A proposal for a reconstruction (derivation) of V1-V6 using leads I, II, and a "sternal notch lead": A solution to the problem of non-reproducibility of precordial leads in serial 12-lead standard electrocardiograms

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A R T I C L E   I N F O

A B S T R A C T

Variation of the amplitude and morphology of V1-V6 leads in serial ECGs, due to variation in the placement of V1-V6 recording electrodes, and the noncompliance in placing the V1-V6 electrodes at the recommended thoracic loci, are 2 problems which have defied solution since the advent of electrocardiography. A proposal is presented herein of a set of 3 recorded leads (conventional limb leads I and II, and a lead recorded via an electrode adjacent to the sternal notch [SNL]), aimed at reconstructing the V1-V6 leads, as a function of the 3 recorded leads, employing patient-specific and general (population) coefficients. The SNL electrode is expected to be placed at a designated thoracic site without ambiguity, and thus in conjunction with the limb leads I and II, to yield a hybrid 12-lead ECG with the conventional 6 limb leads and 6 derived V1-V6 leads. The SNL will result in the elimination of the problems of variation in the placement of V1-V6 electrodes, and the noncompliance of placing the V1-V6 electrodes at the recommended thoracic sites, and the resultant variation in the amplitude and morphology of the V1-V6 leads in serial ECGs.

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Introduction

A serious problem in electrocardiography (ECG), which has defied heretofore a solution, is the haphazard placement of the precordial ECG electrodes on the chest wall, instead of the recommended thoracic sites [1], and the lack of reproducibility of the precordial V1-V6 electrodes in serial standard 12-lead ECG recordings, done at different time intervals, due to the variation in the placement of the 6 chest-wall electrodes, from one recording to the other [1–8]. The morphology/amplitude of the V1-V6 chest leads are almost always different (slightly to markedly) in serial ECG tracings, in clinically stable patients, without an intervening cardiac event. The reason for these major changes in the V1-V6 leads from different ECG recordings is that the proximity of the chest electrodes to the heart (where major potential gradients exist) engender major morphology/amplitude alterations with small differences in the recording electrode location. These reasons are visually revealed in body surface potential maps. Such variation is further augmented when there are major changes in the chest-wall sites where the V1-V6 electrodes are placed in repeat ECGs, an unfortunate common practice. Specifically, while some ECG technicians attach the V1-V6 electrodes appropriately, others place the electrodes 1 or even 2 intercostal spaces higher (a common

practice), generating ECGs with features of "old anteroseptal myocardial infarction" [1]. Also the placement of V4-V6 electrodes along the 6th (or even lower) intercostal spaces, is a common practice particularly in large breasted women. Casual observation in any medical environment reveals that violations in the placement of the ECG leads in the proper thoracic sites are rampant. An additional problem is the necessity to detach and then later reapply the ECG electrodes to the patients' chestwall when they return to their units, after having been transferred to other hospital locations to undergo procedures (e.g., x-rays, CT scans, MRIs, noninvasive and invasive procedures, surgeries, etc.). This poor performance by people recording ECGs often prevents meaningful qualitative and quantitative ECG comparisons, or leads to incorrect diagnoses, resulting in inappropriate testing, harm to the patients, and escalation of medical cost. Finally, the various ECG electrode systems proposed previously [9–20], include attachment of electrodes in *specific thoracic sites*, that are of course also expected to be handled *inappropriately*, as done currently, for the electrode placement for recording of the standard 12-lead ECGs [2–7].

A proposal for a "sternal notch lead" for V1-V6 reconstruction (derivation)

What follows is a proposal to reconstruct the V1-V6 ECG leads employing a hybrid approach, using the conventional I and II leads

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and a "sternal notch lead" (SNL). This will require that the ECG operators affix the SNL adhesive electrode just below the sternal notch, so that the upper edge of the adhesive electrode abuts the nadir of the curve formed by the sternal notch (Fig. 1). Unlike all other than conventional approaches, in recording the ECG, [2–7,9–28], the requirement to place the SNL electrode, *just below the rim* of the sternal notch on the chest-wall (manubrium sterni), is not expected to generate any ambiguity, and will ensure that such electrode positioning will be reproducible in repeat serial ECG recordings. Indeed, even with closed eyes, and employing only tactile sensation, one can place an adhesive electrode lead reproducibly just below the rim of the sternal notch with the upper ridge of the adhesive electrode abutting the sternal notch, in the upper part of the manubrium sterni (Fig. 1) (try this!). The proposed ECG electrode system will consist of 5 electrodes, as the currently popular EASI electrode system [13–15]: the 4 conventional limb electrodes will be attached distally to the 4 extremities, or later after experience with the proposed technique is acquired, to any modification in the placement of the limb electrodes required for stress test or Holter ambulatory ECG recordings, monitoring, etc., and along with the SNL electrode, will provide a *hybrid ECG* consisting of the conventional limb leads (I, II, III, aVR, aVL, aVF), and the 6 V1-V6 precordial leads, each of which will be reconstructed (or derived), as a function of 3 leads, i.e., I, II, and the SNL (Fig. 1), employing mathematical algorithms with transfer coefficients, both patient-, and population-specific. This method of an ECG 5 recording electrodes-system, in contrast to all other previously proposed electrode systems, is *unique* because of the inclusion of the SNL, which in conjunction with the other 4 conventional limb electrodes, will provide a set of 5 recording electrodes, devoid of the ambivalence, as to their placement.

Further development of the "sternal notch lead"

No supporting data are included with this proposal. Thus, actualization of the proposed ECG recording system will require the contribution of colleagues from a variety of disciplines (cardiology, electrocardiology, electrical engineering, computer science) and the industry manufacturing electrocardiographs. Facilities which will develop the proposed I/II/SNL lead system will record a large number of ECGs initially commencing the analysis with a learning set followed by a test set of equal sizes, as done previously [16]. Many insights could be gained by consulting an excellent review of the previous relevant work on using different lead systems for the recording or reconstructing the ECG, provided by Macfarlane in chapter 11 of the leading textbook "Comprehensive Electrocardiology" [29]. Both individual patient-specific and general (population) sets of 18 coefficients for the derivation of the V1-V6 sets of leads will be calculated, and the performance of the derived and simultaneously recorded V1-V6 set of leads will be compared with Pearson's cross correlation coefficient analysis. A starting point for the development of the proposed ECG recording system could be based on available body ECG potential maps, where a lead similar to the proposed SNL could be used to reconstruct the precordial leads V1-V6, which in turn could be compared to actually recorded leads V1-V6 of the body ECG potential maps.

Potential weaknesses of the proposed "sternal notch lead"

One could envisage that the choice of the SNL is not ideal, since its electrode lead is placed cephalad to the thoracic loci from where the conventional precordial leads V1-V6 are recorded, and where major dynamic changes in the ECG curve are manifest in the setting of various acute and chronic cardiac pathologies. However the SNL will be evaluated as to its merit, or lack thereof, in reconstructing the V1-V6 precordial leads, and not for its diagnostic content. Also, it is conceivable that the SNL's vectorial nature will render it unsuitable to "capture" local changes in the ECG curve manifest exclusively or mainly in the precordium "scanned" by leads V1-V6. Because of the above, the SNL may turn out to be suboptimal as a choice ECG lead employed for the mathematical derivation of leads V1-V6, and such leads may prove to be poor in terms of their diagnostic content. However one should also consider that new lead sets (e.g., SNL) might have diagnostic merit
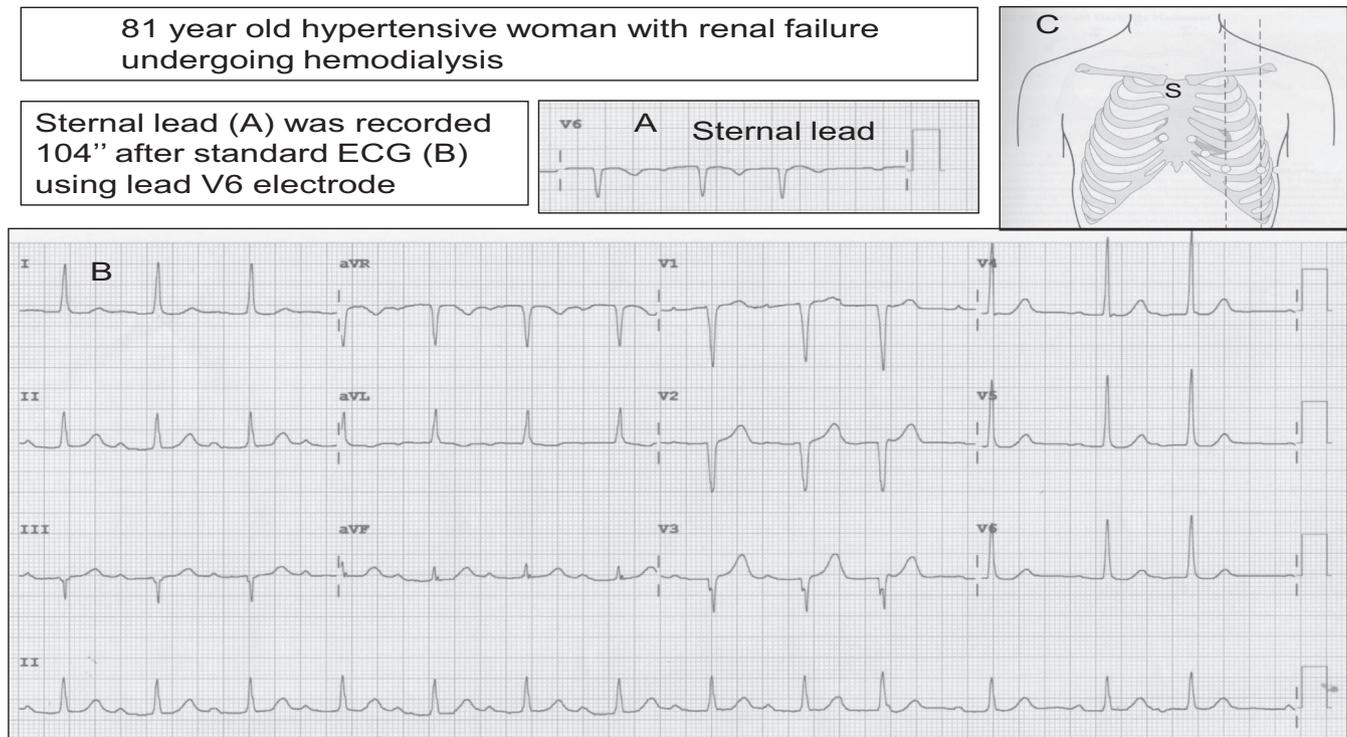

Fig. 1. The SNL shown above (A) was recorded after the conventional 12-lead ECG (B), using the V6 electrode lead; however the method proposed herein requires that the SNL be acquired *simultaneously* with all the other 12-leads, as done currently for all 12-leads of the standard ECG by all electrocardiographs; panel C shows the attachment site (S) of the SNL.

separate from accuracy of the reconstruction. It is possible that the re-constructed V1-V3 might have useful diagnostic value even if correlation with standard leads is not strong.

Another potential limitation is the one stemming from the employment of population-specific rather patients' specific coefficients in deriving the reconstructed precordial V1-V6 leads via the SNL electrode, although population-specific coefficients have been employed by other currently used unconventional ECG recording systems [5–7]. However all the above would be evaluated and decided upon after actual data using the SNL become available. One could even consider the worst scenario, i.e., that the derived V1-V6 leads via the SNL electrode are poor representations of the recorded V1-V6 leads in terms of their diagnostic merit, an outcome which does not mitigate the possible value of the derived V1-V6 leads for monitoring purposes, via a reproducible 12-lead ECG tracing. Thus, a possible unique strength of the SNL is its potential for rendering serial ECGs reproducible.

Future possibilities of the "sternal notch lead"

There are many possible applications of the proposed ECG recording system, which should wait its initial evaluation. Due to the *Journal's* space constraints, the above is a short version of what was initially submitted; however the original version will be available to colleagues who would be interested in working to develop an embodiment of this proposal and produce patient data for evaluation of its possible merits. The author is open to facilitate and help, in any suggested ways, investigations of the merits and limitations of the proposal, led by any of his colleagues, and to contribute, and collaborate in any proposed venture.

Conflicts of interest

There are no conflicts of interest to disclose.

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