Reliability and Reproducibility of Advanced ECG Parameters in Month-to-Month and Year-to-Year Recordings in Healthy Subjects

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Abstract— **Advanced resting ECG parameters such the spatial mean QRS-T angle and the QT variability index (QTVI) have important diagnostic and prognostic utility, but their reliability and reproducibility (R&R) are not well characterized. We hypothesized that the spatial QRS-T angle would have relatively higher R&R than parameters such as QTVI that are more responsive to transient changes in the autonomic nervous system. The R&R of several conventional and advanced ECG parameters were studied via intraclass correlation coefficients (ICCs) and coefficients of variation (CVs) in: (1) 15 supine healthy subjects from month-to-month; (2) 27 supine healthy subjects from year-to-year; and (3) 25 subjects after transition from the supine to the seated posture. As hypothesized, for the spatial mean QRS-T angle and many conventional ECG parameters, ICCs were higher, and CVs lower than QTVI, suggesting that the former parameters are more reliable and reproducible.**

I. INTRODUCTION

Advanced resting ECG parameters such as the spatial QRS-T angle, the QT variability index (QTVI), and measures of QRS and T-wave complexity obtained through singular value decomposition (SVD) are known to have both diagnostic and prognostic value, e.g. for coronary artery disease, heart failure, myocardial ischemia, cardiomyopathies or cardiac death as reviewed by Schlegel et al [1]. In spite of their diagnostic and/or prognostic utility, the reliability and reproducibility of results (R&R) from the above parameters have only rarely been explored [2-4]. Knowledge of the R&R of these parameters will also be important for choosing the best advanced ECG "scores" that combine the results from some of these parameters to improve overall diagnostic sensitivity and specificity [1,5]. In the present investigation, we therefore tested the intermediate (month-to-month) and long term (year-to-year) R&R, as well as the postural (supine-seated) stability of results from the afore-mentioned parameters and from several conventional ECG parameters in 15, 27 and 25 healthy subjects, respectively.

II. METHODS

Two ~5-min 12-lead ECG recordings were acquired in the supine position about one year apart in 27 subjects and about one month apart in 15 subjects. In another 25 subjects, a ~5-min seated 12-lead ECG recording was acquired after an initial ~5-min supine recording following a 1-min seated equilibration period. A high-fidelity PC ECG system (Cardiax, IMED, Budapest, Hungary) with a frequency response to 300 Hz and a sampling rate of 1000 samples/s was used to acquire the 12-lead surface ECGs.

Signal averaging was performed over both 10 ("snapshot" ECG, SS) and 256 ("full-disclosure" ECG, FD) QRS and T complexes by using software developed by the authors [3, 6-7] to generate results for: (1) the spatial mean QRS-T angle, derived by using the Frank-lead reconstruction technique of Kors et al.[8], and (2) parameters of QRS and T-waveform complexity derived by SVD, for example the PCA ratio, the relative T-wave residuum (rTWR) [3, 9], and the nondipolar (NDPV) and dipolar voltage (DPV) equivalents [10] of the QRS and T waveforms, respectively.

Several variability parameters of beat-to-beat QTV and RRV that have been described in previous publications [7, 11-13] were again evaluated over 256 beats through custom software programs [12]. These included: the standard deviation of normal to normal RR intervals (SDNNr); the "QT variability index" (QTVI) in lead II; and the "unexplained" part of the QT variability. For the latter, the QTV signal in lead II was decomposed into two parts, one part that can be accounted for by the concomitant HRV and/or by the concomitant variability of the QRS-T angle and ECG voltages, and the other part representing the "unexplained" part of QTV (UQTV) [7, 12]. Among conventional ECG parameters we evaluated the heart rate, 12-lead QRS amplitudes, frontal plane QRS axis, and the PR, P-wave, QRS and Bazett-corrected QT (QTc) intervals derived from the 10-sec "snapshot" conventional ECG.

The reliability of results from each continuous parameter was quantified in terms of the intraclass (intrasubject) correlation coefficient (ICC). This coefficient should approach unity for measures with good diagnostic capability [14, 15].The intra-subject reproducibility of results from each continuous parameter was evaluated by calculating the coefficient of variation (CV). Smaller CVs reflect more reproducible results. ICCs and CVs were calculated through a one-way analysis of variance (ANOVA) with the results of each individual parameter as dependent variables using Stata software (College Station, TX).

III. RESULTS

In the Year-to-Year study (Table I), QRS axis was the most reliable of all parameters from year-to-year (ICC of 0.976), whereas QRSNDPV was the most reliable of the advanced ECG parameters. The rTWR and the PCA ratio of the T

wave from snapshot recordings were the least reliable parameters, while all other parameters had ICCs greater than 0.65. CVs for conventional ECG parameters such as QRS axis, 12-lead QRS voltage and HR were all below 6%, lower than those for most advanced ECG parameters. In the Month-to-Month study (Table II), QRS axis was again the most reliable (ICC of 0.983) of all parameters. QRSNDPV, TDPV, spatial mean QRS-T angle and UQTV in lead II were more reliable than all conventional ECG parameters other than QRS axis and 12-lead QRS voltage. Interestingly, QTc - a parameter that clinically is already in widespread use - was the least reliable parameter, with an ICC of 0.347. In the Supine/Seated study (Table III), the only parameter that changed significantly from the supine to the seated position was QTVI in lead II. Results from the snapshot (SS) and full-disclosure (FD) recordings were almost identical for TDPV, QRSNDPV, and the spatial mean QRS-T angle.

TABLE I.   YEAR-TO-YEAR STUDY

Parameter	ICC	CVI
QRS Axis (°)	0.976	5.800
12 Lead QRS Voltage (mV)	0.954	0.600
QRSNDPV (µV , FD)	0.939	1.600
Spatial Mean QRS-T Angle (°, FD)	0.872	6.000
QTc (ms)	0.791	0.500
SDNNr (ms)	0.764	4.500
UQTV (II, units)	0.683	13.900
QTVI (II, units)	0.663	8.700
rTWR (Ln, SS)	0.564	10.300
T-Wave PCA ratio (%, SS)	0.527	15.500

TABLE II.   MONTH-TO-MONTH STUDY

Parameter	ICC	CVI
QRS Axis (°)	0.983	5.400
Spatial Mean QRS-T Angle (°, FD)	0.950	3.300
SDNNr (ms)	0.862	4.100
QTVI (II, units)	0.614	8.100
QTc (ms)	0.347	0.800

TABLE III.   SUPINE/SEATED STUDY

Parameter	ICC	CVI
QRS Axis (°)	0.966	7.400
SDNNr (ms)	0.950	2.800
QRSNDPV (µV)	0.926	1.800
Spatial Mean QRS-T Angle (°)	0.918	3.700
QTc (ms)	0.800	0.500
UQTV (II, units)	0.771	11.600
QTVI (II, units)	0.580	15.400

IV.   DISCUSSION AND CONCLUSION

Our results confirm our hypothesis that in healthy subjects, the spatial mean QRS-T angle and the QRSNDPV yield more reliable and reproducible results than parameters such as QTVI that are presumably more affected by autonomic nervous system activity [16]. QTVI nonetheless had somewhat better reproducibility, as quantified by CV, in this study than in a previous study [2], possibly due in part to our more automated method for deriving QTVI [12, 17]. Like QTVI, the T-wave complexity parameters such as the T-wave PCA ratio and rTWR also yielded somewhat less reliable and reproducible results than the spatial QRS-T angle and most conventional ECG parameters.

Limitations. Only a small number of asymptomatic individuals participated in this study. Thus R&R of results were not tested in individuals with known cardiac disease. Further study is therefore needed to verify the R&R of the above-mentioned parameters in diseased individuals.

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