Assessing the Accuracy of Limited Lead Recordings for the Detection of Atrial Fibrillation

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Abstract

Atrial Fibrillation (AF) is a common cardiac arrhythmia which, if left untreated, can lead to ischaemic stroke. A number of low cost hand held devices which use a single lead I ECG to facilitate detection of a cardiac arrhythmia have recently appeared on the market. This study aimed to assess the accuracy of using limited lead ECG recordings for the detection of AF using the University of Glasgow (Uni-G) ECG analysis program. A 12-lead ECG dataset consisting of 98 confirmed cases of AF and 98 confirmed cases of Sinus rhythm, 49 with PVCs and 49 with PACs, all of which were correctly reported by the Uni-G program and a further 9 cases of confirmed AF which had not been correctly reported by the Uni-G program was used. Each 12-lead ECG was processed to generate two separate ECGs, one with only lead I available and another with only leads I and II available. The sensitivity of reporting AF using a single lead ECG and a 2-lead ECG was identical at 93.8%. However, specificity was greater in the 2-lead ECG at 94.8% compared to 83.6% in the single lead ECG. The results show that a single lead ECG or a 2-lead ECG recording could be effective in screening populations for cardiac arrhythmias.

1. Introduction

Atrial Fibrillation (AF) is an extremely common cardiac arrhythmia that is estimated to affect between 1-2% of the population [1]. It is most common in the elderly population where the prevalence exceeds 5% in the over 65s although younger individuals can also be diagnosed with AF. The increasingly aging population due to recent improvements in health care is set to cause the prevalence of AF double by 2050 [2].

AF patients are at 5-7 times increased risk of ischaemic stroke [3] and are also more likely to suffer a recurrence of stroke [4]. Increased stroke rates in AF patients with a previously low pre-diagnosis stroke risk score such as CHADS2 highlight AF as an independent risk factor for stroke [5].

For such a significant condition, in one third of patients AF is often asymptomatic and is not often detected before the onset of a debilitating stroke. The most effective way to screen for AF is by recording a 12-lead electrocardiogram (ECG). Although very effective at detecting chronic as opposed to paroxysmal AF, 12-lead ECGs take time to be recorded, require patients to undress so that electrodes can be placed on their chest and limbs and require a trained individual to operate the ECG machine. Family doctors and public health specialists are therefore unlikely to use this method for screening for an arrhythmia which may produce little or no symptoms in some individuals.

Hand held automated devices that claim to accurately detect AF by having an individual simply press two thumbs onto electrodes have recently appeared on the market. A cardiologist could look at the recording on the display of this device and make a diagnosis of the cardiac rhythm but in a screening situation, where a cardiologist is not available, it is possible for the device to have a computer program inside to produce an automated interpretation [6]. If shown to be accurate, these devices could provide a valuable approach to community screening for AF.

2. Methods

Resting 12-lead ECGs were selected for use in this study from an existing ECG repository by an experienced electrocardiologist at the Electrocardiology Core Lab at Glasgow Royal Infirmary. The repository from which the ECGs were chosen contained a large number of normal and abnormal ECGs taken from clinical trials or population studies for which volunteers (or parents) had previously given informed consent to their participation.

In total, 210 ECGs were initially used in this study. These were recorded from 108 female and 102 male caucasian patients with an age range from 4 weeks to 95 years old. The ECGs had been recorded prior to this study between the years of 1981 and 2011.

12-lead ECGs exhibiting one of 3 different types of cardiac arrhythmias of interest to this study were selected. These arrhythmias were:-

1. Atrial Fibrillation (AF);
2. Sinus rhythm with premature ventricular contractions (PVCs);
3. Sinus rhythm with premature atrial contractions (PACs).

Each 12-lead ECG was reviewed by the same experienced electrocardiologist with respect to the quality of the ECG and to confirm that it was indeed suitable for inclusion within the given groups of arrhythmias. The confirmed 12-lead ECGs were taken to be the "gold standard" for this study.

For each 12-lead ECG used in this study, two additional ECG data files were created, one containing only the original lead I from each 12-lead ECG and the other containing only the original leads I and II from each 12-lead ECG. The Uni-G ECG analysis program incorporates a feature that allows ECGs with a limited set of recorded leads to be processed by allowing the other missing leads to be computed by applying a transformation based upon the original lead I or leads I and II. For example, in the single lead ECG, lead V1 is computed as the inverted lead I. This is in addition to the transformations used to generate leads III, aVR, aVL and aVF.

100 confirmed cases of AF were chosen to test the ability of the reduced lead ECGs to correctly interpret AF. In addition, 100 confirmed cases of sinus rhythm, 50 with PVCs and 50 with PACs, were selected to test if there were a chance that the reduced lead ECGs would incorrectly interpret sinus rhythm plus PACs or PVCs as AF. Furthermore, other 10 confirmed cases of AF which had not been correctly reported as such by the 12-lead Uni-G ECG analysis program were included to observe what the 2-lead ECG and the single lead ECG would report.

All ECGs were processed twice, once as a single lead ECG and once as a 2-lead ECG. ECGs were excluded if a diagnostic interpretation could not be made, perhaps due to a very low voltage in lead I, or if the ECGs were believed to be duplicates from the same patient. The ECG reports were printed and examined individually by hand. The diagnostic interpretation produced by the Uni-G ECG analysis program for each ECG report was compared to the 'gold standard' validated diagnosis of the particular ECG and a result of 'correct interpretation' or 'wrong interpretation' was determined.

The findings were then collated to determine True Positive (TP), False Negative (FN), True Negative (TN) and False Positive (FP) values for each of the ECG sets. Sensitivity, Specificity and overall accuracy were calculated from these values.

Differences in the sensitivities and specificities between the single lead ECG, the 2-lead ECG and the 12-lead ECG were statistically analysed using a McNemar test [7] using the statistics package IBM SPSS 19. A p-value of less than 0.05 was deemed to be significant.

3. Results

Following 5 necessary exclusions from the data set on account of failure to analyse the data using the single lead or 2-lead data, 205 'gold standard' 12-lead ECGs were used in this study. These comprised of 98 AF, 49 sinus rhythm with PVCs, 49 sinus rhythm with PACs and 9 further 12-lead ECGs which failed to report true cases of AF.

The performance of the single lead ECG and the 2-lead ECG at reporting AF is compared in Table 1. The 9 cases where the original 12-lead ECG failed to be reported as AF were excluded from this comparison, leaving 196 cases to be analysed.

Table 1. Single lead ECG and 2-lead ECG performance in reporting AF. 196 ECGs were analysed.

	Single Lead ECG	2-Lead ECG
TP	92	92
TN	82	93
FP	16	5
FN	6	6
Total	196	196
Sensitivity	93.9%	93.9%
Specificity	83.7%	94.9%
Accuracy	88.8%	94.4%

Sensitivity was the same in the single lead and 2-lead ECGs at 93.9% while specificity was greater in the 2-lead ECG, being 94.9% compared to 83.7% in the single lead ECG but this difference was not statistically significant.
The performance of the single lead ECG and the 2-lead ECG at reporting PVCs based on an analysis of all 205 ECGs is compared in Table 2. In the 2-lead ECG, of the 7 cases that were incorrectly reported as FN, 1 case was reported as AF. In the single lead ECG, of the 24 cases that were incorrectly reported as FN, 6 were reported as AF. Specificity was greater in the 2-lead ECG at 92.3%

Table 2. Single lead ECG and 2-lead ECG performance in reporting PVCs.

	Single Lead ECG	2-Lead ECG
TP	25	42
TN	142	144
FP	14	12
FN	24	7
Total	205	205
Sensitivity	51.0% *	85.7% *
Specificity	91.0%	92.3%
Accuracy	81.5%	90.7%

* Statistically significant difference ($p < 0.05$).

compared to 91.0% in the single lead ECG. Sensitivity in the 2-lead ECG was significantly greater than in the single lead with 85.7% compared to 51.0% respectively.

The performance of the single lead and the 2-lead ECG at reporting PACs is compared in Table 3. Of the 6 cases reported incorrectly as FN in the 2-lead ECGs, 4 were incorrectly reported as AF. In the single lead ECG, of the 12 cases incorrectly reported as FN, 10 of these cases were reported as AF.

When combined, the 2-lead ECG incorrectly reported 5 sinus rhythms with PVCs/PACs as AF. In the single lead ECG, 16 sinus rhythms with PVCs/PACs were incorrectly reported as AF.

The 2-lead ECG was able to correctly report 5 out of the 9 cases of AF when the 12-lead ECG reported none correctly. The single lead ECG correctly reported 8 out of the 9 cases of AF when the 12-lead ECG reported none correctly. Therefore, out of 107 cases of AF, the single lead ECG reported 93.4% correctly while the 2-lead ECG reported 90.7% correctly.

Table 3. Single lead ECG and 2-lead ECG performance in reporting PACs.

	Single Lead ECG	2-Lead ECG
TP	37	43
TN	147	147
FP	9	9
FN	12	6
Total	205	205
Sensitivity	75.5%	87.8%
Specificity	94.2%	94.2%
Accuracy	89.8%	92.7%

4. Discussion

The results of this study show that automated analysis of a single lead ECG is 88.8% accurate in detecting AF. There is no significant difference between the accuracy of reporting AF using a single lead ECG, a 2-lead ECG and even a 12-lead ECG in this sample.

The only significant difference found in this study was when the sensitivities of the single lead ECG and the 2-lead ECG for detecting Sinus rhythm with PVCs were compared. Further visual examination of the single lead ECG recording of cases where PVCs had incorrectly not been reported using the single lead ECG found that the morphology of the QRS complex in lead I was sometimes not markedly different for the PVC when compared to the normally conducted beats whereas, in the same individual, the morphology of the PVC in leads II and aVF of the 2-lead ECG could be seen to be quite different from the normally conducted beats. Figure 1 shows the appearance of a PVC in the 12-lead and single lead ECGs for the same patient. When the additional leads are derived from lead I of the single lead ECG, the derived leads will have PVCs with a morphology similar to other normally conducted complexes and so the shape of all complexes within a lead will remain the same but inverted or amplified to some extent. This is thought to be why in some cases the single lead ECGs fails to report PVCs correctly. This could lead to a report of sinus with PACs rather than PVCs.

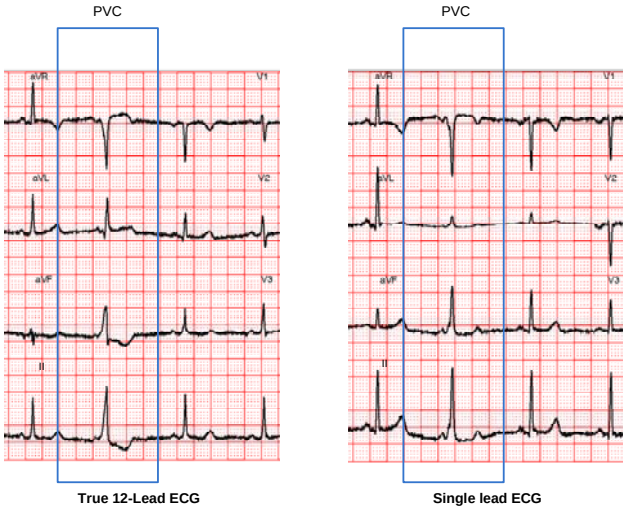

Figure 1. A true 12-lead ECG (left) showing a clear PVC while in the single lead ECG (right) the PVC morphology is similar to the normally conducted beats.

Single lead automated devices would mainly be of use in a GP's surgery or a chemist for quick and easy non-invasive screening of communities. The Uni-G program, which could be incorporated in such a device, was shown to accurately detect an irregular heart rhythm correctly each time, as there were no cases where the single limb lead ECG incorrectly reported only sinus rhythm. The Uni-G program, however, did misdiagnose AF in some cases of true sinus rhythm accompanied by PACs or PVCs. In practice, if a single lead ECG report suggested AF, it would need to be confirmed by a full 12-lead ECG and reviewed by an expert before treatment could commence.

In some cases, artefact caused a false positive report of pacemaker activity. This is due to artefact in a single lead ECG being replicated in all other leads of the reconstructed ECG. In the 2-lead ECG, there will be a lower probability of artefact being reported as pacemaker activity in the reconstructed 12-lead ECG because artefact in lead I may not appear in lead II [8].

The 9 cases of AF which had not been reported as AF by the Uni-G program in the original 12-lead ECG were included in the test set to determine what might happen using a single or 2-lead analysis. Surprisingly, in the

single lead ECG analysis, 8 of these cases were reported as AF. The Uni-G program uses only three leads for rhythm analysis, including V1 [9]. In the single lead ECG, V1 is replaced by an inverted lead I and possibly there was less atrial activity in this limb lead than might have been found in a true V1. This can be seen in the example 12-lead ECG recording shown in Figure 2, where atrial activity is absent from lead I but visible in the augmented limb leads and chest leads. The equivalent single lead ECG shows no atrial activity in any lead due to being based on lead I only.

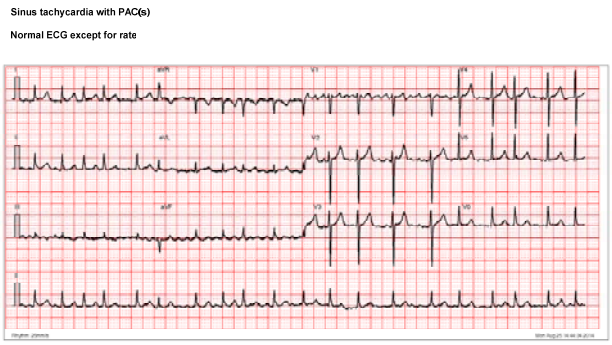

Figure 2. A 12-lead ECG showing Atrial Fibrillation but wrongly reported as Sinus tachycardia with PAC(s). The single lead ECG from the same patient correctly reported Atrial Fibrillation.

5. Conclusion

This study has examined the potential usefulness of a new type of device which can record a single lead of an ECG for the purpose of detecting cardiac arrhythmias in a screening situation. In this study, there were no cases where either the single lead or the 2-lead ECG reported pure sinus rhythm (without any other irregularity) so the software was 100% specific in detecting an arrhythmia. The accuracy of the software which could be incorporated in a device for single lead analysis was 89% for AF, 82% for sinus rhythm with PVCs and 90% for sinus rhythm with PACs. The study also showed that if all limb leads could be recorded, the corresponding accuracies would be 94%, 91% and 93% respectively, which is clearly better than the use of a single lead. These results suggest that even a single lead automated ECG interpretation could be of value in a screening situation though the use of all limb leads would result in increased accuracy.

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