European Heart Journal (1992) **13**, 1164–1172

The European ST-T database: standard for evaluating systems for the analysis of ST-T changes in ambulatory electrocardiography

A. TADDEI, G. DISTANTE, M. EMDIN, P. PISANI, G. B. MOODY*, C. ZEELENBERG† AND C. MARCHESI‡

*CNR Institute of Clinical Physiology, Pisa, Italy; *Massachusetts Institute of Technology, Cambridge, MA, U.S.A.; †Centre for Med. Informatics, NIPG-TNO, Leiden, Netherlands; ‡Department of Computer Engineering, University of Firenze, Italy*

KEY WORDS: Myocardial ischaemia, ST-T change analysis, annotated ECG database, performance evaluation of instrumentation.

The project for the development of the European ST-T annotated Database originated from a 'Concerted Action' on Ambulatory Monitoring, set up by the European Community in 1985. The goal was to prototype 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 Erasmus University in Rotterdam. Thirteen research groups from eight countries provided AECG tapes and annotated beat by beat the selected 2-channel records, each 2 h in duration. ST segment (ST) and T-wave (T) 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. Recently the 90 records were completed and stored on CD-ROM. The records include 372 ST and 423 T changes. In cooperation with the Biomedical Engineering Centre of MIT (developers of the MIT-BIH arrhythmia database), the annotation scheme was revised to be consistent with both MIT-BIH and American Heart Association formats.

Introduction

The use of ambulatory recording of the electrocardiogram (AECG) for diagnosis and monitoring patients with suspected or ascertained heart disease 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. Annotated ECG databases have been generally available since 1980, when the MIT-BIH Arrhythmia Database was first released. The AHA Database for Evaluation of Ventricular Arrhythmia Detectors was released in several parts during the early 1980s, permitting developers and users of automated arrhythmia detectors to evaluate these detectors reproducibly and to make quantitative performance comparisons among them. During the years since these databases were developed, interest in using ambulatory ECG recordings for detection of myocardial ischaemia has grown, as recording technology has improved to the point at which this application has become feasible. 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 . . .'. Recurrent ischaemia, in particular, most of which is silent and occurs only 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 ischaemic 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] with the goal of defining an ECG database as a reference for assessing the quality of ambulatory ECG analysis systems. Experts from 12 nations participated in the initial phase of the project. Given the existence of two standard arrhythmia databases, and the need to evaluate ischaemia detectors, the participants agreed to concentrate on developing a standard for annotating ST segment and T-wave changes. The European ST-T Database was thus designed to complement rather than to replicate the AHA and MIT-BIH databases. Funding

Submitted for publication on 27 August 1991, and accepted 13 April 1992.

Correspondence: Dr Alessandro Taddei, CNR Institute of Clinical Physiology, via Trieste 41, 56100 Pisa, Italy

0195-668X 92 091164 + 09 $08.00 0

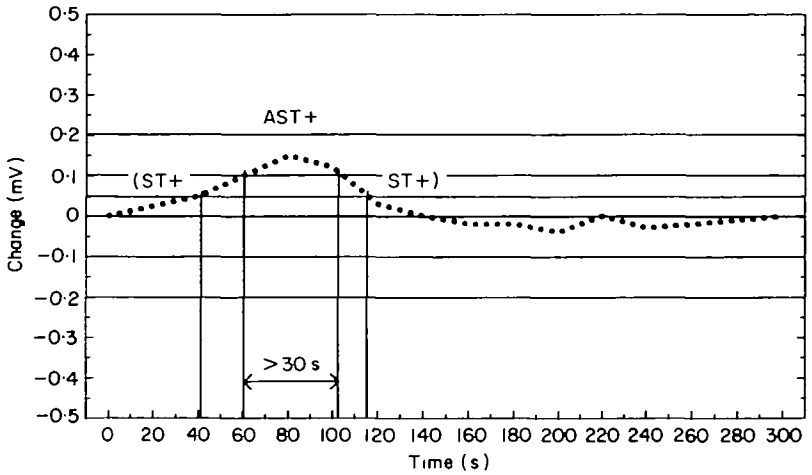

Figure 1 Representation of the typical trend of ST-segment deviation (. . . .) during a positive ST episode. The beginning, peak and end of the episode are annotated.

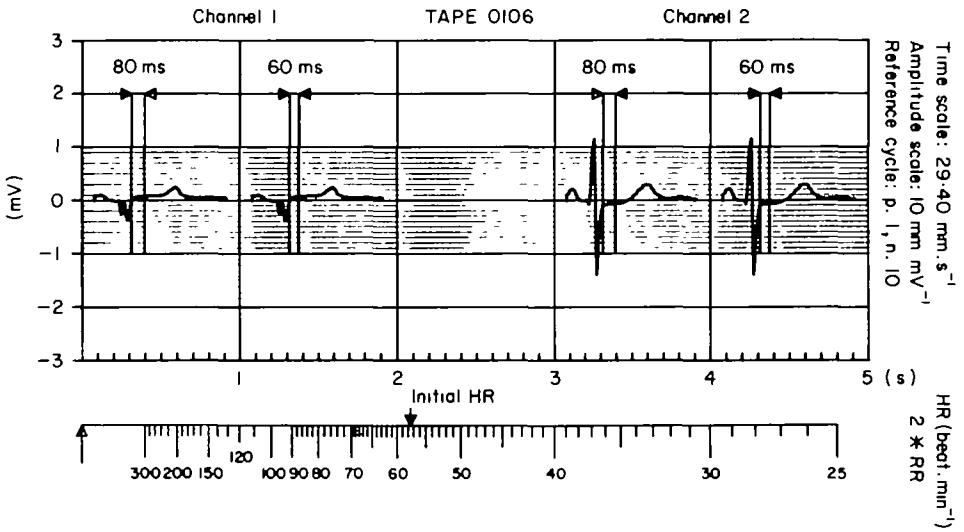

Figure 2 Example of tape-specific ruler applied for measuring ST-T deviations and time interval durations.

from the European Community supported development of the annotation protocol and of a small prototype database. The Concerted Action ended in 1986. Development of the database was continued by the joint efforts of the Institute of Clinical Physiology of the National Research Council (CNR) in Pisa (Italy) and of the Thoraxcenter of Erasmus University in Rotterdam (Netherlands), with the voluntary participation of 13 research groups from eight countries which provided ECG recordings and contributed to the demanding work of annotating them. Recently, 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 and distribution of the database.

Methods

A pilot study was set up, using the experience gained from similar databases of rhythm abnormalities. The pilot study was thus able to concentrate on the problem of defining a standard for abnormalities of the ST-T interval. The cardiologists participating in the project jointly defined and followed a set of rules for locating ST episodes and T episodes (i.e., intervals during which the ECG exhibits significant ST segment or T-wave changes). At this stage, the experience gained at the CNR Institute of Clinical Physiology, when annotating ST-T changes for the VALE database[6], proved useful.

DEFINITION OF ST AND T EPISODES

To identify and annotate an ST episode (Fig. 1), these criteria were applied: ST segment deviations were measured relative to a reference waveform for each subject (usually selected from the first 30 s of each record) (see Fig. 2). Measurements of ST segment deviation were taken 80 ms after the J point if the heart rate did not exceed 120 beat . min^{-1}, and 60 ms after the J point

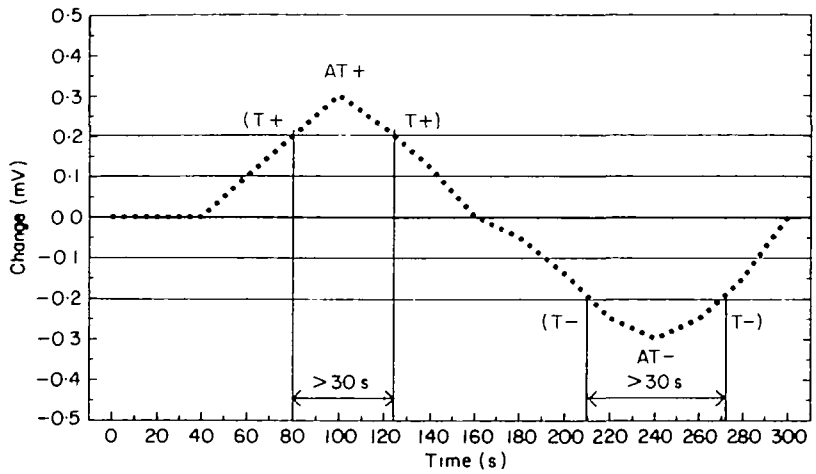

Figure 3 Representation of the typical trend of T-wave amplitude deviation (. . . .) during a positive and a negative T episode. The beginning, peak and end of each episode are annotated.

otherwise; ST episodes had to contain an interval of at least 30 s during which the absolute value of the ST deviation was no less than 0·1 mV. The beginning of each ST episode was annotated; the beginning was located by searching backward from the time at which the absolute ST deviation first exceeded 0·1 mV. The search continued until a beat was found for which the absolute ST deviation was less than 0·05 mV, and for which the absolute ST deviation was less than 0·1 mV throughout the previous 30 s. An ST change annotation which indicates the beginning of the episode was placed immediately following this beat. The peak (i.e. the greatest deviation, positive or negative) of each ST episode was annotated; an ST change annotation was placed before the beat judged to exhibit the greatest ST deviation; this annotation contains a manual measurement of the peak ST deviation. The end of each ST episode was annotated. The end was located by searching forward from the time at which the absolute ST deviation last exceeded 0·1 mV. The search continued until a beat was found for which the absolute ST deviation was less than 0·05 mV, and for which the absolute ST deviation was less than 0·1 mV throughout the following 30 s. An ST change annotation which indicates the end of the episode was placed immediately before this beat.

To identify and annotate a T-wave episode (Fig. 3), similar criteria were applied: T deviations were measured relative to the same reference waveform which was used for measuring ST deviations (see Fig. 2). The quantity A_T was defined as the amplitude of the dominant phase of the T-wave, measured relative to baseline (at the PQ junction); if the T-wave was inverted, or if the dominant phase of a biphasic T-wave was below the baseline, A_T was negative. The T deviation was defined as the difference (positive or negative) between the values of A_T for the current waveform and for the reference waveform. T episodes had to contain an interval of at least 30 s during which the absolute value of the T deviation was no less than 0·2 mV. The beginning of each T episode was annotated. The beginning was located by searching backward from the time at which the absolute T deviation first exceeded 0·2 mV. When an interval of at least 30 s was found in which the absolute T deviation did not exceed 0·2 mV, the end of that interval defined the beginning of the episode; a T-change annotation was placed before the first beat of the episode. The peak (i.e. the greatest deviation, positive or negative) of each T episode was annotated. A T change annotation was placed before the beat judged to exhibit the greatest T deviation; this annotation contained a manual measurement of the peak deviation. The end of each T episode was annotated. The end was located by searching forward from the time at which the absolute T deviation last exceeded 0·2 mV. When an interval of at least 30 s was found in which the absolute T deviation did not exceed 0·2 mV, the beginning of that interval defined the end of the episode. A T change annotation was placed after the last beat of the episode; within T episodes which contained absolute T deviations exceeding 0·4 mV, additional T change annotations were placed whenever the absolute T deviation crossed the 0·4 mV threshold value, which defines extreme T deviations. These additional T change annotations indicate the beginning and end of each such interval of extreme T deviation.

These rules were applied to each of the two ECG channels independently; for this reason, each ST and T change annotation indicates the channel to which it applies.

ORGANIZATION

Various European research groups, involved in AECG analysis, participated in the project during the initial phase (see Appendix). Thirteen groups from eight countries (see Table 1) 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

Table 1 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 (Germany)	III Medical Clinik (Hoberg)
Odense (Denmark)	University Hospital (Moller, Mickley)
Paris (France)	Groupe Pitié-Salpêtrière (Fillette, Ghanem)
Paris (France)	Hopital Lariboisière (Maisonblanche)
Pavia (Italy)	C. M. Montescano (La Rovere, Del Rosso)
Pisa (Italy)	Fisiologia Clinica (Biagini, Mazzei)
Rotterdam (Netherlands)	Thoraxcenter (Algra, Le Brun)
Straubing (Germany)	Elisab. Krankenhaus (Von Olshausen)
Tampere (Finland)	Univ. Central Hosp. (Parviainen)

Physiology, whose duties were to interact with the annotators, solicit the submission of tapes according to the agreed-upon criteria, perform operations for database generation, and finally to supervise annotations and insert them into the database. The Coordinating Group in Pisa and the Group at the Thoraxcenter of Erasmus University in Rotterdam continued to develop the database after the end of the pilot study. This was possible through the voluntary participation of the 13 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, with the cooperation of the Biomedical Engineering Centre of MIT, production of the first edition of the European ST-T database on CD-ROM went ahead.

Results

SELECTION CRITERIA

The source of the ECGs included in the European ST-T Database is a set of 24-h Holter recordings which were provided by the participating research groups from eight countries (see Table 1). The European ST-T Database is intended to be used for evaluation of algorithms for analysis of ST and T-wave changes. This database consists of 90 continuous two-channel records, each 2 h in duration, taken from ambulatory ECG recordings from 79 patients. The patients were 70 men aged 30 to 84, and eight women aged 55 to 71. (Information is missing for one patient. Some records come from the same patient.)

Each record contains at least one ST or T episode, as defined above. Most ST episodes and many T episodes in the database are related to diagnosed or suspected myocardial ischaemia, but a majority may be the result of axis shift due to positional changes. In order to obtain a representative selection of ST abnormalities in the database, we solicited contributions of records exhibiting baseline ST segment displacement resulting from conditions such as hypertension, ventricular dyskinesia, and effects of medication. Contributed recordings were excluded from the database only if they failed to meet the selection criteria; most of those which were were excluded did not exhibit 'significant' ST or T changes, according to the given definition.

The database includes 372 episodes of ST segment change, and 423 episodes of T-wave change, with durations ranging from 30 s to several minutes, and peak displacements ranging from 100 mVs to more than one mV. Compact clinical reports document each record. These reports summarize pathology, medications, electrolyte imbalance, and technical information about the recording.

ECG LEAD CONFIGURATION

For each case, the two leads which were considered most likely to reveal ST-T changes were recorded. In practice, the analysis of myocardial ischaemia often requires monitoring specific precordial regions. The electrodes were thus placed on the chest in various (not necessarily standard) locations. The leads which were used included modified leads V_1, V_2, V_3, V_4, and V_5, and modified limb leads I and III (MLI, MLIII), obtained by placing the electrodes on the chest. Normal QRS complexes are usually in one channel; they are sometimes difficult to discern in the other channel, although both ST-T changes and ectopic beats can be more prominent.

ANALOG RECORDING AND PLAYBACK

The original analog recordings were made using a variety of two-channel ambulatory ECG recorders: ICR model 7200 (37 records); Del Mar Avionics model 445B (14 records); Oxford Medilog model 4-24 (12 records), MR-14 (2 records), MR-20 (14 records), MR-35 (2 records), and MR-40 (2 records); Ela Medical model 2448 (3 records), Reynolds Tracker (3 records); Applied Cardiac Systems (1 record). A one-millivolt signal was recorded at the beginning of each tape in order to permit calibrated measurements of ST and T deviations. During the sampling process, each analog recording was played back on a compatible high-speed tape scanner.

SAMPLING

The analog outputs of the playback unit were filtered for anti-aliasing and digitized at 250 Hz per channel relative to real time, using a buffered A/D converter (ADC) constructed for this purpose at the Institute of

Clinical Physiology. Since playback was at up to 240 times real time, the ADC is capable of sampling at 120 KHz from multiplexed analog inputs. The interchannel sampling skew was 2 ms relative to real time (i.e., half the sampling interval); skew between the two signals is dominated by tape skew, however, which is variable and generally one order of magnitude larger. The ADC was unipolar, with 12-bit resolution over a nominal ±10 mV range. The sample values were rescaled after digitization with reference to calibration signals in the analog recordings, in order to obtain a uniform scale of 200 ADC units per mV for all signals. (The calibration signals are not included in the signal file.) The sample values were converted into signed (two's complement) form; sample values thus range from −2048 to +2047 inclusive, with a value of 0 roughly corresponding to zero volts.

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 h, two-channel ECG record was printed out in full disclosure format, each page 2 min in duration, with the addition of QRS detection marks, trend plots of ST segment displacement and T-wave amplitude (measured for each beat), and boxes for checking annotation operations. For each record, two cardiologists (neither of whom was a member of the research group which had submitted the record) were given copies of the full-disclosure printout, trend plots of mean heart rate and ST-T parameters at 10-s intervals, and tape-specific transparent plastic rulers for measuring time intervals and ECG signal displacements (see [7] and Fig. 2). A heart rate scale and a two-channel reference QRST complex (taken from the first 30 s of each record) were printed on each ruler.

Working independently, the cardiologist–annotators visually checked the computer-generated beat labels on the full-disclosure printouts and manually corrected them, and inserted annotations indicating changes in ST and T morphology, rhythm, and signal quality. Annotations from the two cardiologists were compared and the differences resolved by a cardiologist in 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 [8]).

A high degree of compatibility was maintained with the existing MIT-BIH Arrhythmia Database (see [9,10]) and the AHA Database for the Evaluation of Ventricular Arrhythmia Detectors (see [11,12]). 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. The codes, actually used in the database, are represented in Table 2.

Each ST and T change annotation contains a text field which describes its significance. The text field contains characters which identify the episode type ('ST' or 'T'), the signal number ('0' or '1'), and the direction of the deviation ('+' or '−'; extreme T deviations are signified by '++' and '−−'). The text field of an annotation which marks the beginning of an episode contains a '(' prefix. For an annotation which marks the peak of an episode, there is a prefixed 'A' and an appended three- or four-digit decimal number which expresses the magnitude of the peak deviation in microvolts. An annotation which marks the end of an episode has a ')' appended to the end of its text field. Thus, an episode of ST depression in signal 0 with a peak (absolute) deviation of 300 mV would be marked by three annotations, with text fields of '(STØ-', 'ASTØ-300', 'STØ-)'. Samples of ECG strips with annotations are represented in Fig. 4. A supplementary revision of ST-T annotations was suggested to identify the minority of changes likely due to axis shift; the same codes used for ST-T episodes were applied but with lower-case letters. Total counts of main events, included in the database, are reported in Table 3.

Table 2 Annotation codes used in the database

Symbol	Meaning
	BEAT annotations:
a	Aberrated atrial premature beat
J	Nodal (junctional) premature beat
S	Supraventricular premature or ectopic beat
V	Premature ventricular contraction
F	Fusion of ventricular and normal beat
Q	Unclassifiable beat
I	Isolated QRS-like artifact
	RHYTHM annotations:
(SB	Supraventricular bigeminy
(B	Ventricular bigeminy
(B3	Third degree heart block
(N	Normal sinus rhythm
(SBR	Sinus bradycardia
(SVTA	Supraventricular tachyarrhythmia
(T	Ventricular trigeminy
(VT	Ventricular tachycardia
	ST and T change annotations:
(ST..	Beginning of ST episode (see text)
AST...	Peak of ST episode
ST..)	End of ST episode
(T...	Beginning of T episode
AT...	Peak of T episode
T..)	End of T episode
	(lower-case letters used for axis shifts)
	Other annotations:
qq	Signal quality change: the first character ('c', 'n', or 'u') indicates the quality of the upper signal (clean, noisy, or unreadable), and the second character indicates the quality of the lower signal
BUTTON	Patient-activated event button pressed
TS	Tape slippage

PERFORMANCE OF CARDIOLOGIST ANNOTATORS

The annotations provided by the pair of independent cardiologists were analysed in order to evaluate the reproducibility of the human expert opinions. The

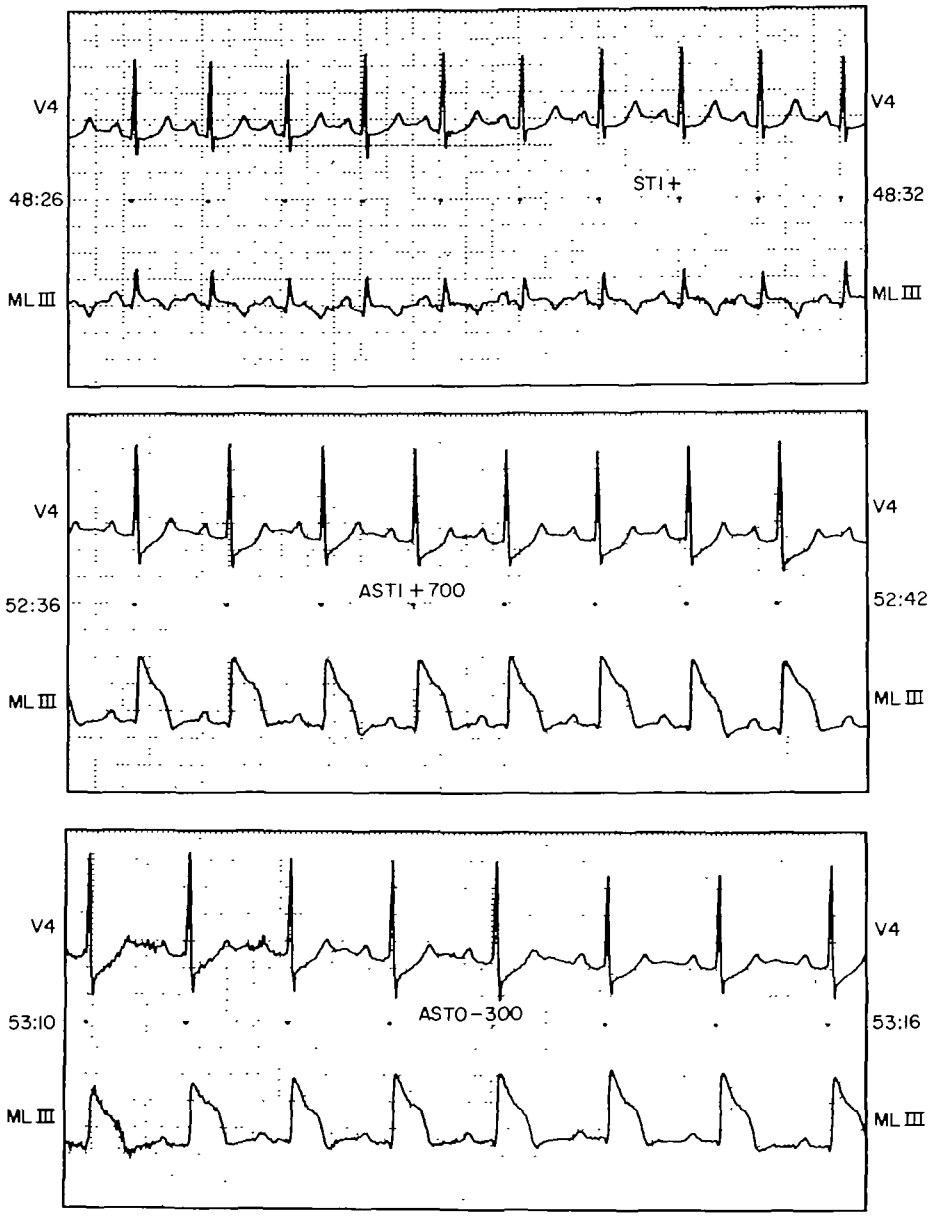

Figure 4 Representation of ECG strips selected from the database Top to bottom shows: the beginning of a positive ST episode at the lower signal; the peak of a positive ST episode at the lower signal; the peak of a negative ST episode at the upper signal. Time and leads are reported on each strip.

reference annotations (as described by the supervising cardiologist) were used to determine the sensitivity and positive predictive accuracy (PPA) of each annotating cardiologist. Table 4 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−). This evaluation was performed on a subset of 50 records of the database. In Tables 4 and 5, 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 [8]). 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. 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 5 shows the resulting sensitivity and PPA for both annotators. The results start to be acceptable for ST

Table 3 Total counts of main events

Beats	790565			
SVPC	1093			
PVC	4467			
Fusion PVC	354			
Supraventricular ectopy				
Isolated beats	819			
Couplets	103			
Runs	22			
Ventricular ectopy				
Isolated beats	3771			
Couplets	122			
Runs	191			
ST-T episodes	No.	Peak (μV) mean	Duration (h:m:s) mean	total
(first channel)				
Positive ST deviation	65	+250	2:32	2:45:33
Negative ST deviation	121	−200	8·52	17:53:40
Positive T deviation	141	+300	5:12	12:15:27
Negative T deviation	94	−300	5:02	7:54:19
(second channel)				
Positive ST deviation	53	+300	4:04	3:35:44
Negative ST deviation	133	−200	9:40	21·25:52
Positive T deviation	89	+350	4:21	6.28:27
Negative T deviation	99	−300	6:02	9·58:42

Table 4 ST-T annotations: sensitivity/positive predicted accuracy (obtained on a subset of 50 records)

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

Table 5 ST-T annotations: sensitivity/positive predicted accuracy (obtained on a subset of 50 records)

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

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.

THE DATABASE ON CD-ROM

The first edition of the database has now been completed and distributed on CD-ROM[13]. The CD-ROM includes the VALE database (see [6]), which was developed by 1983 at the Institute of Clinical Physiology; it contains ST-T changes but also many rhythm abnormalities. Software in binary form for MS-DOS systems has been contributed by MIT, and is also included on the CD-ROM; this software includes a library of C-callable functions for access to the database records, and application programs for converting user-selected portions of database signal or annotation files into text form, and for interactively displaying signals and annotations using popular PC graphics adapters. MS-DOS users may link their application programs with the library provided on the CD-ROM; the MIT database software, including many additional applications, is available separately in C source format for MS-DOS, UNIX, and other systems. Version 4.0 (February, 1990), and later versions of the MIT database software are compatible with the European ST-T and VALE databases.

The database is accompanied by a 2000 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.

Discussion

The European ST-T Database is intended to be used mainly for evaluating the performance of algorithms for detecting changes in ST segment and T-wave morphology. 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.

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 change episodes, related to diagnosed or suspected ischaemia, or even to artefactual changes due to electrical axis deviation, is extremely valuable in studying correlations between ECG patterns and myocardial ischaemia. 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.

References

[1] Sheffield LT, Berson A, Bragg-Remschel D *et al.* Recommendations for standard of instrumentation and practice in the use of Ambulatory Electrocardiography. Circulation 1985; 71: 626A–36A.

[2] Knoebel SB, Crawford MH, Dunn MI *et al.* Guidelines for Ambulatory Electrocardiography. Circulation 1989; 79: 206–15.

[3] Pepine CJ Ambulant myocardial ischemia and its prognostic implications. Circulation 1990; 81. 1136–8.

[4] Deedwania PC, Carbajal EV. Silent ischemia during daily life is an independent predictor of mortality in stable angina. Circulation 1990; 81: 748–56.

[5] Marchesi C. The European Community concerted action on Ambulatory Monitoring. J Med Eng Techn 1986; 10: 131–4.

[6] Taddei A, Varanini M, Macerata A *et al.* An annotated database for the evaluation of algorithms for the analysis of arrhythmias and ischemic events. Com Cardiol 1983; 10: 191–4.

[7] Taddei A, Benassi A, Biagini A *et al.* ST-T change analysis in ECG ambulatory monitoring: a European standard for performance evaluation. Com Cardiol 1988; 14: 63–8.

[8] Taddei A, Biagini A, Distante G *et al.* An annotated database aimed at performance evaluation of algorithms for ST-T change analysis. Com Cardiol 1990; 16: 117–20.

[9] Mark RG, Moody GB. Evaluation of automated arrhythmia monitors using an annotated ECG database. In: Marchesi C, ed. Ambulatory Monitoring. The Hague: Martinus Nijoff Publ. 1984: 339–57.

[10] MIT-BIH Arrhythmia Database. Available from: MIT-BIH Database Distribution, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Room 20A–113, Cambridge, MA 02139 U.S.A.

[11] Hermes RE, Geselowitz DB, Oliver GC *et al.* Development, distribution and use of the AHA database for ventricular arrhythmia detector evaluation. Com Cardiol 1981; 7: 263–6.

[12] AHA database distributor: Emergency Care Research Institute, 5200 Butler Pike, Plymouth Meeting, Pennsylvania 19462, U.S.A.

[13] European ST-T Database. Available from: ST-T Database Distribution, Institute of Clinical Physiology, Computer Laboratory (A. Taddei), 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; [5,7]), 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. During the 5 years since its beginnings, this project has been supported with dedication and enthusiasm by many cardiologists, Holter technicians, laboratory assistants, and engineers at research institutions throughout the European Community and beyond. We gratefully acknowledge their contributions. In particular, we wish to thank: The Project Management Group, whose members were: D. Clement (Belgium), P. Coumel (France), C. Marchesi (Italy), F. Stott (United Kingdom), C. Zeelenberg (Netherlands); The research groups which contributed to the definition of the protocol for annotating ST-T changes. 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 (U.S.A.), 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); The experts who contributed ECG recordings and performed the difficult task of beat-by-beat annotation of the ECGs: 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), H. Mickley (Denmark), M. Moller (Denmark), K. von Olshausen (Federal Republic of Germany), T. Parviainen (Finland), A. Pietersen (Denmark), and P. Torner (Spain); The members of the Coordinating Group at the Institute of Clinical Physiology; particularly we mention for their continuous and significant contributions to the realization of the database: A. Biagini, G. Distante, M. Emdin, C. Marchesi, M. G. Mazzei, P. Pisani, N. Roggero, A. Taddei (coordinator), and M. Varanini. They designed the database, implemented software and hardware to support its development, solicited contributions of tapes, arranged and coordinated the work of the annotators, and supervised

the verification of the annotations; The group of experts of the Thoraxcenter of Erasmus University, in particular A. Algra and C. Zeelenberg, who contributed to the design and development of the database; Our colleagues at the Massachusetts Institute of Technology: R. G. Mark, who lent early and continuing support and advice, and G. B. Moody, who assisted in auditing the final annotations, developed software for annotation editing and for inclusion on the CD-ROM, and coordinated preparation of the CD-ROM version of the database.