THE EUROPEAN ST-T DATABASE: DEVELOPMENT, DISTRIBUTION AND USE

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ABSTRACT

The European project for the development of an ST-T annotated database originated from the "Concerted Action" on Ambulatory Monitoring, set up by the European Community in 1985. The goal was to define an ECG database for assessing the quality of Ambulatory ECG monitoring (AECG) systems. After the "Concerted Action", the development of the full database was coordinated by the Institute of Clinical Physiology of the National Research Council (CNR) in Pisa and the Thoraxcenter of the Erasmus University in Rotterdam. Thirteen research groups from 8 countries continued providing AECG tapes and annotating beat by beat the selected 2-channel records, each 2 hours in duration. ST segment and T-wave changes were identified and their onset, offset and peak beats annotated in addition to QRSs, beat types, rhythm and signal quality changes. In 1989 the European Society of Cardiology sponsored the remainder of the project. The first set of 50 records was completed and stored on CD-ROM. It includes more than 200 ST segment and almost 300 T-wave changes. In cooperation with the developers of MIT-BIH Arrhythmia Database, the annotation scheme was revised to be consistent with both MIT-BIH and AHA formats.

INTRODUCTION

The use of ambulatory recording of the electrocardiogram (AECG) for diagnosis and monitoring is quite common in clinical practice, but several matters concerning its effectiveness and applicability are still controversial. Some of these issues will be solved only through further research. Others are best addressed by collaborative efforts of researchers, clinicians, and standards and regulatory organizations; these include definitions of events to be detected and of diagnostic criteria, performance standards, and guidelines for clinical use. For many years, the clinical application of the AECG technique was confined to arrhythmia monitoring. A Special Report of the American Heart Association(AHA) [1], published in 1985, was dedicated to this topic, but it goes on to state that "detection of asymptomatic ST-segment shifts ... must be considered with caution." The report further recommends the use of standard databases, containing ECG strips, as a method for assessing the quality of the instrumentation. The AHA and MIT-BIH databases have been used for evaluating arrhythmia detectors. Meanwhile, interest has been growing in using the AECG for the analysis of ST-T changes to diagnose myocardial ischemia. A report written in 1989 by a joint committee of the AHA and of the American College of Cardiology [2] states: "There is now convincing evidence that ST-segment shifts of the ischemic type can be detected by AECG ..." In particular, recurrent ischemia, most of which is silent and occurs during daily life at low activity and heart rate levels, may be detected by AECG [3,4]. In spite of this evidence, most instrumentation provided for AECG analysis is inadequately equipped for detecting ST-T changes, but is mainly concerned with arrhythmia detection. One of the reasons appears to be the lack of standard definitions of ischemic events and the controversies about their meaning. The initiation of a standard approach to the detection and interpretation of ST-T changes was made by the "Concerted Action" on Ambulatory Monitoring, set up by the European Community in 1985 [5]. As reported at previous Computers in Cardiology conferences [6,7], the ECG project concentrated on setting up an annotated database of ST-T changes. The Concerted Action ended in 1986 after setting up a small prototype database. The development of the full database was further coordinated by a joint effort of the CNR Institute of Clinical Physiology in Pisa and the Thoraxcenter of the Erasmus University in Rotterdam.

DEVELOPMENT OF THE EUROPEAN ST-T DATABASE

The goal of the project for the development of the ST-T Database was to define an ECG database to be used as reference for assessing the quality of AECG analyzers. Using the experience gained from similar databases of rhythm abnormalities [8-11], the experts participating to the pilot study agreed to concentrate on the problem of defining a standard for detecting abnormalities of the ST-T interval. A set of rules was established by the participating cardiologists for defining significant ST-T changes. At this stage, the experience gained at the CNR Institute of Clinical Physiology, when annotating ST-T changes for the VALE database [12], proved useful.

Definition of ST-T episodes

The characteristics of "ST-T episodes" were defined as follows:

a. Minimum duration: 30 seconds.
b. ST segment changes: ST segment deviations of 0.1 mV from the reference value, measured 80 ms after the J point, are considered to start or end an ST segment change. In cases of sinus tachycardia (heart rate > 120 bpm) ST deviation should be measured 60 ms after the J point.
c. T wave changes: T wave amplitude deviations of 0.2 mV from the reference value are considered to start or end a T wave change, while deviations of 0.4 mV start or end an "extreme" T wave change.
d. Beginning and end of the ST-T change episodes: a 0.05 mV threshold is applied to locate the first and the last beat of each ST change, whereas a 0.2 mV threshold is applied for T wave amplitude changes.
e. Successive episodes are considered as separate only if there is a baseline interval of at least 30 seconds. Moreover, the extreme ST or T deviation of each episode is identified and the corresponding ECG displacement represents its intensity.

Organization

Various European research groups involved in AECG analysis participated in the project during the initial phase (see

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Appendix). Thirteen groups from eight countries (see Table I) took part in the final working phase providing AECG tapes and contributing to the beat-by-beat annotation of those recordings which were selected for inclusion in the database. A Coordinating Group was established at the CNR Institute of Clinical Physiology, whose duties were interacting with the annotators, soliciting the submission of tapes according to agreed-upon criteria, performing operations for database generation, and finally supervising annotations and inserting them into the database. The Coordinating Group in Pisa and the Group at the Thoraxcenter of the Erasmus University in Rotterdam continued to develop the database after the end of the pilot study, supported by the European Community. This was possible through the voluntary participation of the thirteen research groups who continued providing tapes and annotating ECG records. In 1989, the European Society of Cardiology agreed to sponsor the remainder of the project, providing both financial and scientific backing so as to enable the completion of the database. Finally, the developers of MIT-BIH database assisted in producing the first edition of the European ST-T Database on CD-ROM.

TABLE I
Contributing research groups

ARHUS (Denmark)	UNIV.DEPT.CARDIOLOGY (Bjerregaard)
ATHENS (Greece)	UNIV.MEDICAL SCHOOL (Anthopoulos)
BARCELONA (Spain)	HOSP.LA SANTA CRUZ (Torner)
COPENHAGEN (Denmark)	RIGSHOSPITALET (Pietersen)
HEIDELBERG (F.R.G.)	III MEDICAL CLINIK (Hoberg)
ODENSE (Denmark)	UNIVERSITY HOSPITAL (Moller,Mickley)
PARIS (France)	GROUPE PITIE'-SALP. (Fillette,Ghanem)
PARIS (France)	HOPITAL LARIBOISIERE (Maisonblanche)
PAVIA (Italy)	C.MED.MONTESCANO (La Rovere,Del Rosso)
PISA (Italy)	FISIOLOGIA CLINICA (Biagini,Mazzei)
ROTTERDAM (Netherlands)	THORAXCENTER (Algra, Le Brun)
STRAUBING (F.R.G.)	ELISAB.KRANKENHAUS (Von Olshausen)
TAMPERE (Finland)	UNIV.CENTRAL HOSP. (Parviainen)

Characteristics of the database

Continuous two-channel ECG records, each 2 hours in duration, were taken from contributed recordings and digitized at a rate of 250 samples per channel per second. Selection criteria were established [6] in order to obtain a representative sample of ECG abnormalities in the database. Each record contains at least one ST-T episode, which is related to diagnosed or suspected myocardial ischemia. Each record was accompanied by a clinical report including information concerning pathology, drug treatment, electrolyte imbalance, and additional technical information. For each case, the two leads which were considered most likely to reveal ST-T changes were recorded. In fact, the analysis of myocardial ischemia often required monitoring specific precordial regions. Thus the electrodes were placed on the chest in various (not necessarily standard) locations. Normal QRS complexes are usually prominent on one channel; they are sometimes difficult to discern in the other channel (especially if obtained from an inferior lead), although both ST-T changes and ectopic beats can be more prominent.

Almost 100 records were processed by the Coordinating Group using the following protocol:

a) local selection by a research group providing the tape;
b) digitization and preprocessing;
c) provisional admission to the database and preparation of two special printouts for annotation;
d) annotation by two different groups, neither of which was the contributor of the tape;
e) comparison of the two sets of annotations.

Annotations

An initial set of beat labels was produced by a slope-sensitive QRS detector, which marked each detected event as a normal beat. Each 2-hour two-channel ECG record was printed out in full disclosure format, each page two minutes in duration, with the addition of QRS detection marks, trend plots of the ST segment displacement and of the T wave amplitude, and boxes for checking annotation operations. The computer-generated beat labels were manually checked on those printouts and possibly edited. Two copies of such a printout for each record were submitted to two cardiologists for beat by beat annotation. Each cardiologist made annotations only of those cases provided by other centers. A tape-specific ruler was also provided for measuring time intervals and ECG signal displacements (see reference 6). On this ruler a heart rate scale is included, as well as a two-channel reference QRST complex, taken from the first 30 seconds of each record. This QRST complex is printed on the ruler and it serves as reference for measuring ST-T deviations. To aid in identifying ST-T episodes, the annotators were given trend plots showing the mean values of the heart rate and the ST-T parameters at 10-second intervals. The cardiologists worked independently to annotate QRS complexes, episodes of change in ST segment or T wave morphology, rhythm changes, and signal quality. Episodes of ST segment and T wave changes were identified in both leads (using the predefined criteria), and their onsets, extrema, and offsets were annotated. Annotations from the two cardiologists were compared and the differences were resolved by a cardiologist of the coordinating group. This method assumes that the third cardiologist is able to make a more reliable judgement since he knows both sets of annotations (see reference 7).

A high degree of compatibility was maintained with the existing MIT-BIH Arrhythmia Database and the AHA Database for the Evaluation of Ventricular Arrhythmia Detectors. Several annotation codes were newly defined for the European ST-T Database, and were added to those previously defined for the MIT-BIH and AHA Databases. In cooperation with the developers of MIT-BIH database, the annotation scheme was revised to be consistent with both AHA and MIT-BIH formats. ST-T changes are annotated in addition to rhythm and signal quality changes [see Table II].

The first edition on CD-ROM

The first edition of the database has now been completed and stored on CD-ROM. It contains fifty 2-channel ECG records, each two hours in duration. The MIT-BIH database software was modified to accomodate the extended annotations of the European ST-T Database. The library routines and several application programs for accessing the database, have been included on CD-ROM (in binary form for MS-DOS systems). There are more than 200 episodes of ST segment change, and nearly 300 episodes of T-wave change (see Table III), with durations ranging from 30 seconds to several minutes, and extrema ranging from 100 microvolts to more than one millivolt. The database is available for distribution [13] and is accompanied by an 800 page manual, which contains annotated full-disclosure of the complete database, selected high-resolution plots of interesting segments, a compact clinical report and tables representing the database contents.

TABLE II
List of main annotation codes

- BEAT Annotation codes:
  - N Normal beat
  - S Supraventricular beat
  - V Premature Ventr. Contraction
  - ...
- NON-BEAT annotation codes:
  - ST segment change
    - ST+ ST segment elevation
    - AST+"n" peak of "n" microvolts
    - ST- ST segment depression
    - AST-"n" peak of -"n" microvolts
  - T-wave change
    - T+ T-wave elevation
    - T++ T-wave elevation >.4 mV
    - AT+"n" peak of "n" microvolts
    - T- T-wave depression
    - T-- T-wave depression < -.4 mV
    - AT-"n" peak of -"n" microvolts
  - Rhythm change
    - AFIB atrial fibrillation
    - AFL atrial flutter
    - B ventricular bigeminy
    - VT ventricular tachycardia
    - ...
  - Signal quality change
    - moderate level noise
    - high level noise

TABLE III
Summary of main events

Total of beats	431524
SVPC	640
PVC	1329
Ventricular couplets	41
" runs	25
ST elevation episodes	81
ST depression "	143
T elevation "	161
T depression "	128

Performance of Cardiologist Annotators

The annotations provided by the pair of independent cardiologists were analyzed in order to evaluate the reproducibility of the human expert opinions. The reference annotations (as determined by the supervising cardiologist) were used to determine the sensitivity and positive predictive accuracy of each annotating cardiologist. Table IV summarizes the performance of the best and worst annotators in detecting episodes of ST elevation (ST+), ST depression (ST-), T-wave elevation (T+), and T-wave depression (T-). In tables IV and V, the best annotator is the one whose opinion is closer to the final decision. Thus the comparison between the annotations provides an estimate of their variability. Successfully reconciling the annotations is obviously crucial to the reliability of the reference database. However it is very difficult to determine an acceptable inter-human variability from the published data (see reference 7). This variability is strongly dependent on the medium used, the level of the displacement of the ST changes, the slope of the ST trend and probably on the specific experience and belief of the observer.

TABLE IV
ST-T Annotations: Sensitivity/Pos.Pred.Accuracy

Episode (no.)	Best Annotator	Worst Annotator
ST+ (81)	83/90	70/85
ST- (143)	80/93	71/85
T+ (161)	66/98	60/92
T- (128)	63/99	53/85

Clearly, ST changes are detected better than T-wave changes and sensitivity is lower than PPA. In order to determine the influence of the magnitude of ST displacement on the annotator accuracy, the pooled data for ST changes were divided into three groups: episodes with displacement between 0.1 and 0.15 mV, between 0.15 and 0.25 mV and episodes with displacement greater than 0.25 mV. Table V shows the resulting sensitivity and PPA for both annotators. The results start to be acceptable for ST-displacements greater than 0.15 mV. PPA data are still better in the same range of displacement. The annotation protocol of the project required T-wave displacements to be annotated starting from 0.2 mV. Sensitivity data seem acceptable only for displacements greater than 0.35 mV, while PPA data are better also for lower values. Many cardiologists are not well acquainted with the significance of minor T-wave changes; this may explain the difference between sensitivity and PPA.

TABLE V
ST-T Annotations: Sensitivity/Pos.Pred.Accuracy

Range(mV)	Best Annotator		Worst Annotator	
	ST+	ST-	ST+	ST-
0.10-0.15	55/83	54/76	33/55	46/57
0.15-0.25	89/86	90/95	64/90	73/83
>0.25	92/97	92/98	97/92	79/100
	T+	T-	T+	T-
0.20-0.25	57/96	52/100	37/87	55/74
0.25-0.35	52/100	59/100	48/92	46/95
>0.35	84/98	79/97	87/93	62/86

Use of the database

The European ST-T Database is intended to be used mainly for evaluating the performance of algorithms for ST-T change detection. Version 4.0 (February,1990), and later versions, of the MIT-BIH Database software can be applied to the European ST-T Database. MS-DOS users may link their application programs with the binary version of the library provided on the CD-ROM. A subset of the programs developed for the MIT-BIH database is also included on CD-ROM. The database software, including many additional applications, is available separately in C source format for MS-DOS, UNIX, and other systems.

Criteria for testing ST-T change detectors differ from those used for arrhythmia detector evaluation because of the need to cope with the uncertainty in the identification of the time extrema of ST-T episodes. Experience in using the database will be helpful in guiding the development of algorithms for evaluating ST-T change detectors.

CONCLUSIONS

The European ST-T Database represents the result of a multinational effort for defining a standard in the analysis of ST-T changes in AECG. It fills a gap in the scope of previously developed databases, which are complementary in evaluating the performance of analysis systems. The compatibility of the annotation scheme with both MIT-BIH and AHA formats allows the MIT-BIH Database software to be used with the European ST-T Database, as a basis for a definition of a standard protocol for evaluating performance. The variety of selected ST-T episodes,related to diagnosed or suspected ischemia, is extremely valuable in studying correlations between ECG patterns and myocardial ischemia. The availability of two arrhythmia databases and an ST-T change database makes feasible the task of a certification center for assessing the quality of AECG instrumentation.

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13. European ST-T database distributor: Institute of Clinical Physiology, Computer Laboratory, via Trieste n.41, 56100 Pisa, Italy.

APPENDIX

The European ST-T Database was produced as a result of the European Community's "Concerted Action on Ambulatory Monitoring" (project II.2.4, Ambulatory Monitoring, contract MR049; see references 1 and 2), which was begun in 1985 under the supervision of the COMAC-BME. Funding from the European Community supported development of the annotation protocol and of a small prototype database. In 1989, the European Society of Cardiology agreed to sponsor the remainder of the project.

The project was directed by a Project Management Group, whose members were: D. Clement (Belgium), P. Coumel (France), C. Marchesi (Italy), F. Stott (United Kingdom), C. Zeelenberg (Netherlands). The protocol for annotating ST-T changes was developed by the combined efforts of 21 research groups from 12 countries. The leaders of these research groups were: A. Algra (Netherlands), A. Bayes de Luna (Spain), A. Biagini (Italy),P. Bjerregaard (Denmark), S. Chierchia (United Kingdom), C. Contini (Italy), F. Fillette (France), E. Hoberg (Federal Republic of Germany), P. Maisonblanche (France), R. Mark (USA), J.L. Medvedowsky (France), S. Moulopoulos (Greece), K. von Olshausen (Federal Republic of Germany), O. Pahlm (Sweden), E. Sandoe (Denmark), N. Saranummi (Finland), G. Specchia (Italy), A. Taddei (Italy), D. Tayler (United Kingdom), J. Willems (Belgium), Chr. Zywietz (Federal Republic of Germany).

A Coordinating Center was established in the CNR Institute of Clinical Physiology in Pisa for the development of the database. After the Concerted Action, work on database continued by a joint effort of the Coordinating Group in Pisa and the Thoraxcenter of the Erasmus University in Rotterdam (see the list of authors), with the continued voluntary participation of the thirteen research groups.The work of annotating the European ST-T database has been performed by: A. Algra (Netherlands), L.P. Anthopoulos (Greece), A. Biagini (Italy), P. Bjerregaard (Denmark), G. Del Rosso (Italy), F. Fillette (France), N. Ghanem (France), E. Hoberg (Federal Republic of Germany), M.T. La Rovere (Italy), H. Le Brun (Netherlands), P. Maisonblanche (France), M.G. Mazzei (Italy), M. Moller (Denmark), H. Mickley (Denmark), K. von Olshausen (Federal Republic of Germany), T. Parviainen (Finland), A. Pietersen (Denmark), P. Torner (Spain).

Final preparation of the European ST-T Database for the CD-ROM has been performed with the assistance of G.B. Moody of the Massachusetts Institute of Technology, who has also contributed a new version of the MIT-BIH utility software. The software was originally developed for the MIT-BIH Arrhythmia Database project, directed by R.G.Mark.