degree AV blocks) · Sinus Arrhythmia · Marked Sinus Arrhythmia · Marked bradycardia (Sinus Rhythm, Bradycardia) · Sinus Tachycardia (Sinus Rhythm, Tachycardia) · PVCs Rhythm modifiers included with KAI 12L v2 · Short PR Interval · Ventricular Bigeminy · Atrial Bigeminy

2	Morphological determinations	· Intraventricular block
		  o Right bundle branch block (RBBB)
		  o Left bundle branch block (LBBB)
		  o Other Intraventricular block
		· Hypertrophy
		  o Left Ventricular Hypertrophy (LVH)
		  o Right Ventricular Hypertrophy (RVH)
		· Atrial enlargement
		  o Left Atrial Enlargement (LAE)
		  o Right Atrial Enlargement (RAE)
		· Old/previous myocardial infarction
		  o Anterior MI old
		  o Inferior MI old
		  o Lateral MI old
		· Recent/Acute myocardial infarction
		  o Anterior MI acute
		  o Inferior MI acute
		  o Lateral MI acute
		· Ischemia
		  o Anterior Ischemia
		  o Inferior Ischemia
		  o Lateral Ischemia
		· Prolonged QT
		· Paced ECG
		
		· Other morphological defects
		  o Early Repolarization
		  o Wolff-Parkinson-White (WPW) Syndrome
		
		· Normal or otherwise normal
		· Left Axis Deviation (KAI 12L v2 determination)
		· Right Axis Deviation (KAI 12L v2 determination)

3	Interval estimations	PR interval QRS duration QT interval Heart-rate corrected QT (QTcB, and QTcF) Heart rate
4	Axis measurements	P axis QRS axis T axis

Note: A detailed discussion of KAI 12L's methods and performance is provided in the Appendix section below.

Rhythm, Morphology, and Interval Analysis

General DNN Model Structure

All classification DNN models used in the analysis have a general structure as shown in Figure 14. The models consist of 4 major blocks:
1. Lead formation layer, which reformats input leads of signals, 4 for the current models, to the format needed for the model training.
2. Convolution layers, which include 5-8 CNN blocks with different numbers of filters for each block.
3. Dense layers, which first reshape the multi-filter output of the final CNN layer to a flattened layer and pass the results to the next dense layers with full connections, meaning each unit of the previous layer is connected to all units of the next layer.
4. Classification layer, which generates a probability for each determination.

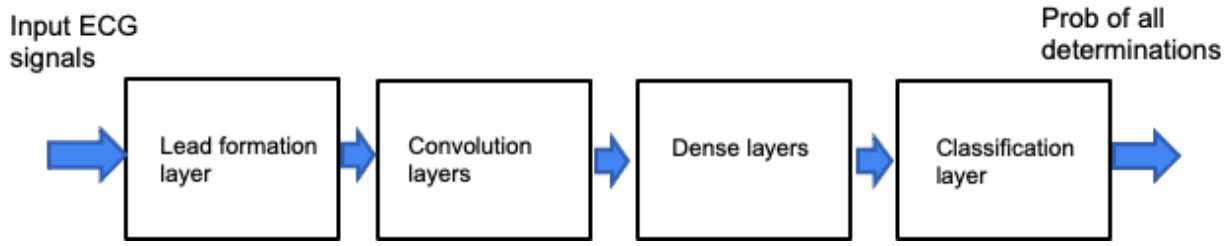


Figure 14: The General DNN structure for Rhythm and Morphology Classifications

Final ECG Determinations/Interpretations Overview

ECG final determinations/interpretations of KAI 12L are mainly based on the results of DNN models, as shown in Figure 15. Some simple logic is added by combining the interval and axis measurements to make correct exclusions/inclusions based on the cardiology science and clinical practice. This logic is very different from the expert criteria used in other 12-lead ECG interpretation algorithms. The ECG measurements are used with relatively relaxed thresholds. There are two final analysis modes used: Asymptomatic (default), and Symptomatic.

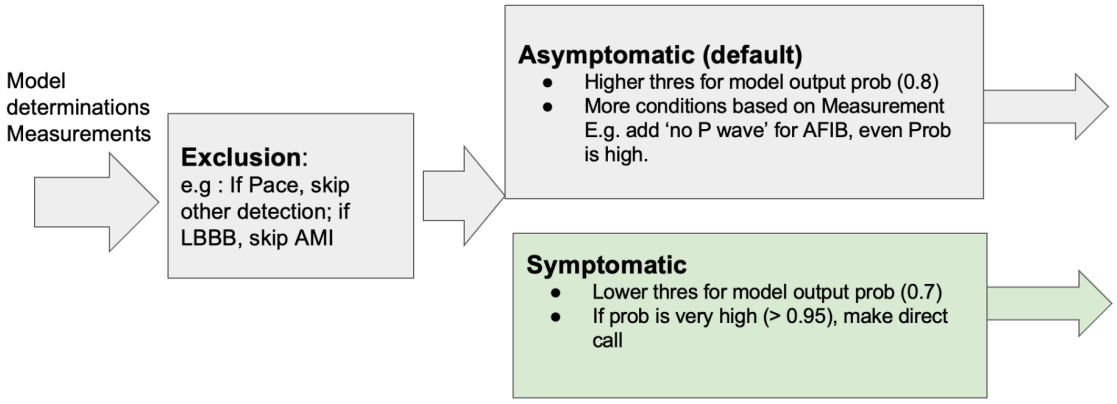


Figure 15: The flowchart of ECG final determinations/interpretations of KAI 12L

The first task of the final analysis is about exclusion under various conditions. Since both the rhythm and morphology DNN models are trained for nonexclusive multi-class classifications, it is possible that multiple abnormalities can be identified. In some cases, multiple abnormal conditions can happen for the same ECG, like ischemia of infarction, or bundle branch blocks and ischemia. But in some other cases, especially in rhythm analysis, certain abnormalities can either affect other one's detection, or they should be mutually exclusive, like Sinus rhythm and AFIB, or Pace rhythm with Sinus, etc.

ECG Rhythm Model

The rhythm DNN model is designed to classify 14 rhythm determinations, see Table 15. The model's inputs are 10-second, 4 leads rhythm signals down-sampled to 150 Hz. 9.5 seconds out of 10 seconds of data is used for the input to allow 0.5 seconds of data as a need for augmentation with a time-shifting training. The convolution network block consists of a special structure similar to Resnet which uses a combination of a convolution layer and a skip layer. There are 6 Resnet blocks, followed by 2 dense layers, and 1 output layer. The output layer generates probabilities for each determination. The batch normalization layer and dropout layer are used for every Resnet block and dense layer to improve the robustness or generalization of the trained model.

Table 15: Rhythm determination/interpretation list

Order	Determinations
1	Normal Sinus Rhythm
2	Sinus rhythm
3	Atrial fibrillation
4	Atrial flutter
5	1st degree AV block
6	High degree AV block (including 2nd and 3rd degree AV blocks) (Complete AV block)

7	Sinus Arrhythmia
8	Marked Sinus Arrhythmia
9	Paced rhythm
10	Marked bradycardia
11	Junctional rhythm
12	Sinus Tachycardia
13	Bigeminy
14	PVCs

ECG Morphology Model

The Morphology DNN model has a similar model structure to the Rhythm DNN model, but with a smaller input layer and fewer Resnet layers, since the median beats have a much shorter length than rhythm's 10 seconds. Also, all median beats are relatively aligned around their Another important design consideration for the Morphology model QRS region, so that the variations along the time axis are relatively smaller than rhythm signals. The main variations the DNN model needs to capture are morphology changes for each lead and relative changes from lead to lead, the so-called spatial domain.

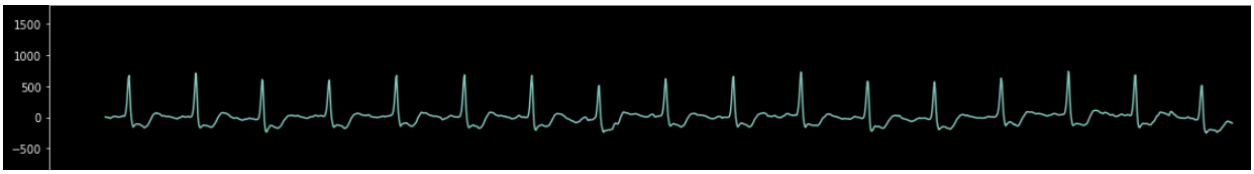
In order to capture the spatial domain changes, an ECG imaging is formed by the layout of all leads in a 2-D matrix/image pattern with X-axis as time and the Y-axis as a lead order of [aVL, I, -aVR, II, aVF, III, v2, v4], where the limb leads are reordered in so-called Cabrera sequence. The 2-D ECG signal matrix can be processed with a 2-D convolutional filter as in image classification cases. Therefore, 2-D convolutional modes are applied to this ECG image input.

Median beats generation: The median beats are generated from the rhythm signals with the following steps:

1. Form a QRS detection function
2. Beat detection and classification
3. Beat alignment
4. Calculating median and average beats from the dominant beat type

Figure 16 shows an example of an ECG rhythm signal and its median beat. Here the ECG morphology features are captured in the median beat while the data length is much shorter.

(a)



(b)

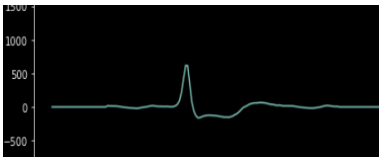


Figure 16: An example of ECG rhythm data (a), and its median beat (b)

The Morphology DNN model has a similar structure to the Rhythm model. It is designed to classify 21 morphology determinations as shown in Table 16. The model's inputs are 1.2-second, 4 leads median beat signals + 4 derived limb leads. The convolution network block consists of 2-D convolution filters to process ECG images.

Table 16: Morphology model determination list

Order	Determinations
1	Right bundle branch block (RBBB)
2	Left bundle branch block (LBBB)
3	Other Intraventricular block
4	Left Ventricular Hypertrophy (LVH)
5	Right Ventricular Hypertrophy (RVH)
6	Left Atrial Enlargement (LAE)
7	Right Atrial Enlargement (RAE)
8	Anterior MI old
9	Inferior MI old
10	Lateral MI old
11	Anterior MI acute
12	Inferior MI acute
13	Lateral MI acute
14	Anterior Ischemia
15	Inferior Ischemia
16	Lateral Ischemia
17	Early Repolarization
18	Prolonged QT
19	Paced ECG
20	Wolff-Parkinson-White (WPW)

21	Normal or Otherwise Normal ECG
22	Left Axis Deviation (KAI 12L v2 determination)
23	Right Axis Deviation (KAI 12L v2 determination)

Interval Analysis (ECG global measurements)

PR interval, QRS duration, QT Interval, and heart rate are the group of ECG global measurements. They are called 'global' because the measurements are not lead-specific, and most time they are estimated based on a combination of multiple leads (Kligfield et al., 2014; P et al., 2018) (J. Q. Xue, 2009). In KAI 12L, 4 leads are used for estimating the global measurements. These parameters are usually detected with complicated signal processing and feature detection algorithms based on domain knowledge. We decided to estimate these three ECG parameters using a deep learning model applied to the ECG median beat signals generated from raw ECG waveform. The premise is that these parameters are closely related to ECG morphology and therefore a network can be trained to perform a regression of the raw ECG on the target intervals as determined by experts. Another aim of the model training is to also be able to identify the absence of a valid P wave as in atrial fibrillation cases.

Model and algorithm design: The lead set [I, II, v2, v4] is used, and the median beats are formed for each lead. For the 1st step, the similar deep Learning model structure used for the morphology classification. The final classification layer of the model is then replaced by a regression layer and was trained to output three intervals: PR interval, QRS duration, and QT interval by minimizing the absolute error between the physician-estimated intervals and the model-estimated intervals. An external test evaluation was performed on the ECG Standard CSE test data set of 100 ECGs.

Prepare for Final ECG Determination/Interpretations

Up to this point, we have already generated all Morphology and Rhythm results, but these results are in a probability range between 0-1. That's how we can generate the Area-Under-the-Curve (AUC) by setting the final determination threshold. However, there are several reasons why we need to take another step to get to the final determinations.

Firstly, we need to convert the probability values to 'Yes' or 'No' as it is done in clinical practice.

Secondly, in multi-class classifications, the results are not exclusive to each other, unlike categorical classification where only one out of many is chosen. For ECG classifications, especially in morphology classifications, multiple conditions can coexist. However, in this type of non-exclusive multi-classification, we need to sort out certain exclusive cases or intentionally 'suppress' certain determinations under special conditions. For example, in Rhythm

determination, we would make Pace rhythm, Sinus rhythm, and AFIB exclusive, meaning if one is detected with high probability, like Pace rhythm, then the final analysis will suppress Sinus rhythm and AFIB, etc. In Morphology analysis, if Pace ECG is detected, then we will suppress LBBB, RBBB, and infarction. The main reason for these exclusions is not that certain determinations cannot coexist, but rather to avoid false positive determinations.

Thirdly, we would like to make two final 'Yes' or 'No' determinations biased towards higher sensitivity or higher specificity. The purpose is to let users choose the right mode in different situations. For example, in regular hospital checks, Asymptomatic mode can be chosen to reduce false positive cases, especially for some determinations like Acute MI and Ischemia. While in other situations, like in a chest-pain clinic, the Symptomatic output can be chosen to increase the detection of MI and ischemia for those who already have symptoms like chest pain and shortness of breath. Please refer to **Table 12** for additional guidance on selecting the appropriate Analysis Mode based on patient clinical presentation.

In order to make final analysis more effective and to add some transparency to the model analysis, a set of ECG lead-by-lead measurements are also calculated, which include amplitude, duration, and area of P,Q-R-S-ST-T components.

A final analysis diagram is shown in Figure 17, which shows that some exclusion conditions can be set for different determinations, and different thresholds can be applied for the 2 analysis modes.

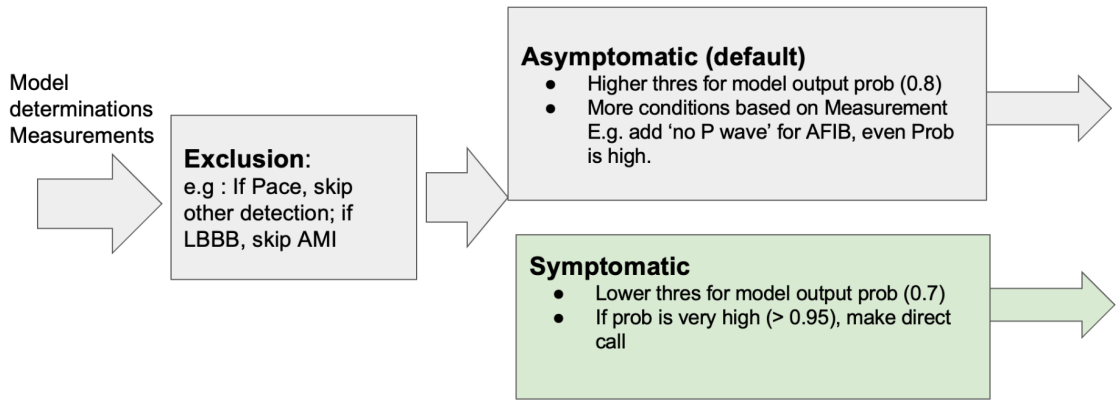


Figure 17: Final Analysis diagram

Before we introduce more details of the final analysis for each determination, it is very important to point out that the criteria used for the final determinations are very different from those algorithms which are based on clinical expert criteria. As stated above, the purpose of the final analysis is to further enhance the DNN model results and to add some transparency when needed.

Rhythm Final Determinations

The main purpose of the rhythm model's final determination function is to find a dominant rhythm from the following list:

1. Paced rhythm
2. Sinus/Normal Sinus
3. Atrial fibrillation
4. Atrial flutter
5. Wide QRS tachycardia
6. Junctional rhythm
7. Short PR Interval*
8. Atrial Bigeminy*
9. Ventricular Bigeminy*

KAI 12L v2 determination

If the dominant rhythm is Sinus rhythm, then try to find the associated modifiers like Sinus arrhythmia, 1st degree AV block, etc.

The input parameters for the final Rhythm determination are as follows:

1. The output of rhythm DNN model
2. The global ECG measurements: HR, PR, QRSD, QT
3. R-R interval sequence of the dominant beats

All rhythm detections are made in 2 modes: Asymptomatic, and Symptomatic as introduced above. The dominant rhythm is confirmed in the following sequence:

Pace rhythm: The main logic for the pace rhythm is shown below. Here the main parameter is the Pace probability of the rhythm DNN model.

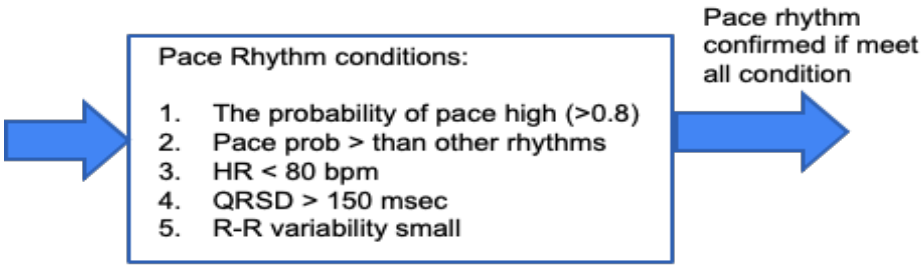


Figure 18: Pace Rhythm conditions

If pace rhythm is confirmed, then skip following rhythm checks.

Sinus/Normal Sinus rhythm: For sinus/normal Sinus rhythm confirmation, there are special points :

1. The specificity and sensitivity settings are opposite from other abnormal rhythms since a high specificity setting for abnormal rhythm also means a higher sensitivity setting for the Sinus rhythm
2. To emphasize the high specificity, Sinus rhythm is confirmed before other abnormal rhythms, except Pace rhythm.
3. If the rhythm DNN model has a very high probability of sinus/normal sinus, the confirmation is made without other conditions.

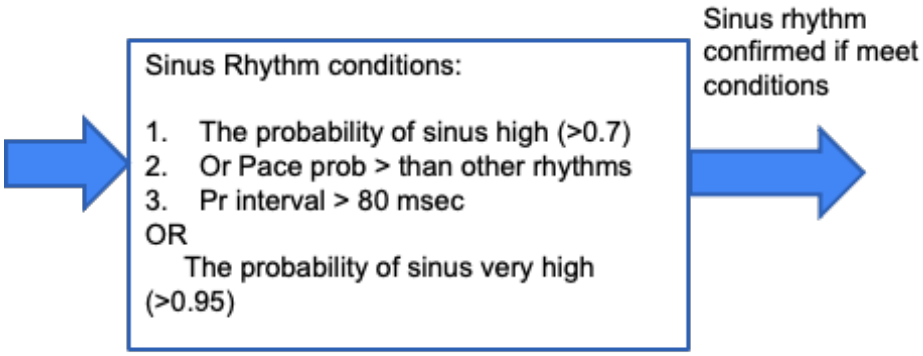


Figure 19: Sinus Rhythm conditions

Atrial fibrillation / Atrial Flutter rhythm: For AFIB/AFLUT detection, besides the requirement of the high probability, no valid P wave is also a condition.

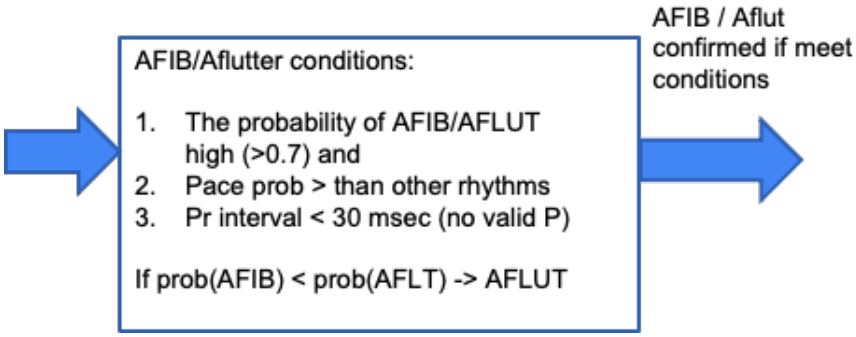


Figure 20: AFIB/Aflutter conditions

Junctional rhythm: After ruling out all other dominant rhythm, Junctional rhythm is checked with the condition:

1. High prob of Junctional rhythm from the rhythm DNN model
2. Low R-R variation

The regulation of P wave detection is used to rule in and out for Junctional Rhythm. Considering the P wave is estimated from the DNN model, the range of valid PR interval is adjusted to maintain the balance of the sensitivity and the specificity.

Final confirmation of the dominant rhythm: This section is served when no other dominant rhythms are confirmed. Then to check if it is a possible sinus rhythm by using a relatively relaxed condition:

1. Lower the threshold for Prob of Sinus to 0.6 and with a valid P wave
2. All global measurements are in normal range: PR [120, 200], QRSD < 115, QTcF < 460msec

Confirmation of Arrhythmia with Sinus Rhythm: After the Sinus rhythm is determined, following associate arrhythmias are checked:

1. Atrial-Ventricular Conduction Block (AVB):
    1. The 1st degree AVB : conditions: a. high 1st AVB probability, b. PR interval > 220 msec
    2. The 3rd degree AVB: conditions: high 3rd degree prob, and the prob > other arrhythmia prob.
    3. NOTE: KAI 12L currently does not detect 2nd degree AV Block.
2. Sinus bradycardia: High prob of bradycardia, and HR < 60 bpm
3. Sinus Tachycardia: High prob of tachycardia, and HR > 100 bpm
4. Marked (severe) Sinus arrhythmia: High prob (> 0.8) of marked sinus arrhythmia.
5. Sinus arrhythmia: High prob (> 0.8) of sinus arrhythmia.

Other determinations like Premature Ventricular Complex (**PVC**), **Bigeminy** are classified based on the Rhythm DNN model's output with a high probability > 0.8 for the Asymptomatic mode, and 0.7 for the Symptomatic mode.

Note: No PAC or other forms of supraventricular ectopy are identified.

KAI 12L v2 determinations are classified based on the following:

1. Short PR Interval: Short PR is called if the PR Interval is < 123 msec.
2. Ventricular Bigeminy: Ventricular Bigeminy is called if the DNN Bigeminy probability is > 0.95 and a PVC pattern is found.
3. Atrial Bigeminy: Atrial Bigeminy is called if the DNN Bigeminy probability is > 0.05 and a PVC pattern is not found.

Morphology Final Determinations

The main purpose of the Morphology final determinations is to improve the specificity of major morphology abnormal determinations. The DNN morphology classification model also works in a nonexclusive mode, meaning multiple abnormal conditions can be called for the same ECG. Although multiple conditions can happen physiologically, it might be helpful to focus on the main source of an abnormal condition, instead of multiple sources.

For example, in Acute myocardial infarction (Acute MI) interpretations, adding ST segment changes on top of the DNN model probability is a way to improve specificity. But if the bundle branch block, especially the left bundle branch block (LBBB) is confirmed, then the ST segment deflection can be secondary due to depolarization change, which can be difficult to differentiate from primary repolarization. Therefore, Acute MI final determination is ruled out if LBBB or Pace ECG is confirmed.

The morphology final determinations run in following order:

1. Pace ECG
2. RBBB
3. LBBB
4. Other Intra-Ventricular Blocks
5. LVH
6. RVH
7. Old MI
8. Acute MI
9. Other ST Elevation (Early Repolarization)
10. Ischemia
11. Long QT
12. WPW
13. Atrial enlargement
14. Normal ECG
15. Left Axis Deviation
16. Right Axis Deviation

All conditions listed below are generally applied for both the Symptomatic and the Asymptomatic modes, only thresholds are relatively different.

Pace ECG: Pace ECG is confirmed with the results from both the Morphology and the Rhythm DNN models. The Pace ECG is called if:

1. The Probs. Of Rhythm model and Morphology model all very high (> 0.95), and
2. R-R beat variations is small (RR_std / RR_mean < 0.04)

If Pace ECG is confirmed, skip all other final confirmations.

RBBB/LBBB/Other Block

The final confirmation of RBBB is made, if:

1. The Prob. of RBBB is high (> 0.8) , and
2. QRS duration > 120 msec

Or

1. The Prob. of RBBB > 0.95, and
2. QRS duration > 110

If RBBB is confirmed, bypass LBBB and other Block's confirmations.

The final confirmation of LBBB is made, if:

1. The Prob. of LBBB is high (> 0.8) , and
2. QRS duration > 125 msec

Or

1. The Prob. of LBBB > 0.95 , and
2. QRS duration > 115 msec.

If LBBB is confirmed, bypass other Block's, Acute MI, Ischemia's confirmations.

Other Intraventricular block is confirmed, if:

3. The Prob. of Other BBB is high (> 0.8) , and
4. QRS duration > 115 msec

Or

3. The Prob. of Other BBB > 0.90 , and
4. QRS duration > 110 msec.

Note: LAFB, LPFB not identified

LVH/RVH: LVH determinations usually need to use some ECG amplitude measurements. But since only 2 precordial leads are used, and the ECG is more aggressively low pass filtered, the conventional amplitude criteria for LVH are not directly applied. Instead, the DNN model output is used, plus some minimum amplitude and axis measurements checks.

The final confirmation of LVH is made, if:

1. The Prob. of LVH is very high (> 0.99)

Or

2. The Prob. of LVH is high (>0.9) and
3. One of the V leads has QRS deflection > 2500 uV, or R_aVL > 1000 uV

The final confirmation of RVH is made, if:

1. The Prob. of LVH is very high (> 0.9)

and

2. QRS axis > 90 degrees

Note: ST/T patterns associated with LVH or RVH not identified. If LVH is identified, it can suppress identification of T-wave patterns that appear due to ischemia and not strain.

Acute MI: Acute Mis, including all localized calls, Anterior, Inferior, Lateral, and Septal are important determinations. There are several challenges associated with acute MI determinations:

1. Low prevalence compared to other abnormal ECGs, even in large ECG training and testing databases.
2. The balance of sensitivity and specificity. The DNN model's acute MI determination is more on the 'high sensitivity' side, if a regular threshold like 0.5 is used. But it is most likely too sensitive for use in a relatively low prevalence clinical practice. Therefore, the focus is on improving the specificity to reduce false positive cases.
3. Since there are only 2 precordial leads, all ECG measurements associated with Acute MI like ST segment, T wave need to be used cautiously. Like in LVH determination, conventional criteria of acute MI are not directly applied. Therefore, The DNN model results are the main reference, and other measurements are used as needed.

Acute Anterior MI is confirmed with following conditions:

1. The Prob. of Acute Anterior MI is very high (> 0.95) , and
2. At least one of V lead ST > 200 uV, ST/T ratio > 0.3, and
3. At least one of the reciprocal lead (limb leads) ST < -50 uV (ST depression)

Or

4. The Prob. of Acute Anterior MI is very high (>0.99) and
5. At least one of V lead ST > 160 uV, ST/T ratio > 0.3

Acute Inferior MI is confirmed with following conditions:

1. The Prob. of Acute Inferior MI is very high (> 0.95) , and
2. At least one of the inferior lead ST > 100 uV, ST/T ratio > 0.3

Or

3. The Prob. of Acute Inferior MI is very high (>0.99) and
4. At least one of the inferior lead ST > 60 uV, ST/T ratio > 0.3

Acute Lateral MI is confirmed with following conditions:

1. The Prob. of Acute lateral MI is very high (> 0.95) , and
2. At least one of the lateral lead (I, aVL) ST > 100 uV, ST/T ratio > 0.3

Or

3. The Prob. of Acute lateral MI is very high (>0.99) and
4. At least one of the lateral lead ST > 60 uV, ST/T ratio > 0.3

Previous Myocardial Infarction (Old MI): In order to make a more specific call of old MI, this version excludes cases of detected Pace ECG, LBBB/RBBB, LVH/RVH.

For all old MI calls including anterior, inferior, lateral, the following general rules applied:

1. The Prob. of old MI is very high (> 0.90) , and
2. There are significant Q waves in the corresponding lead groups.

Ischemia: The exclusions for all Ischemia calls include Pace ECG, LBBB/RBBB, LVH/RVH, Acute MI, Pericarditis, Early Repolarization.
For all ischemia calls including anterior, inferior, and lateral, the following general rules applied:

1. The Prob. of Ischemia is very high (> 0.90 for the Asymptomatic mode, > 0.8 for the Symptomatic mode) , and
2. There are significant ST depressions (< -100uV for the Precordial leads, < -50 uV for Limb leads) corresponding to the specific location calls in the leads' groups: Anterior leads: ST in V2, V4; Inferior leads: II, III, aVF; lateral leads: I, aVL.
3. Or there is T wave inversion (< -100 uV)

Nonspecific ST/T abnormality is not part of the determination, although the models would classify significant ST/T abnormality into the Ischemia group.

Prolonged QT : The exclusion conditions for Prolonged QT are Paced ECG, and Heart Rate > 120 bpm

The conditions to call prolong QT are:
Asymptomatic mode:

1. The Prob. of Long QT is high (> 0.8) , and
2. QTcF (Corrected QT interval by Fridericia formula) > 460 msec

Symptomatic mode:

QTcF (Corrected QT interval by Fridericia formula) > 450 msec

Left Axis Deviation (KAI 12L v2 determination):

Left Axis Deviation is called if the QRS axis is < -30 degrees.

Right Axis Deviation (KAI 12L v2 determination):
Right Axis Deviation is called if the QRS axis is < 250 degrees and >/= 95 degrees.

Normal (possible) ECG: The criterion for normal ECG is less dependent on the results of DNN models compared to other abnormal determinations. It is more dependent on ruling out any abnormal condition detection.

The criteria are:

1. No abnormal morphology conditions listed above are detected
2. Sinus rhythm
3. Heart rate is higher than 50 bpm, and lower than 90 bpm
4. QRS duration is not wider than 120 msec
5. PR interval is smaller than 230 msec
6. QTcF < 460 msec
7. P, QRS, T axes all larger than 0

Performance Table:

Table 17: Performance table

Rhythm	Acceptance Criteria (%)		KAI 12L v2 (Mayo 500K Validation)			KAI 12L v2 (Mayo New 100K Validation)		
	Sens.	Spec.	Sens.	Spec.	PPV	Sens.	Spec.	PPV
High Degree AV Block, Asymptomatic Mode, Leadset: {I, II, V1 V4}	40	95	48.1	99.4	18.3	50.8	98.3	57.6
High Degree AV block, Symptomatic Mode, Leadset: {I, II, V1 V4}	45	95	64.4	99.3	18.2	66	99.3	17.5
High Degree AV Block, Asymptomatic Mode, Leadset: {I, II, V2 V4}	30	95	35.2	99.2	10	33.5	99.2	8.9
High Degree AV block, Symptomatic Mode, Leadset: {I, II, V2 V4}	35	95	50.1	98.9	10.7	47.1	98.9	9.2
Atrial Flutter, Asymptomatic Mode, Leadset: {I, II, V1 V4}	60	95	62.1	99.5	67.6	58.4	99.4	63.5
Atrial Flutter, Symptomatic Mode, Leadset: {I, II, V1 V4}	60	95	55.7	99.3	58.1	51.6	99.3	55.1
Atrial Flutter, Asymptomatic Mode, Leadset: {I, II, V2 V4}	35	95	39.4	99.2	47	37.6	99.2	8.9
Atrial Flutter, Symptomatic Mode, Leadset: {I, II, V2 V4}	35	95	34.8	99	37.9	33	99	36.3

Rhythm	Acceptance Criteria (%)		KAI 12L v2 (Mayo 500K Validation)			KAI 12L v2 (Mayo New 100K Validation)		
	Sens.	**Spec.**	**Sens.**	**Spec.**	**PPV**	**Sens.**	**Spec.**	**PPV**
Sinus Rhythm with marked bradycardia, Asymptomatic Mode, Leadset: {I, II, V1 V4}	30	95	96.1	97.1	50.6	96.7	96.9	50.6
Sinus Rhythm with marked bradycardia, Symptomatic Mode, Leadset: {I, II, V1 V4}	80	95	92.5	95.4	38.5	92.6	95.3	39.2
Sinus Rhythm with marked bradycardia, Asymptomatic Mode, Leadset: {I, II, V2 V4}	30	95	95.8	97.10	50.8	96.1	96.9	50.8
Sinus Rhythm with marked bradycardia, Symptomatic Mode, Leadset: {I, II, V2 V4}	80	95	92.8	95.4	38.7	92.7	95.3	39.3

Implementer Guide

Compatibility

KAI 12L is currently compatible for operation on POSIX compliant systems running CLANG 14.0. Please check with AliveCor for the latest list of compatible platforms.

Interface Specifications

The KAI 12L provides functionality that is called through an application programming interface (API). KAI 12L provides the following electrocardiogram (ECG) processing and algorithmic analysis functionality through its API. The interface is defined in a C++ header file, SaMD_12L.h.

The following are key aspects of the API:

- *SaMD12L class:* This is the main C++ class used to analyze an ECG and to make a classification determination from sample data.
- `SaMD12L::analysisFromSamples`: This is the main KAI 12L method that runs algorithms when provided ECG recording samples and lead set selection. It responds with a vector of binary determinations (i.e. classifications) and global interval measurements that a target device software can display. The method takes in ECG samples and lead set selection. A status of whether the method executed successfully is also provided.
- `Status` *class:* This class represents the state of algorithm execution. If the operation succeeded, code = ok and error_reason = null. If the operation fails, the status code will contain an error code and error_reason will be set to a readable description of the error.
- `AlgorithmResult` *class:* This class holds algorithm evaluation results, which includes vector of rhythm determinations, vector of morphology determinations, hr, pr, qrs, qt, qtcb, qtcf.
- *LeadsSelector enum:* This enum contains 2 possible lead groups (v1v2, v2v4) which may be passed to *analysisFromSamples*.
- *Code enum:* This enum keeps all possible status codes for algorithm execution: Ok, TooShort, TooLong, MedianBeatsError, GlobalQRSError, InternalError.
- *RhythmDetermination enum*: this enum keeps a list of supported rhythm determinations.
- *MorphologyDetermination enum*: this enum keeps a list of supported morphology determinations.

Basic Interaction with API

1. create instance of SaMD12L class
2. create instance of DNNProcessor
3. Call `analysisFromSamples`, providing an ECG signal adhering to the ECG signal below.
4. Check `Status` for successful analysis of ECG
5. Call `AlgorithmResult` to view analysis results

Interface for analysis From Samples

The interface for the single analysis API (`analysisFromSamples`) is defined in a C++ header file, SaMD_12L.h seen below:

```
Status analysisFromSamples(const vector <vector<float>> &samples,
                                    LeadsSelector leads_selector,
                                    DNNProcessor &dnn_processor,
                                    AlgorithmResult &result,
                                    Explanation &explanation)override;
```

Status codes

When checking for progress or status of an analyzed ecg, the possible responses are below:

```
      OK = 0,             // Algorithm ran successfully.
      TooShort,           // Input had less than 9.5s of samples.
      TooLong,            // Input file has more than 9.5 seconds of samples.
      MedianBeatsError, // Medium beats calculation failed.
      GlobalQRSError,   // Medium beats calculation failed.
```

MedianBeatsError is called if identified waveform is too small to process or other error in median beat calculation.
GlobalQRSError is called if RR cannot be calculated, or if QRS cannot be identified.

Algorithm Result class data

A completed ECG analysis will provide the following data:

```
AlgorithmResult {
	vector<int32_t> rhythm_high_spec;
	vector<int32_t> rhythm_high_sens;
	vector<int32_t> morphology_high_spec;
	vector<int32_t> morphology_high_sens;
	vector<vector<float>> median_beats;

	int32_t hr;
	int32_t pr;
	int32_t qrs;
	int32_t qt;
	int32_t qtcb;
	int32_t qtcf;

	map<RhythmDetermination, bool> rhythm_high_spec_map;
	map<RhythmDetermination, bool> rhythm_high_sens_map;

	map<MorphologyDetermination, bool> morphology_high_spec_map;
	map<MorphologyDetermination, bool> morphology_high_sens_map;
};
```

ECG Signal Specifications

The ecg data passed to `analysisFromSamples` as the vector of samples, must come from an ECG signal that has the following signal specifications:

Table 18: ECG Signal Specifications

Attribute	**Specification**
ECG Leads Input	The input should be either a lead set with leads (I, II, V1, V4), or leads (I, II, V2, V4)
Input bandwidth	0.05 Hz to 150 Hz
Input sampling rate	150 samples per second
Sample resolution	5 microvolt LSB resolution
Dynamic Range	+/- 10 mV
Expected Input ECG lengths	9.5 seconds
ECG Signal Filtering	Notch filtered at 50 Hz and 60 Hz, depending on mains frequency

Integration with KAI 12L

Please contact AliveCor for any integration. AliveCor reviews and must approve all integration prior to release.

The KAI 12L API is a C++ library of classes and functions that is intended to be integrated into a target medical device software. The library is provided as a package that includes binary, header files and resources that are needed for the KAI 12L execution.Refer to the comments in the header files that describe how to use each class in this API.

Please note that all ECG analysis and interpretation results produced by this device are analyzed from 4 leads out of a standard, diagnostic 12-lead ECG.

Change Management

AliveCor will provide routine maintenance and verification of software upgrades and patches as it pertains to KAI 12L.

AliveCor reviews the following items to detect cybersecurity issues that have also been incorporated into AliveCor internal policy, GNPOL-0006, Data Security Policies for HIPAA Data, including,

- Monthly monitoring the OWASP (Open Web Application Security Project) Foundation reports for major security issues as part of Security working group meetings. The meeting is meant to assess reported vulnerabilities against a compiled CBOM for the KAI 12L software.
- Review Linux/POSIX security reports for any cybersecurity issues as part of the operating systems validation protocol 00VAP7 for supported versions of the platform

AliveCor will perform a risk assessment of any cybersecurity issues as related to the device risks documented in 34RSK3 and 34RSK7 and determine whether any further action is necessary. These actions include:

- Updates to the KAI 12L libraries, as needed. These will be made and distributed through the trusted target device developers.
- Updates adhere to the same software integrity controls as for a KAI 12L library release, including continuous malware scanning on approved development laptops, peer code review, updated threat modeling as necessary, and signed library validation before release to targeted developers.
- Notification to target device developers of major incidents, and
- Recovery of data, as appropriate, through backups by AliveCor system administrators that are further supported by Software Agreements with target device developers.

AliveCor will partake in security testing on the following schedule:

- Vulnerability Scanning - Quarterly

- Penetration Testing - Bi-annually
- Static/Dynamic Analysis - Per major release

Alivecor Scheduled updates for known Unacceptable Vulnerabilities

- Patch Release:
    - Low/Moderate Severity: Patches bundled and released quarterly
    - High Severity: Accelerated release within 30 days of vulnerability confirmation, with justification based on CVSS score ≥7.0

AliveCor Out-of-Cycle Updates for Critical Vulnerabilities

- Definition: Vulnerabilities scoring CVSS ≥9.0 or posing uncontrolled risks (e.g., remote code execution, unauthorized data access)
- Timeline:
    - Identification to Patch Development: 72-hour SLA for initial assessment and 14-day maximum for validated patch development.
    - Testing & Deployment: 7-day validation period

To ensure compliance with FDA cybersecurity requirements and maintain patient safety, the KAI 12L update process is structured around three pillars: pre-deployment validation, controlled rollout, and transparent customer communication. This protocol adheres to IEC 62304 for medical device software lifecycle management and ISO 14971 for risk mitigation, ensuring patches are secure, reliable, and delivered with minimal disruption. Below is the workflow:

For validation, all patches will undergo:

- Regression testing in a sandboxed environment.
- Feature testing of functionality is thought to interact with changes
- Validation of the vulnerability resolution

Rollout: Staged deployment to implementing partners to monitor stability.

AliveCor Patch Deployment & Communication

Effective and transparent communication is essential to ensure that customers are informed about available updates and patches, and can implement them promptly to maintain device security. Our patch deployment and communication protocols are designed to provide timely notifications and clear instructions for both scheduled and critical updates.

Customer Notification of scheduled patches will follow a 30-day advance notice via email to implementing customers, as well as advisories via the Developer portal, and HCP outreach to high-risk healthcare providers.

Critical patches will be released within 72 hours of validation.

Patches will be provided to implementing customers via a private and secure developer portal.

It is the responsibility of the integration partner to provide routine maintenance and verification of software upgrades and patches for the target device integrating KAI 12L.

Cybersecurity

KAI 12L should only be executed in a trusted environment in which adequate cybersecurity controls have been established by the target medical device. AliveCor includes several cybersecurity protections to prevent unauthorized or inappropriate execution of the library. These measures include:

- AliveCor only distributes KAI 12L as a signed library for specific platforms including POSIX compatible systems such as Linux
- Target device developers will need to be authorized by AliveCor to access the library to statically link KAI 12L into their device.
- AliveCor also performs necessary verification, validation and/or regression testing as necessary, dictated by AliveCor's Software Lifecycle, before releasing KAI 12L to the target device developer. All code in the KAI 12L library undergoes a rigorous review process before being released to approved target developers. That review process includes updating vulnerability assessments of both the KAI 12L and current vulnerability assessments of the operating systems targeted by KAI 12L.
- KAI 12L testing includes specific API parameters checks, fuzz testing of exposed data interfaces and injecting API's with attempted buffer overruns. These checks are to protect KAI 12L functionality, even when the target device's cybersecurity has been compromised.

AliveCor disclosures:
To ensure timely identification and mitigation of cybersecurity threats, we have established a Coordinated Vulnerability Disclosure (CVD) process. This process facilitates secure and transparent communication with external researchers, implementing customers, and other stakeholders regarding potential vulnerabilities. It also ensures that all reports are reviewed and addressed in a timely and systematic manner.

- External Reporting: Dedicated portal for implementing customers, researchers with 48-hour acknowledgment and 15-day triage SLA.
- Internal Escalation: Cross-functional team (engineering, regulatory, QA) reviews critical issues within 24 hours.

Resolution of Identified Cybersecurity Vulnerabilities
To comply with Section 524B(b)(2) of the FD&C Act and FDA guidance, AliveCor will address cybersecurity issues as follows:

1. Percentage of Identified Vulnerabilities Patched (Defect Density)
   - Target: Strive for 95% or higher of critical vulnerabilities patched, with documentation for exceptions (e.g., legacy system limitations)
   - Rationale: While 100% remediation is ideal, practical constraints may necessitate prioritization of critical risks.
2. Duration from Vulnerability Identification to Patch
   - Critical Vulnerabilities: Patch within 30 days of identification, as per NIST guidelines and FDA expectations for urgent risks

- Non-Critical Vulnerabilities: Address within 90 days, aligning with NIST's outer limit for standard patches.

3. Duration from Patch Availability to Field Implementation
   - Critical Patches: Implementor Deployment to 90% of deployed devices within 60 days of patch release.
   - Non-Critical Patches: Implement within 90 days, ensuring alignment with routine update cycles.

To meet FDA guidance for aggregated data, AliveCor will calculate averages for these three metrics using the following approaches:

a. Percentage of Vulnerabilities Patched (Defect Density)

- Calculation:
  - Quarterly Averages: Track the percentage of patched vulnerabilities each quarter, then average results over 2 years.
  - Criticality-Based Averages: Separate averages for critical (CVSS ≥7.0) and non-critical vulnerabilities (CVSS <7.0).
- Example:
  - Q1 2025: 92% of critical vulnerabilities patched.
  - Q2 2025: 96% of critical vulnerabilities patched.
  - 6-Month Average: 94% (critical), 88% (non-critical).

b. Duration from Identification to Patch

- Calculation:
  a. Rolling 90-Day Average: Compute the mean time-to-patch for all vulnerabilities addressed in the prior 90 days.
  b. Post-Process-Change Averages: Compare pre- and post-implementation averages after introducing efficiency measures (e.g., automated testing).
- Example:
  c. Pre-Automation: 42 days (critical), 110 days (non-critical).
  d. Post-Automation: 28 days (critical), 75 days (non-critical).

c. Duration from Patch to Availability to Field Implementation

- Calculation:
  - Annual Averages: Measure the mean deployment time across all patches released in a calendar year.
  - Segmented by Deployment Method: Separate averages for OTA updates vs. manual updates.
- Example:
  - 2024 Averages: 22 days (OTA), 67 days (manual).

It is the target ECG device and integrating engineers responsibility to ensure that KAI 12L should only be executed in a trusted environment in which adequate cybersecurity controls have been established by the target medical device. It is the responsibility of the target ECG device and integrating engineers to provide this trusted execution environment. Please contact AliveCor for KAI 12L integration.

- AliveCor reviews and must approve all integration prior to release including evaluating whether appropriate cybersecurity controls have been implemented.
    - It is the integrating partners responsibility to document and provide these for review by Alivecor before release of software.
- A comprehensive cybersecurity assessment of their chosen OS/platform
- Documentation proving ongoing security updates for the selected OS throughout the device's lifecycle
- Vulnerability monitoring plans aligned with Section 524B(b)(2) requirements
- The implementor will include in the review, notification of the host OS platform to be used, which AliveCor will track for security support to be cross-referenced with implementor's supported platforms.
    - If a supported platform is targeted for end of life (EOL) and/or will no longer be receiving vendor security support, the implementor is expected to drop support of said platform within 30 days of announcement
    - In addition, AliveCor will notify the implementor of such upcoming EOL for supported platforms. It is expected that support is dropped within 30 days of AliveCor notification.

Please refer to FDA Guidance, “Cybersecurity in Medical Devices: Quality System Considerations and Content of Premarket Submissions”, issued in September 27, 2023, for details on cybersecurity approaches to consider in medical devices.

Predetermined change control plan (This section is applicable for the USA only)

As part of K231010, KAI 12L includes a PCCP to perform the following changes:

- Improving algorithm performance by retraining with additional data without modifying the architecture,
    - Such improvements will be made by acquiring additional high quality, diverse training data from major clinical institutions similar to the data used to train the models within the 510(k).
    - The performance of the retrained models will be evaluated using the same datasets used within the 510(k). Additional large validation datasets will also be created from sites independent of the training data to ensure model generalization. The performance will be acceptable when the overall performance is noninferior to the performance of the models used in the 510(k). Some minor individual determination performance variation would be acceptable.
    - When such improvements are made and found to be acceptable, the KAI 12L device labeling will be updated to incorporate the updated performance specifications. The changes would be also communicated to KAI 12L API software integrators so that they can also communicate the changes to the end users.

KAI 12L v2 has an authorized PCCP and the labeling will be updated with additional information when a modification has been implemented.

As part of the K252589 submission, KAI 12L v2 includes a PCCP to perform the following changes:

- Improving algorithm performance by retraining with additional data without modifying the architecture,
    - Such improvements will be made by acquiring additional high quality, diverse training data from major clinical institutions similar to the data used to train the models within the 510(k).
    - The performance of the retrained models will be evaluated using the same datasets used within the 510(k). Additional large validation datasets will also be created from sites independent of the training data to ensure model generalization. The performance will be acceptable when the overall performance is noninferior to the performance of the models used in the 510(k). Some minor individual determination performance variation would be acceptable.

When such improvements are made and found to be acceptable, the KAI 12L v2 device labeling will be updated to incorporate the updated performance specifications. The changes would be also communicated to KAI 12L v2 API software integrators so that they can also communicate the changes to the end users.

Labeling/User Interface Requirements for the Integrated Device

All the contents of the section in the section “Physician’s Guide” starting on page 7 shall be included in the labeling of the integrated device.

The warning ‘The provisional automated ECG analysis should not be used for clinical action if it has not been reviewed by a qualified healthcare professional capable of independently interpreting the ECG signal’ shall be prominently communicated to the user as part of the device labeling and user interface.

The ECG report including KAI 12L unconfirmed automated interpretation shall include the language “(Unconfirmed – must be reviewed by a qualified physician)”. This language can be removed once the interpretation has been reviewed by a qualified physician.

The user interface of the integrated system shall include means to assist in selecting the appropriate lead set and KAI 12L mode of operation (i.e., Symptomatic Mode or Asymptomatic Mode) by asking about the patient's symptoms, such as chest pains or palpitations, and will automatically recommend/select the correct lead set and mode of operation, according to the suitable lead set for the ECG recording based on this clinical representation (refer to the discussion in the Physician’s Guide and Table 12 for guidance on the recommended configuration. User interface may allow to manually select a different lead set and/or mode of operation.

KAI 12L Software Bill of Materials

Table 19: KAI 12L Software Bill of Materials

Component	Version	Manufacturer	End of Life	Vulnerabilities
Eigen	3.4.0	Eigen	N/A	None
NumCpp	2.8.0	NumCpp	N/A	None
TensorFlowLiteC	2.12.0	TensorFlowLiteC	N/A	None

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