TMSJ TURKISH MEDICAL STUDENT JOURNAL

Turk Med Stud J 2023;10(1):9-12
DOI: 10.4274/tmsj.galenos.2023.2022-9-2

ORIGINAL ARTICLE

A RELIABLE WAY FOR DIGITIZATION AND INTEGRAL ANALYSIS OF PAPER ELECTROCARDIOGRAM

Ahmet Taş[1], Yaren Alan[1], İlke Kara[2], Fatih Sezer[1], Muhammed İkbal Bayhan[1], Ali Yekta Dönmez[3], Dilara Türkmen[1], Çağla Kitaplı[1]

[1]İstanbul University School of Medicine, İstanbul, TÜRKİYE
[2]Bahçeşehir University School of Medicine, İstanbul, TÜRKİYE
[3]İstanbul Technical University School of Electrical and Electronics Engineering, Department of Control and Automation Engineering, İstanbul, TÜRKİYE

ABSTRACT

Aims: In this paper, we aim to present our designated digitization tool and interrogate its reliability and feasibility by comparing ST shift, ST area, T-amplitude, and QT interval measurements from three observers.

Methods: Fifty ST elevation myocardial infarction electrocardiograms were digitized and analyzed offline by three investigators blindly via in-house developed software in MATLAB environment. Measurements were compared with analysis of variance and Friedman's test, and correlations were quantified via Pearson's and Spearman's tests.

Results: Six electrocardiogram records were excluded prior to digitization due to inadequate quality. Mean ST shift (0.19±0.27, 0.21±0.27, 0.19±0.27 mV, p=409), ST area (0.0841±0.1069, 0.0885±0.0981, 0.0871±0.1113 mV sec, p=0.792), T-amplitude (0.59±0.42, 0.59±0.40, 0.57±0.38 mV, p=0.071), and QT interval measurements (0.35±0.07 sec, 0.36±0.06 sec, 0.36±0.05 sec, p=0.256) of three observers were not statistically different. All observer pairs showed significant and substantial correlations in all four parameters with correlation coefficients ranging between 0.803-0.974 (p<0.001 was for all correlations between each paired observer).

Conclusion: Digitization of paper electrocardiogram records enables integral (area) analysis in paper records and more detailed analysis for researchers with paper electrocardiogram archives or lack of signal recording opportunity. Our designated publicly available tool can be reliably used in this process.

Keywords: Electrocardiogram, digitization, myocardial infarction, ST segment area, integral

INTRODUCTION

Electrocardiogram (ECG) is a widely employed, low-cost diagnostic tool that holds an irreplaceable place in current clinical practice. In the era of data digitization, most clinics continue to use paper records. This lack of digital data inevitably prevents researchers from postprocessing recorded ECG into more usable forms in a context-dependent manner, which is especially important in experimental and novel concepts.

Digitization of paper ECG (p-ECG) records may enable researchers to expand their analysis beyond simple voltage and interval assessment to include more complex examinations including static and dynamic indices such as ST area (integral). Integral analysis of ECG segments has been previously assessed in several studies and repeatedly shown to be relevant in physiopathological aspects (1-6). Additionally, processing of records (e.g., noise removal, ensemble averaging, magnification of amplitudes) becomes possible.

In this context, we aim to present our designated digitization tool and interrogate its reliability and feasibility by comparing ST shift, ST area, T-amplitude, and QT interval measurements of three observers.

Address for Correspondence: Ahmet Taş, İstanbul University School of Medicine, İstanbul, TÜRKİYE
e-mail: ahmettas.cor@gmail.com
ORCID IDs of the authors: AT: 0000-0002-1944-2576; YA: 0000-0002-6204-2391; İK: 0000-0003-0770-4142; FS: 0000-0002-5099-933X; MİB: 0000-0002-6986-5876; AYD: 0000-0001-8061-6232; DT: 0000-0002-2914-0635; ÇK: 0000-0001-7056-0474
Received: 19.09.2022 Accepted: 25.01.2023

Cite this article as: Taş A, Alan Y, Kara İ et al. A reliable way for digitization and integral analysis of paper electrocardiogram. Turk Med Stud J 2023;10(1):9-12.

Copyright@Author(s) - Available online at https://www.turkmedstudj.com/

OPEN ACCESS

MATERIAL AND METHODS

ECG Records

We have used the strongly anonymized, publicly available, and open ECG records of Khan et al. (7). Ethical statements and conditions for the use of this open dataset can be found in the related data article (8). ECG segmentation was made in concordance with American Heart Association/American College of Cardiology recommendations (9). The end of the ST segment (=T wave beginning) for ST integral calculation was determined as previously described (1). The digitization process necessitates two steps. Firstly, plot representing the ECG signal on paper should be extracted. For the first part of the task, we integrated a previously designed code by Jung (10), which creates 2-dimensional matrices depicting the plot via pixel-level color detection on images (in our case scanned p-ECG records), that enables plotting any given images on Cartesian coordinate system. Next, calibration as well as amplitude, interval, and integral analyses of interested segments are made by the MATLAB software (MATLAB R2021b, The MathWorks, Inc., Natick, Massachusetts, United States), this software enables the user to select predefined segments by clicking or brushing following the on-screen shown directions (11). Figure 1 shows an example of the digitization process.

Protocol

After visual evaluation, one investigator picked and cropped an ECG segment with manifest ST shifts consisting of three consecutive beats in each of 50 ECG records of acute myocardial infarction. Three other investigators (intern doctors) blindly digitized and analyzed the cropped ECG parts. Another investigator merged and analyzed the data.

Statistical Analysis

Standard statistical tests were used. Continuous variables were expressed as mean ± standard deviation. The normality of variables was assessed quantitively by Shapiro-Wilks test and visually by histogram. Correlation coefficients were calculated with Pearson's and Spearman's tests for parametric and non-parametric data, respectively. Bland-Altman analysis was conducted to examine mean differences in observer pairs. One-Way analysis of variance (ANOVA) and Friedman's tests were used to assess intergroup differences in parametric and non-parametric data, respectively. Paired t-test was used when comparing repeated measurements from the same observer. PA p-value of <0.05 was considered statistically significant. All data were blindly analyzed offline using SPSS (v28.0.1.1 IBM).

RESULTS

Six ECG records were excluded prior to digitization by the principal investigator due to the lack of a stable isoelectric line in the cropped ECG part. Forty-four ECGs were digitized and analyzed by three blinded investigators.

ECG Characteristics

Electrocardiogram characteristics and comparisons between mean measurements are demonstrated and compared in Table 1 and Figure 2. Figure 3 shows a correlation between paired observers. Bland-Altman plots for ST shift and ST Integral of paired observers are provided in Figure 4.

ST Shift

Mean ST shifts were 0.19±0.27, 0.21±0.27, and 0.19±0.27 mV for observers 1, 2, and 3, respectively, and it did not significantly vary between observers (Friedman's test, p=0.409). Measured ST shift magnitudes were highly correlated between observers (observer 1-2: r= 0.974, p<0.001; observer 1-3: r= 0.940, p<0.001; observer 2-3: r= 0.951, p<0.001).

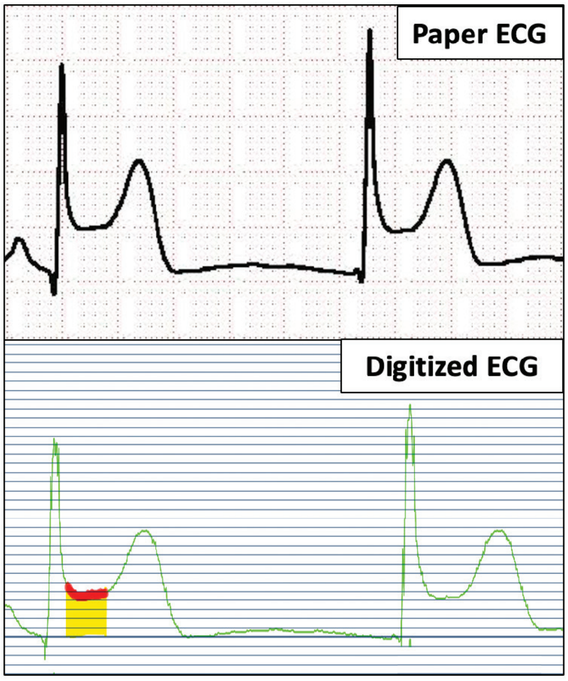

Figure 1: Paper ECG record (top) and ST integral (yellow area) analysis on digitized version (bottom) (Horizontal lines are not calibrated).

ECG: Electrocardiogram

Table 1: Comparison of mean measurements.

	Observer 1	Observer 2	Observer 3	P value
ST shift (mV)	0.19±0.27	0.21±0.27	0.19±0.27	0.409
ST area (mV sec)	0.0841±0.1069	0.0885±0.0981	0.0871±0.1113	0.792
T-amplitude (mV)	0.59±0.42	0.59±0.40	0.57±0.38	0.071
QT (sec)	0.35±0.07	0.36±0.06	0.36±0.05	0.256

One-Way ANOVA (ST area) and Friedman's tests (others) for parametric and non-parametric measurements, respectively.

ST Segment Integral

Mean ST integral were 0.0841±0.1069, 0.0885±0.0981, and 0.0871±0.1113 mV sec for observers 1, 2, and 3, respectively, and measurements were not statistically different from each other (ANOVA, p=0.792). Remarkable intergroup correlations were observed. Correlation coefficients (r) were 0.940 (O1-O2, p<0.001), 0.915 (O1-3, p<0.001) and 0.888 (O2-3, p<0.001).

T-amplitude

Differences between measured T-amplitude values were statistically insignificant (0.59±0.42, 0.59±0.40, 0.57±0.38 mV for O1, O2, and O3, respectively: Friedman's test: p=0.071). Remarkable interobserver correlations were present (O1-O2: 0.840, O1-O3: 0.871, O2-O3: 0.982; p<0.001).

QT Interval

All measurements obtained from 3 observers were significantly correlated with each other, and the mean differences were irrelevant (O1: 0.35±0.007 sec, O2: 0.36±0.06 sec, O3: 0.36±0.05 sec; Friedman's test p=0.256). Finally, correlation coefficients were remarkable in each observer pair (O1-O2 r: 0.841, O1-O3 r: 0.803, and O2-O3 r: 0.888, p<0.001).

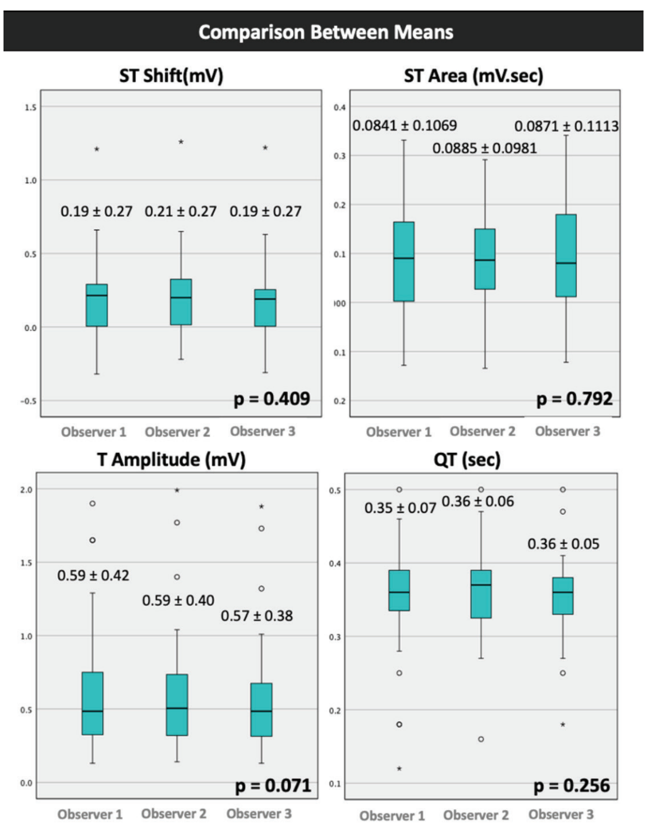

Figure 2: Comparison of mean measurements between 3 observers. ANOVA and Friedman's tests were used for parametric (ST area) and non-parametric data (others), respectively. The difference between mean values of measured ST shift, ST area, T-amplitude, and QT were not statistically significant. N=44 for all observers.

Intraobserver Reliability

In 44 ECGs, repeated ST shift measurements of observer 2 significantly correlated to initial measurements (r: 0.99 p<0.001), and mean measurements were numerically identical (0.21±0.27 mV vs. 0.21±0.27 mV, p=0.309).

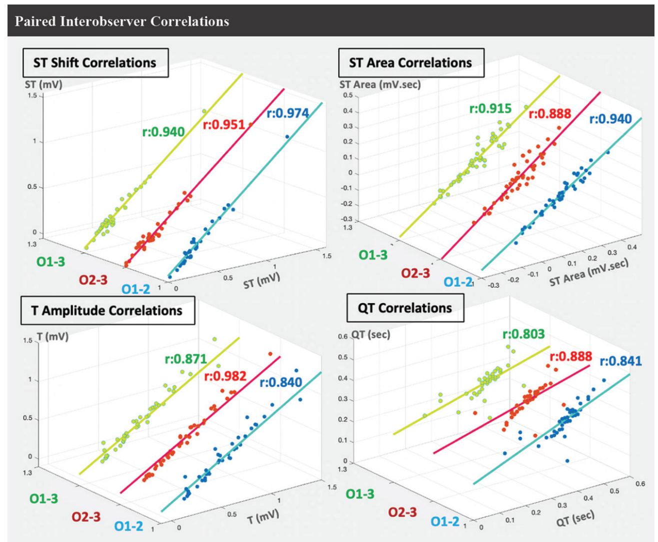

Figure 3: Paired correlations between observers 1, 2, and 3 (O1, O2, O3). Correlations between O1 and O2 were demonstrated with blue line, O2-O3 with red line, O1-O3 with green line. All demonstrated correlations coefficients were statistically significant (p<0.001). N=44 for all observers.

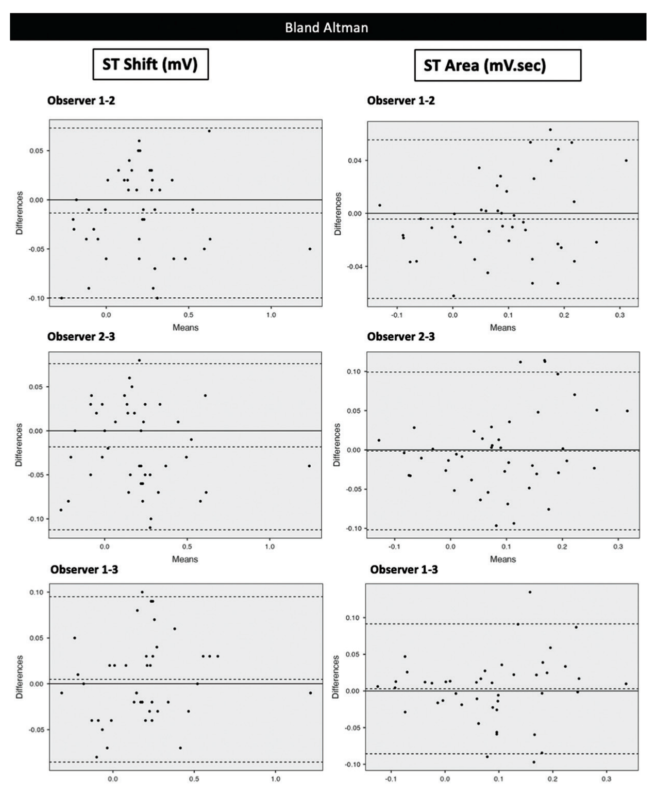

Figure 4: Bland-Altman plots for ST shift, ST area, T-amplitude and QT values of observer pairs.

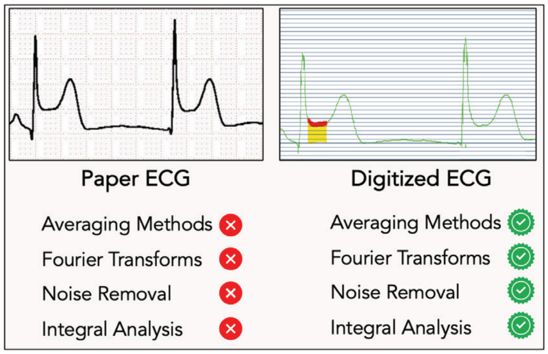

Figure 5: Paper ECG and digitized ECG.

ECG: Electrocardiogram

DISCUSSION

In this study, we have compared ST shift, ST integral, T-amplitude, and QT interval measurements from p-ECG records digitized by a simplistic in-house developed software by three investigators. In all four parameters, the measurements of three observers showed significant and substantial correlations and there were no statistically significant differences in measured values. In the light of these results, we propose that our publicly available software can be reliably used in p-ECG digitization and analysis.

Integral analysis of ECG segments has been previously assessed in several studies and repeatedly shown to be relevant in physiopathological aspects (1-6). Bigler et al. (1) have recently demonstrated that ST integral in intracoronary ECG has remarkable sensitivity for myocardial ischemia. On the other hand, postprocessing of ECG with a miscellanea of techniques has been assessed in several concept studies so far, including root mean squared ECG for long QT syndrome detection, signal averaged ECG inducible ventricular tachycardia prediction, and Fourier transforms for cardiovascular pathology classification (12-14). All of these inherently necessitates digitized version of ECG (Figure 5). In parallel, researchers wishing to utilize their p-ECG archives to train machine learning models share the same need. With the use of publicly available p-ECG digitization tools, researchers with large p-ECG archives can utilize these methods.

Future Directions

We aim to deploy a fully automated follow-up version of this software by employing machine learning algorithms, which is required for more rapid digitization of large p-ECG archives.

Limitations

Comparison between measurements of experienced cardiologists could reinforce the reliability of the software.

CONCLUSION

A simplistic software can reliably digitize p-ECG records, which can enhance cardiovascular research by enabling inclusion of p-ECG records in experimental research that otherwise would be limited to signal ECG.

Ethics Committee Approval: N/A

Informed Consent: N/A

Conflict of Interest: The authors declared no conflict of interest.

Author Contributions: Concept: A.T., Design: A.T., Y.A., İ.K., F.S., M.İ.B., A.Y.D., D.T., Ç.K., Data collection or processing: A.T., Y.A., İ.K., F.S., M.İ.B., A.Y.D., D.T., Ç.K., Analysis or Interpretation: A.T., Y.A., İ.K., F.S., M.İ.B., A.Y.D., D.T., Ç.K., Literature Search: A.T., Y.A., İ.K., F.S., M.İ.B., A.Y.D., D.T., Ç.K., Writing: A.T., Y.A., İ.K., F.S., M.İ.B., A.Y.D., D.T., Ç.K.

Financial Disclosure: The authors declared that this study received no financial support.

REFERENCES

1. Bigler MR, Zimmermann P, Papadis A et al. Accuracy of intracoronary ECG parameters for myocardial ischemia detection. J Electrocardiol 2021;64:50-7. [Crossref]
2. Hänninen H, Takala P, Rantonen J et al. ST-T integral and T-wave amplitude in detection of exercise-induced myocardial ischemia evaluated with body surface potential mapping. J Electrocardiol 2003;36(2):89-98. [Crossref]
3. Okin PM, Bergman G, Kligfield P. Heart rate adjustment of the time-voltage ST segment integral: identification of coronary disease and relation to standard and heart rate-adjusted ST segment depression criteria. J Am Coll Cardiol 1991;18(6):1487-92. [Crossref]
4. Hänninen H, Holmström M, Vesterinen P et al. Magnetocardiographic assessment of healed myocardial infarction. Ann Noninvasive Electrocardiol 2006;11(3):211-21. [Crossref]
5. Okin PM, Kligfield P. Effect of measurement interval on performance of the ST integral for the identification of three-vessel coronary disease. J Electrocardiol 1992;25 Suppl:35-9. [Crossref]
6. Forlini FJ, Cohn K, Langston MF Jr. ST-segment isolation and quantification as a means of improving diagnostic accuracy in treadmill stress testing. Am Heart J 1975;90(4):431-8. [Crossref]
7. Khan AH, Hussain M. ECG Images dataset of cardiac patients. Mendeley Data 2021;2. doi: 10.17632/gwbz3fsgp8.2. [Crossref]
8. Khan AH, Hussain M, Malik MK. ECG Images dataset of cardiac and COVID-19 patients. Data Brief 2021;34:106762. [Crossref]
9. Rautaharju PM, Surawicz B, Gettes LS. AHA/ACCF/HRS recommendations for the standardization and ınterpretation of the electrocardiogram. Circulation 2009;119(10):e241-50. [Crossref]
10. Jung S. Matlab plot digitizer. MATLAB Central File Exchange. (cited 2022 September 11). Available at: URL: https://www.mathworks.com/matlabcentral/fileexchange/97322-matlab-plot-digitizer. [Crossref]
11. GitHub - tasheart/Paper-ECG-Digitization-Analyse. Matlab Digitisation of Paper ECG Records and Area & Voltage & Time Interval Analysis To Enhance Cardiovascular Research. Ahmet Tas & Yaren Alan (2022). (cited 2022 September 11). Available from: URL: https://github.com/tasheart/Paper-ECG-Digitization-Analyse. [Crossref]
12. Lux RL, Sower CT, Allen N et al. The application of root mean square electrocardiography (RMS ECG) for the detection of acquired and congenital long QT syndrome. PLoS One 2014;9(1):e8568. [Crossref]
13. Steinberg JS, Prystowsky E, Freedman RA et al. Use of the signal-averaged electrocardiogram for predicting inducible ventricular tachycardia in patients with unexplained syncope: relation to clinical variables in a multivariate analysis. J Am Coll Cardiol 1994;23(1):99-106. [Crossref]
14. Prasad BVP, Parthasarathy V. Detection and classification of cardiovascular abnormalities using FFT based multi-objective genetic algorithm. Biotechnology and Biotechnological Equipment 2018;32(1):183-93. [Crossref]