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A proposal for monitoring patients with heart failure via "smart phone technology"-based electrocardiograms

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Abstract The ubiquitous smart phone/device technology (SPT) has enabled the safe acquisition/transmission (A/T) of clinical and laboratory patient data, including the electrocardiogram (ECG). SPT-based A/T of the ECG has been found useful in the detection of atrial fibrillation, in monitoring of the QTc interval, in patients undergoing antiarrhythmic drug loading, and in management of patients with acute ST-elevation myocardial infarction. Previous work has shown a relationship between changes in the voltage of the ECG QRS complexes, with perturbations in the edematous state of various etiologies, including heart failure (HF). It is proposed herein to employ serially SPT-based 3-lead ECG A/T for the monitoring and management of patients with HF in their ambient environment. The proposed method will enable patients with HF to acquire/transmit their 3-lead ECG to the caring HF team, using only their smart phone and it takes into consideration the advanced degrees of physical incapacitation and age-related infirmities inherent to the HF population.

Keywords: Electrocardiogram; Heart failure; Electrocardiogram and heart failure; Monitoring of patients with heart failure; Remote monitoring of patients with heart failure; Peripheral edema and the electrocardiogram; Smart phone-based technology and the electrocardiogram

Introduction

Societies world-wide are severely burdened with the monitoring and management of patients with heart failure (HF). Many clinical and laboratory methods have been employed in the monitoring of patients with HF in the hospital, the clinic, and the patients' ambient environment via remotely applied technology. The core idea pertains to periodic acquisition/transmission (A/T) by the patient or caregivers, information necessary for the members of the HF team, to advise the patient about the drug regiment and other aspects of management via a "remote control" approach, obviating the inconvenience and cost of frequent visits to the hospital. It is beyond the scope of this communication to delve in the various methods proposed and implemented for the in-hospital, clinic, and remote monitoring of patients with HF, about whom vast literature is available. This constitutes a proposal to utilize the AliveCor smart phone electrocardiogram (ECG) to better manage patients with HF. The implementation of protocols, analysis of data, and evaluation of clinical and economic impact would be established by a working group of interested researchers, based on the approaches recommended in the paper. The readers may want to be directed to a dedicated web site (for the establishment of which the author seeks the help of his colleagues), where they could read the full proposal and background literature, and may signify interest and register to receive communications related to the project.

Electrocardiogram voltage and body edematous state

Previous work has shown that there is an inverse relationship between the increase in body weight (BW) and attenuation of voltage of the ECG QRS complexes (attQRS) in patients with an edematous state (ES) of diverse etiologies; augmentation of the voltage of the QRS complexes (AuQRS) has been observed in such patients after therapy, particularly diuresis, associated with amelioration of peripheral edema, and BW loss (Fig. 1) [1]. Subsequent to the original investigation [1], many clinical studies [2–21] have revealed several details about the dynamic response of the ECG to the body's ES. Such changes in the voltage are imparted to the same degree to all components of the ECG curve; customarily, measurements are carried out in QRS complexes (Fig. 1) due to their large

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Fig. 1. A 55 year old man with HF experienced a 12% gain of his weight over the course of 5 months, and in the process revealed, by a comparison of ECGs A and B, a loss in QRS voltage by 34%, 37%, and 36%, in ΣI + II, ΣV1–V6, and Σ12Lds, correspondingly.

amplitude, which ensures accuracy of comparisons in serial ECGs. The limb leads are more suitable for QRS voltage monitoring purposes, since the frontal body plane reflects better the body's ES, than the horizontal plane, which is partially influenced by underlying local cardiac currents, and regional thoracic electrical properties, and the V1–V6 leads are plagued by nonreproducible serial recordings, and inaccurate thoracic lead electrode placement [1,5,13]. Since contemporary ECG machines measure only leads I and II, and calculate the voltage of the remaining 4 limb leads via mathematical algorithms [22,23], lead I and II, or their sum (ΣI + II), are adequate for QRS monitoring [6,15]. Accordingly, due to the mathematical relationship between lead aVR and leads I and II (aVR × 2 = I + II, considering only absolute numbers) [22,23], lead aVR can be employed solely for ECG monitoring [16,21]. The sums, of all 6 limb leads (Σ6LbLds) [5,13,17], the 6 precordial leads (ΣPrecLds) [5,17,20], and all the 12 ECG leads (Σ12Lds) [1,2,4,5,17], have been used serially for monitoring of patients with HF [2,8,13,15]. All 6 precordial ECG leads, or sums of leads V1–V3 (ΣV1–V3), and V4–V6 (ΣV4–V6), particularly the later, since they are in proximity to the overloaded with water lung parenchyma, can be used serially when pulmonary edema is present, solely or with peripheral edema [1]. Monitoring for the assessment of attQRS and AuQRS can be accomplished in the presence of left and right bundle branch blocks, and intraventricular conduction delays, provided that the above are stable [1,8,10,11]. Monitoring for the assessment of attQRS and AuQRS via serial tracings is feasible in the presence of electronic temporary or permanent ventricular pacemaking, or biventricular pacing, provided that pacemaking is stable [6]. Obviously patients with HF, implanted ICDs, and intrinsic ventricular depolarization qualify for QRS monitoring. Mere "eye-balling" of leads aVR, I and II, or V4–V6, in serial ECGs may suffice for bedside evaluation in-hospital, or at the clinic for monitoring the ES of patients with HF [11,17,19]. Measurements of the "peak to peak" QRS voltage in leads aVR, or the ΣI + II, or any other ECG lead sets, can be accomplished by considering the ECG paper grid, or on the computer screen from serial ECG tracings, and then entering the results in the patients' records, for HF monitoring [1–21]. "Toggling" between 2, or among many serial ECGs, on the computer screen, while looking specifically at leads aVR, I, II, or ΣI + II, provides instantly an insight about the ES of a patient with HF [11,17,19]. Most of the current ECG machines provide automated measurements of the "peak to peak" voltage in mV, to the nearest 10 μV, of all 12 ECG leads, and were used for calculating the values inserted in Fig. 1, and illustrations of previous communications [1–21]. Finally, manufacturers of ECG machines can be induced to provide automated comparisons (in mV or mm, and graphs of