SCAN CONVERSION OF CLINICAL ELECTROCARDIOGRAMS

Suave M. Lobodzinski, Monika Kuzminska, Michael M. Laks
California State University
Long Beach, California, USA
slobi@csulb.edu

ABSTRACT

The goal of this research is to develop a simple and inexpensive method for rapid digitization of hard copy ECG records, conversion to a "raw" voltage-time format, transmit them over computer networks to a centralized reading location for re-analysis and over-reading. Free Receiver Operator Characteristic methodology was used to prove a null hypothesis that scan converted hard-copy 12-lead ECGs have the same performance (diagnostic accuracy) in detecting cardiac abnormalities in a test sample as the hard copies of digital ECG records. The results of the FROC study comprising 52 clinical ECGs confirmed that there were no statistically significant differences in diagnostic accuracy between scan converted and digital 12-lead electrocardiograms. The power of the t-test was 93%. The 95% confidence interval in which the real difference lies was [-0.0092, 0.00].

Key words: electrocardiography, scan conversion, free receiver operator characteristic.

1. INTRODUCTION

A typical healthcare enterprise may have ECG equipment from several different medical manufacturers. Different ECG data types such as resting ECG, monitoring ECG, exercise testing, signal averaged ECG and pacemaker tests are all a piece of the assessment that clinicians need to make on their patients. These diverse ECG systems have two common characteristics however: 1) their digital recording format (if any) is proprietary (vendor specific), 2) they all produce standard paper records in either single or 12 lead formats. A multiplicity of digital vendor specific formats and lack of ECG data standardization prevents the inclusion of ECGs into electronic patient records. The situation is further complicated by lack of universally accepted standards for ECG data format and communication. As a result, all ECG vendors developed their proprietary systems for electronic ECG management and storage and thus made impossible to share digital ECG records a multi-vendor environment. A simple and inexpensive method for rapid digitization of hard copy ECG records has been developed to convert printed waveforms into a "raw" voltage amplitude samples, thus facilitating ECG transmission over computer networks, centralized storage in XML format and centralized reading. The advantage of proposed approach is that such ECG scan conversion system will work equally well with ECG equipment from all manufacturers.

2. METHODS

A study sample comprised of 52 randomly selected electrocardiograms from a clinical ECG database comprising Hewlett-Packard HP M1729B TraceMaster ECG System running on HP Vectra computer and a laser printer. All digital 12-lead electrocardiograms in a 4x3 format were printed on a standard ECG paper (type M1737) by a Hewlett-Packard LaserJet 4 printer at 600 dpi resolution. Hard copy ECG records produced by TraceMaster (Hewlett-Packard) electrocardiographs were scanned by a flatbed scanner (Visioneer 8600), processed by a scan converter (Dell 450 Dimension) and transmitted to the ECG Database Server (Dell Power Edge 4200) via a 10BaseT 10 mbps TCP/IP network for archiving. The readers accessed the ECG database from workstations that displayed and printed both scan converted and original ECG studies.

The scan converted ECG waveforms were visually analyzed for presence of artifacts prior to inclusion into a database. Figure 2 shows a visual comparison of scan converted and digital ECG pairs.
Figure 2. Superimposed waveforms of digital and scan converted electrocardiograms.

The Null Hypothesis $H_0$ was: “Digital 12-lead ECGs and scan converted hard-copy 12-lead ECGs have the same performance (diagnostic accuracy) in detecting cardiac abnormalities in a test sample”. We used Free-Response Receiver Operating Characteristic (FROC) experiment \[\] to accept or reject the null hypothesis. FROC is suitable for comparing the diagnostic performance of original and scan converted standard 12-lead electrocardiograms. FROC experiment requires so called "clinical truth" (a consensus diagnosis in our case) as a basis for determination whether readers' diagnostic observation was True Positive (TP) or False Positive (FP). FROC requires the electrocardiographer (reader) to render a binary decision (the presence of a specific abnormality in a given ECG) and state the confidence he/she has in that decision. To test a difference between scan converted and original ECGs an FROC curve was generated for each set of ECGs to be compared and the difference between the area under each curve is analyzed. FROC is well suited to measure the ability of readers to detect multiple abnormalities in the same ECG and to specify their pathology. Two sets of standard 12-lead electrocardiograms were used in Phase I research: a set of original ECGs and a set of their scan converted version all printed on the same type of electrocardiographic paper. A group of expert cardiologists determined the consensus diagnosis for all ECGs used in this study. Hard copies of digital ECGs were then scan converted using a scanner-PC combination and printed on an ECG paper. Three board certified cardiologists read all 104 ECGs (a mix of original and scan converted records) in double blinded multiple reading sessions. The readers were asked to assign a confidence level (1 to 4) to their diagnostic findings on a data entry sheet. Confidence level 4 meant that an abnormality was definitely present and 0 that the abnormality was definitely not present (lowest confidence of abnormality presence). The readers had no knowledge of the total number of cases collected.

3. RESULTS

The calculated areas under the AFROC curves $A_t$ and their S.D. (standard error (S.E.): ($\sigma$, $A_t$)) are summarized below.

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Readers} & \text{Original SD} & \text{Scan Converted SD} & \text{Difference (\(\Delta\))} \\
\hline
\text{Reader 1} & .9641 & .0226 & .9645 & .0264 & -0.000400 \\
\text{Reader 2} & .9483 & .0244 & .9391 & .0303 & 0.009200 \\
\text{Reader 3} & .9555 & .0269 & .9482 & .0267 & 0.000100 \\
\hline
\end{array}
\]

Since the same readers read the same ECGs in both modes (case and reader matching) we used a paired $t$-test to determine whether the observed difference was statistically significant. This statistical test accounts fully for both inter- and intra-reader variability. The results of the FROC study confirmed that there was no statistically significant differences in diagnostic accuracy between scan converted and digital 12-lead electrocardiograms. The power of the $t$-test was 93%. The 95% confidence interval in which the real difference lies was [-0.0092, 0.00].

4. DISCUSSION

An important point that must be made here is that although the paired $t$-test accounts for inter- and intra-reader variability, it does not account for the case sampling variability. This means that the results can not be generalized for the whole population of patients, but are valid only for a particular sample of studies. It is obvious that increasing the number of readers would increase the power of the test. By simulating a third reader who performed like Reader 2 the $H_0$ is still not rejected with a power of 98% ($\alpha = 89\%$) and the 95% confidence interval for the difference is [-0.0087, 0.00]. Inclusion of a simulated 4th reader who performed like Reader 1 the power increases to 98% ($\alpha = 92\%$, $H_0$ not rejected) with a 95% confidence interval of [-0.0061, 0.00].

Figure 3. FROC Curves for 3 readers. TPF – true positive fraction, FPF – false positive fraction.
REFERENCES


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