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# Usefulness, pitfalls and interpretation of handheld single-lead electrocardiograms

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ABSTRACT

Single-lead electrocardiograms (1 L-ECGs) are increasingly used in (pre)clinical settings for the detection and monitoring of a range of rhythm and conduction disorders. In this short communication paper, we aim to provide an overview of the usefulness and potential pitfalls when implementing 1 L-ECGs into everyday clinical practice. Moreover, we provide recommendations for improving signal quality, as well as a systematic approach to the interpretation of 1 L-ECGs, which is somewhat different from standard 12-lead ECGs. Clinicians can use our illustrations and checklist as guidance when recording and interpreting 1 L-ECGs.



## Introduction

Developments in electrocardiographic technology have been substantially accelerated with the introduction of wireless technologies for communication and networking. [1] Handheld single-lead electrocardiogram (1 L-ECG) devices to monitor for cardiac arrhythmias are now widely available for use by both patients and clinicians. Furthermore, with the increased availability of direct-to-consumer 1 L-ECG devices, we foresee a new category of patients visiting their clinician with a home-recorded 1 L-ECG. Therefore it is important for clinicians to learn to appreciate the added value of these new devices, but also to be aware of its shortcomings. In this short communication paper we aim to inform clinicians on the usefulness and potential pitfalls of 1 L-ECGs. Furthermore, we will provide a systematic approach for assessing 1 L-ECGs, using case examples obtained using the KardiaMobile (AliveCor) in the Validation of a mobile bedside ECG Screening and diagnostic Tool for Arrhythmias in general practice (VESTA) study. [2]

## 1 L-ECG devices and signal registration

Currently there are multiple 1 L-ECG devices with CE and/or FDA approval that are available to clinicians as well as on the consumer market. [1] Differences between these devices are multiple and include variations in software (variable automatic algorithms), device connectivity (standalone or smartphone-operated) and hardware. [1] Handheld 1 L-ECG devices rely on capturing an ECG signal and registration similar to lead I of a standard 12-lead ECG (12 L-ECG). This is obtained by holding two metal electrodes with two hands or multiple fingers of each hand, as illustrated in Fig. 1. [2]

As many of the more recently issued 1 L-ECG devices are connected to a smartphone, visual assessment is possible during and/or immediately after registration. Smartphone-connectivity also allows for patients and clinicians easily sharing the 1 L-ECG registration with others.

## Visual assessment of 1 L-ECG registration

When visually assessing the 1 L-ECG registration, several rhythm and conduction disorders can be detected. In Figs. 2 through 10 we show case examples of sinus rhythm, atrial fibrillation (AF), atrial flutter, premature atrial contraction (PAC), premature ventricular contraction (PVC), left and right bundle branch block (LBBB and RBBB, respectively), first degree and high-degree (third degree) atrioventricular block (AV block), respectively. For these case examples we relied on recordings obtained with a KardiaMobile device (AliveCor, Mountain View, CA, United States), a widely used smartphone-connected 1 L-ECG device. [2] For practical reasons we included 8-s snippets extracted from 30-s 1 L-ECG recordings.

## When to use a 1 L-ECG?

The intended use of 1 L-ECGs has been detecting AF and it has been validated for this purpose. [3] Detection of AF is important as it is a major cause of stroke, but this can be challenging as patients are often asymptomatic. [1] Opportunistic AF screening in the elderly is

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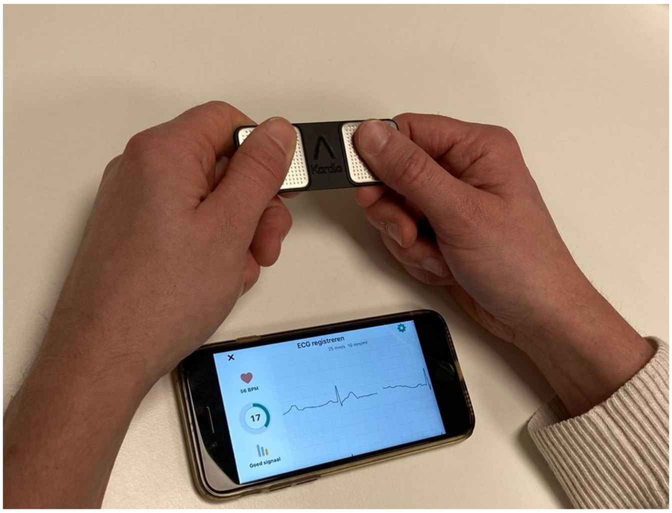


**Fig. 1.** Obtaining a 1 L-ECG registration with the KardiaMobile; photograph by Jailen Hermie.

recommended, but time and workload are barriers for its implementation. [3] 1 L-ECGs can be a less time-consuming alternative for 12 L-ECG, e.g. when pulse palpation has indicated heart rhythm assessment. Therefore AF detection, either for screening purposes or when suspecting a rhythm disorder, will likely be the most common use of 1 L-ECG. When a 1 L-ECG has been recorded, the internal AF algorithm can classify the registration as "normal" or "possible AF". The accuracy of the internal algorithm compared to 12 L-ECG assessment by cardiologists has been evaluated in a systematic review and meta-analysis by Wong et al. [3] For the KardiaMobile they found a pooled sensitivity of 0.82 (95% CI 0.65–0.91) and specificity of 0.99 (95% CI 0.99–1.00) in a community setting and a pooled sensitivity of 0.91 (95% CI 0.66–0.98) and specificity of 0.97 (95% CI 0.94–0.98) in a hospital setting. These results show that the internal AF algorithm can be a reliable tool for clinicians when assessing the 1 L-ECG for AF.

As mentioned previously, clinicians can also visually assess a 1 L-ECG registration. The VESTA study showed that cardiologists can accurately assess 1 L-ECGs for presence of AF, which was demonstrated by an excellent diagnostic accuracy of 100%. [2] This coincides with a high diagnostic accuracy as found in a number of previous studies. [1] In a subsequent case-vignette study we investigated general practitioners (GPs) 1 L-ECG interpretation skills in detection of AF/atrial flutter. We found a high negative predictive value (98.8%), but a low positive predictive value (45.7%), meaning that GPs can safely rule out AF. [4] However, when GPs suspect AF, they are incorrect in half of the cases. These results also account for other relevant cardiac arrhythmias. Therefore, when GPs suspect any relevant ECG abnormality, confirmation by a cardiologist is warranted.

Besides AF, a range of other rhythm and conduction disorders can be detected on 1 L-ECGs, as shown in our practical examples. [2] PACs and PVCs can often be well discerned from the 1 L-ECG signal, as illustrated by Figs. 5 and 6. Furthermore, Figs. 7 through 10 show that evident BBBs and AV blocks can be detected on 1 L-ECG.

## Potential pitfalls

Although a good diagnostic accuracy was found for the internal AF algorithm and for the assessment by cardiologists in detection of AF, AF can sometimes be difficult to distinguish from frequent PACs on 1 L-ECG and can therefore lead to a high false-positive rate. [4]

Furthermore, atrial flutter can be a challenging rhythm disorder to detect on 1 L-ECGs. This is because the typical saw-tooth pattern of an atrial flutter is normally best seen in the inferior leads and V1, while 1 L-ECGs are comparable with a lead I on a 12 L-ECG. [5] In Fig. 4 the flutter wave is clearly visible, due to a low and interchanging ventricular response rate. However, the flutter wave may not always be clearly visible, making it difficult to distinguish from other supraventricular tachycardias (see Supplementary Figs. 1 and 2) or baseline wander. Therefore, we recommend to make a 12 L-ECG whenever a tachycardia is present, which is not evidently a sinus tachycardia or AF.

In the figures selected for this short communication paper, the BBBs and first and third degree AV block are clearly visible due to an evidently prolonged PR interval and broad QRS complex. However, less evident BBBs and AV blocks will not be detected on 1 L-ECGs, as illustrated by the low sensitivity for conduction abnormalities in the VESTA study. [2] A prolonged QRS and AV block can therefore not be excluded based on 1 L-ECG. Furthermore, typical BBB can be difficult to distinguish from interventricular conduction delay.

As the KardiaMobile records a lead I like rhythm strip, it may be less useful in identifying atrial activity compared to conventional ECG devices using precordial electrodes. Therefore this device is not useful to detect specific atrial pathology. Although the KardiaMobile is also not useful in detecting specific ventricular pathology, it was previously suggested that lead I can be useful to predict the site of origin of idiopathic ventricular arrhythmias. [6]

Moreover, a single-lead registration is not useful in excluding acute coronary syndrome, myocardial infarction (acute or old) or left ventricular hypertrophy and it should therefore not be used for these purposes.

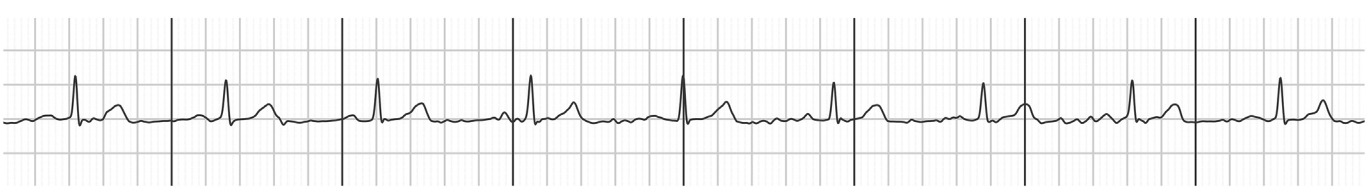

**Fig. 2.** Sinus rhythm on a 1 L-ECG. There is a regular R-R interval with a positive P wave, QRS axis and T wave. Note that the P wave is not always clearly visible before each QRS complex.

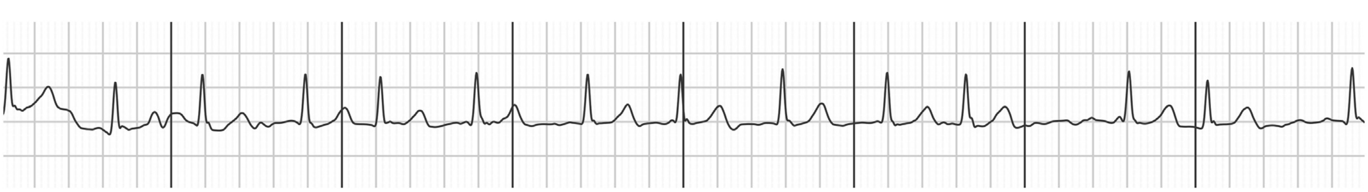

**Fig. 3.** Atrial fibrillation on a 1 L-ECG. P waves are absent and there is an irregular irregularity in R-R interval. In this case there is a high-normal ventricular response rate (+/− 100 bpm).

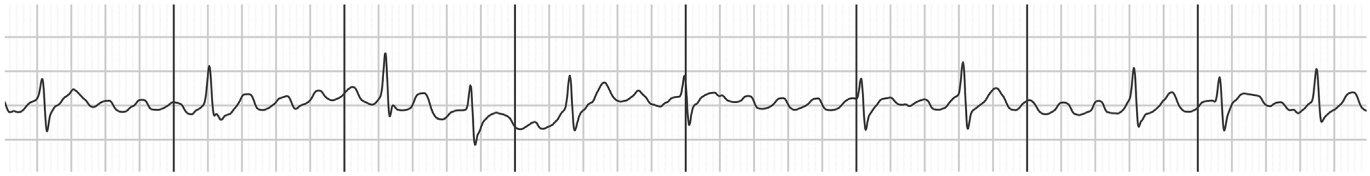

**Fig. 4.** Atrial flutter on a 1 L-ECG with a ventricular response rate interchanging between a 5:1 and 2:1 (+/− 90 bpm) rate. The flutter wave is clearly visible.

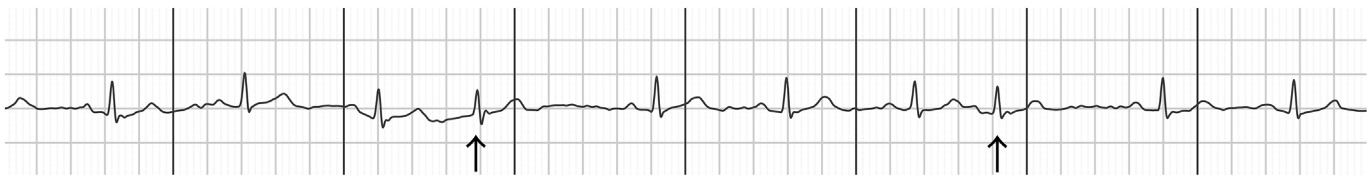

**Fig. 5.** PACs on a 1 L-ECG. P waves are present before all QRS complexes indicating a sinus base rhythm. R-R interval, besides the PACs, is regular.

**Fig. 6.** PVC on a 1 L-ECG. The QRS complex of the PVC is broader and has a different axis, resulting from an electric signal not conducted through the normal conducting system.

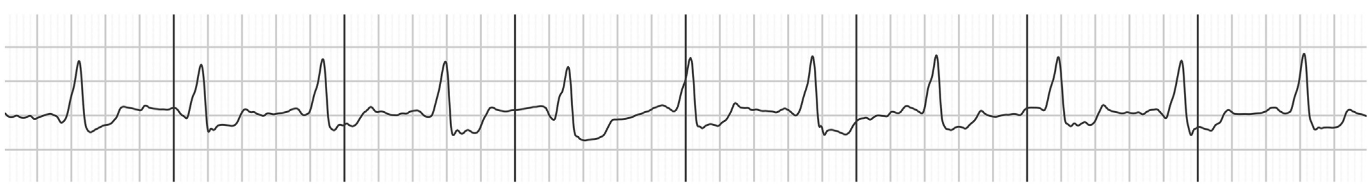

**Fig. 7.** LBBB on a 1 L-ECG. QRS complex is broad (138 ms as measured on 12 L-ECG). Repolarization matches LBBB with ST depression and discordant T waves.

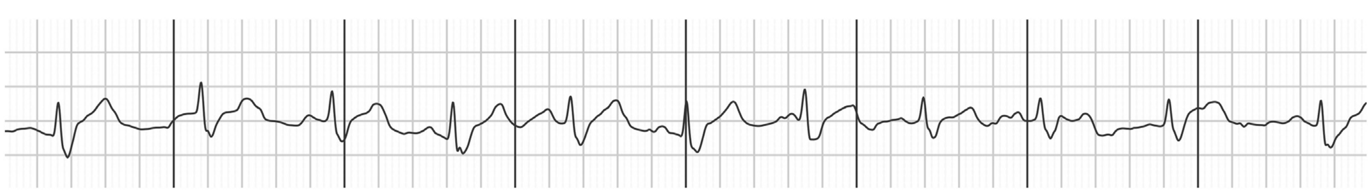

**Fig. 8.** RBBB on a 1 L-ECG. Total QRS complex is broad (161 ms as measured on 12 L-ECG). The R wave is small, the S wave is broad and the T wave is positive.

*Quality of the ECG signal*

As with 12 L-ECGs, the quality of the ECG signal is the most important aspect for correct assessment of 1 L-ECG registrations. [7]. When using the KardiaMobile, the ECG signal is visible in real-time, which allows for visual quality control. Moreover, the application has signal quality optimization software installed as well as quality control algorithms, which results in the built-in algorithm stating the ECG registration to be "unreadable" or "unclassified" when there is substantial noise or when no classification can be given. [2] However, optimizing ECG signal quality can be challenging in a home-setting, as assessing visual quality can be difficult for unexperienced patients. This is illustrated in a real life ambulatory cohort study of 233 patients with almost 6000 KardiaMobile 1 L-ECGs, where the internal algorithm categorized 17% as unclassified and 2% as unreadable. Cardiologists, however, were able to reduce

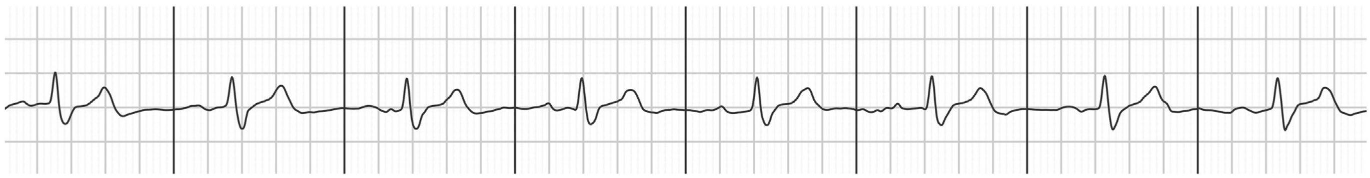

**Fig. 9.** First degree AV block on a 1 L-ECG. The PR interval surpasses 200 ms (230 ms on 12 L-ECG). Note that there is also a RBBB (QRS 173 ms on 12 L-ECG). Therefore this 1 L-ECG shows a bifascicular block.

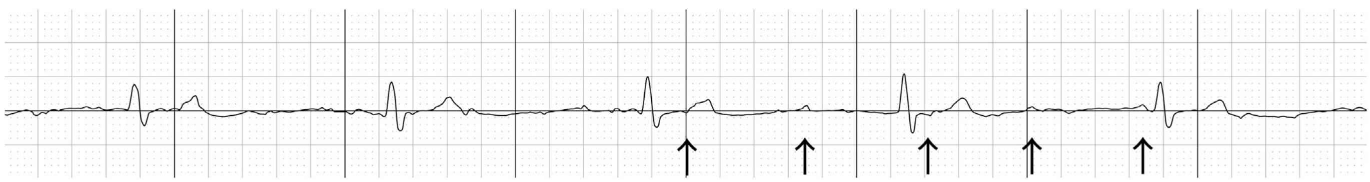

**Fig. 10.** Third degree AV block on a 1 L-ECG. Four P waves are highlighted with arrows. There is no correlation between the P waves and the broad QRS complexes.

the number of uninterpretable 1 L-ECGs to only 8% with visual assessment. [7]

*Improving 1 L-ECG signal*

To optimize ECG signal quality during home-measurements, patients should be instructed to rest their hands on a surface (e.g. table or their legs), as a tight grip on the electrodes or a tremor will lead to substantial noise. Furthermore, to optimize electrical conduction, patients who have sweaty hands or use hand lotion should be advised to use alcohol wipes on the fingertips or wash their hands with soap prior to 1 L-ECG use.

## Importance of systematic approach

As some rhythm and conduction disorders present differently on 1 L-ECG compared to 12 L-ECG, a systematic approach for assessing 1 L-ECGs is warranted. In the supplementary material we have provided a systematic approach to interpret 1 L-ECGs, adapted from the pocket guide for 12 L-ECG interpretation of ECGpedia.org. We advise clinicians to use such a systematic approach as guidance for interpretation of 1 L-ECGs.

## Conclusion

In this short communication paper we provided an outline on the usefulness and potential pitfalls of 1 L-ECGs, which are increasingly used in the community. Clinicians can use our illustrations and systematic approach as reference in this era of mobile technology.

## Author statement

M. Patrick Witvliet: Investigation, Writing - Original Draft, Visualization.

Evert P.M. Karregat: Conceptualization, Methodology, Writing - Review & Editing.

Jelle C.L. Himmelreich: Writing - Review & Editing.

Jonas S.S.G. de Jong: Writing - Review & Editing.

Wim A.M. Lucassen: Supervision.

Ralf E. Harskamp: Writing - Review & Editing.

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## Declaration of Competing Interest

None.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelectrocard.2021.02.011.

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