Journal of Cardiography 16: 133-139, 1986

Automatic on-line measurement of systolic time intervals using a personal computer

Luciano BERNARDI
Alessandro CALCIATI
Chiara LUMINA
Enrico LICCI
Giorgio FINARDI

Summary

A personal computer-based system for automatically evaluating external systolic time intervals (STI) suitable for practical clinical use is presented. In 56 consecutive unselected subjects, ranging in age from 16 to 77 years (mean=51 years), the STI recorded with standard technique were computed manually and automatically. Manual and automatic techniques correlated closely in all indices studied (Q-Q interval: $r=0.995$; electromechanical systole: $r=0.975$; pre-ejection period (PEP): $r=0.985$; left ventricular ejection time (LVET): $r=0.973$, PEP/LVET: $r=0.981$, $p<0.001$). These results demonstrate that automatic evaluation of STI can be effectively made with good reliability using inexpensive hardware.

Key words
Systolic time intervals Automatic signal analysis Personal computer

Introduction

The hemodynamic factors involved in determining systolic time intervals (STI) are now well recognized, and the utility and limits, such as dependence on load conditions, of the method as an indicator of myocardial and cardiovascular status have been established[1,2]. Since simultaneous measurements of intracardiac dynamics have demonstrated close correlation between direct and indirect measurements of systolic time intervals[3], externally recorded systolic time intervals have been used on a large scale for evaluating left ventricular performance in man in acute and chronic cardiovascular disease. At present, this method appears to be a simple and

Dipartimento di Medicina Interna e Terapia Medica-Sezione Clinica Medica 2—University of Pavia, Pavia, Italy
Address for correspondence: Luciano Bernardi, M.D., Clinica Medica 2, Universita' di Pavia, 27100-Pavia, Italy
Supported in part by a Grant from Remco Italia—Cardioline for development of biomedical equipment
Received for publication July 31, 1985; accepted August 27, 1985 (Ref. No. E-3)

useful, though not a specific test of left ventricular performance. However, the time and operator's experience necessary to obtain reliable results limit its bedside use.

To obviate the need for tedious manual techniques for calculating STI, we have constructed a microcomputer-based system for automatic on-line identification of systolic time intervals. The purpose of this study is to determine the reliability of rapid computer analysis of STI measurements.

Methods

Equipment and recording protocol

Fifty-six unselected consecutive subjects were examined. Their average age was 51 years (range 17 to 77 years).

Simultaneous recordings of electrocardiogram, phonocardiogram (Electronics for Medicine microphone No. 03040502), and externally recorded carotid pulse (Electronics for Medicine pulse detector No. 03040002) were obtained using a VR12 Electronics for Medicine Simultrace Recorder at a paper speed of 100 mm/sec, and standard recording techniques[1)]. Signal outputs of the recorder were fed to an Apple II 48-KRam personal computer (Apple Inc. Coupertino, CA, USA) via a 12 bit A/D converter (model AI13, Interactive Structures, Bala Cyndwyd, PA, USA) at a sampling rate of 250 Hz. Signal sequences of 6 seconds were recorded simultaneously on photographic paper and on computer, and stored on a floppy disk. Time markers were positioned on the photographic paper for precise identification of the sequence recorded by the computer.

Data analysis

STI were computed manually by two independent observers, and automatically. The two sets of results were then compared.

Manual computations

The six second sequence was manually analyzed by standard identification techniques using a Houston Hi-Pad Digitizer (Houston, TX, USA), interfaced with a 48 KRam Apple II personal computer. The optical resolution of the digitizer was 1/8 mm. The BASIC written program calculated STI by visually recognizing the following points: 1) onset of the ECG Q wave, 2) onset of the next Q wave, 3) onset of aortic high frequency components of the second heart sound, 4) onset of the carotid pulse, and 5) the dicrotic notch.

The following time intervals were computed: 1) Q-Q interval, 2) total electromechanical systole (Q-S2), 3) pre-ejection period, and 4) left ventricular ejection time (LVET). Since the aim of this study was to compare manually- and automatically-obtained results, the STI were computed without correcting for heart rate.

Automatic computations

The automatic STI analysis program consists of the following steps: 1) identification of QRS complexes, 2) identification of onset of Q wave, or, in absence of Q wave, of the onset of R wave, 3) identification of carotid pulse upstroke, 4) identification of carotid pulse dicrotic notch, 5) identification of onset of high frequency components of second heart sound, and 6) calculations of STI and evaluation of results.

To accelerate the computations, a second microprocessor card (Motorola 32-bit 68008) was added to the Apple computer, allowing true

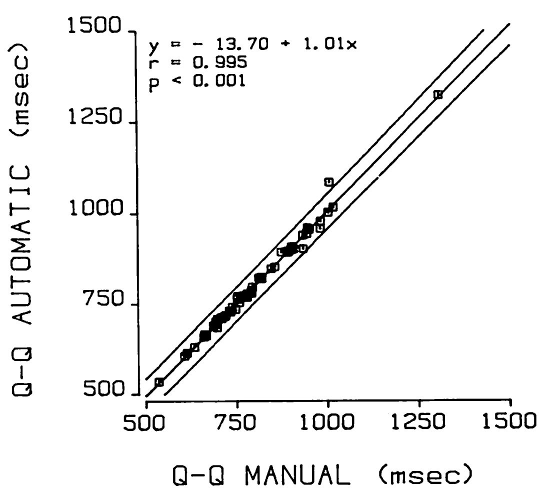

Fig. 1. Graphic plot of the comparison between the automatic- and manually-determined Q-Q intervals (n=56).

Confidence limits lines are for $p<0.001$.

Table 1. Systolic time intervals: Mean values of 56 subjects (mean±S.D.)

		Manual		Automatic	F	p
		Observer A	Observer B			
Q-Q interval	msec	801±133	803±136	803±136	0.731	n.s.
Q-S2	msec	378±27	376±27	382±27	16.231	<0.001
LVET	msec	277±24	275±22	280±24	14.273	<0.001
PEP	msec	101±16	101±15	102±17	0.604	n.s.
PEP/LVET		0.37±0.07	0.37±0.6	0.36±0.07	0.459	n.s.

F: analysis of variance F ratio (repeated-measures, one-way design).

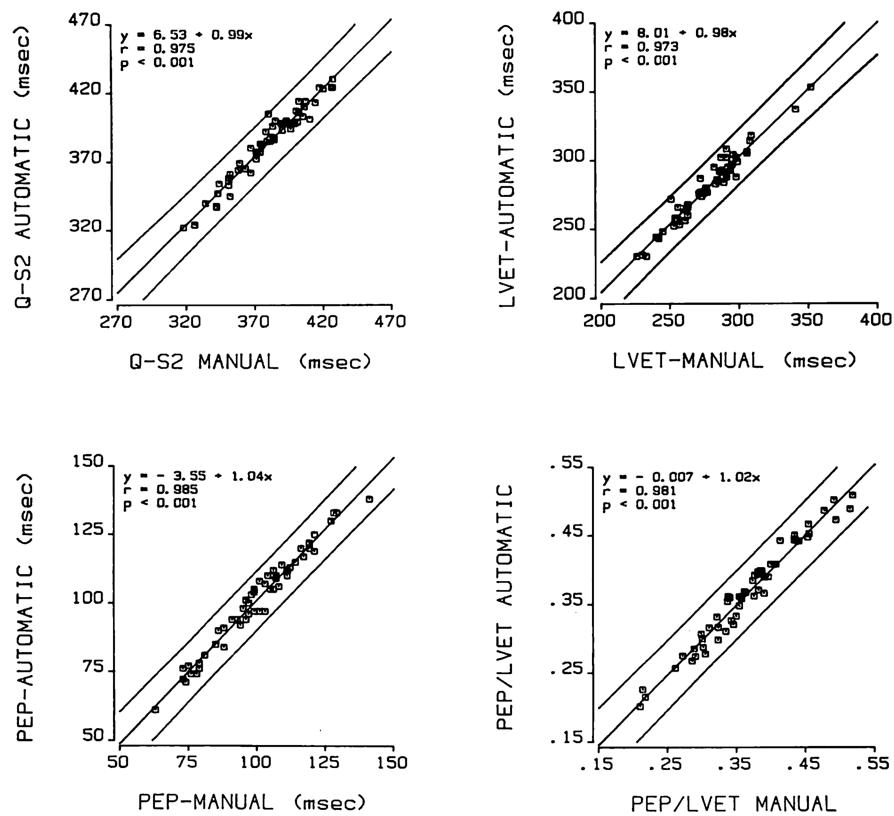

Fig. 2. Graphic plot of comparison of automatic- and manually-determined Q-S2 interval (upper left), **LVET** (upper right), **PEP** (lower left), **and the PEP/LVET ratio** (lower right) (n=56). Confidence limits lines are for p<0.001.

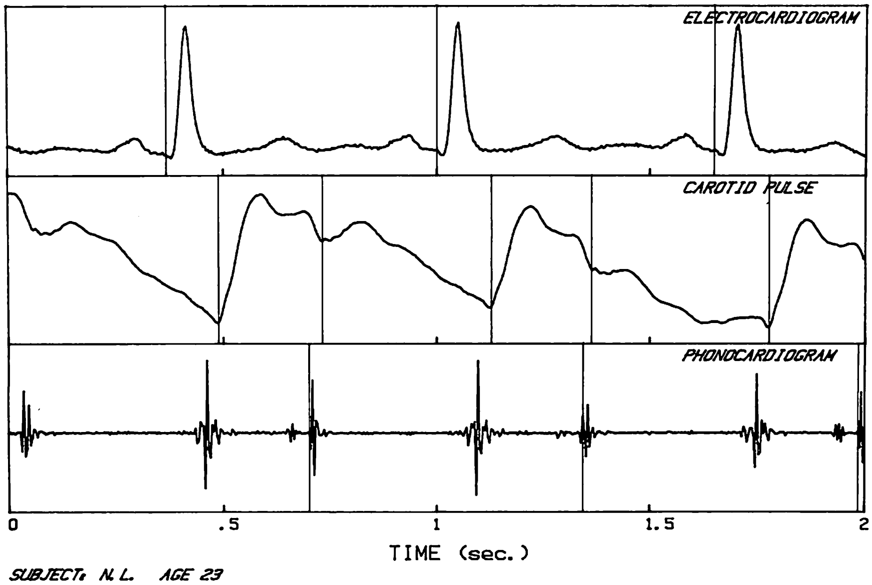

Fig. 3. Computer plot showing the acquired signals and the points automatically identified. It is an example of good quality data from a 23-year-old subject with a late-systolic click.

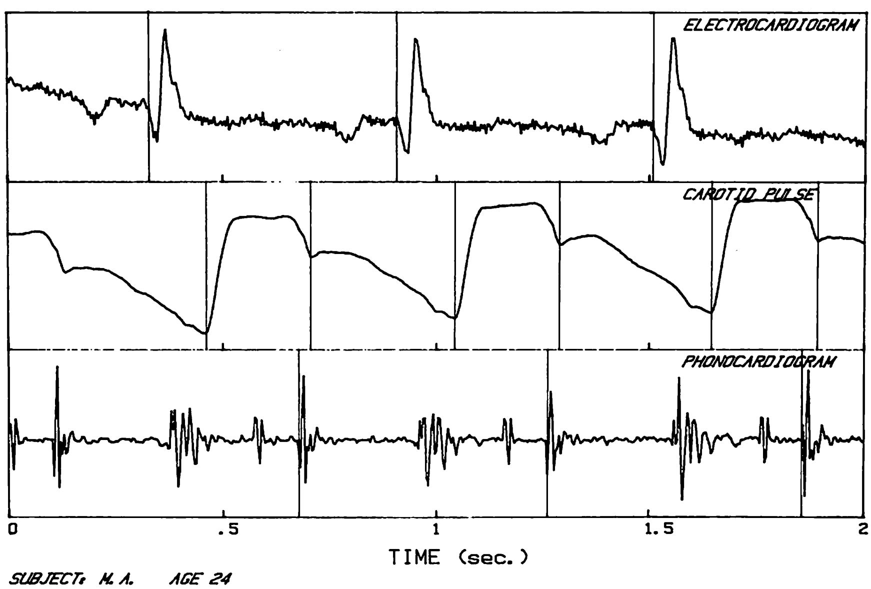

Fig. 4. Computer plot showing the acquired signals and the points automatically identified. Data are from a 24-year-old subject with mitral valve prolapse and a mid-systolic click.

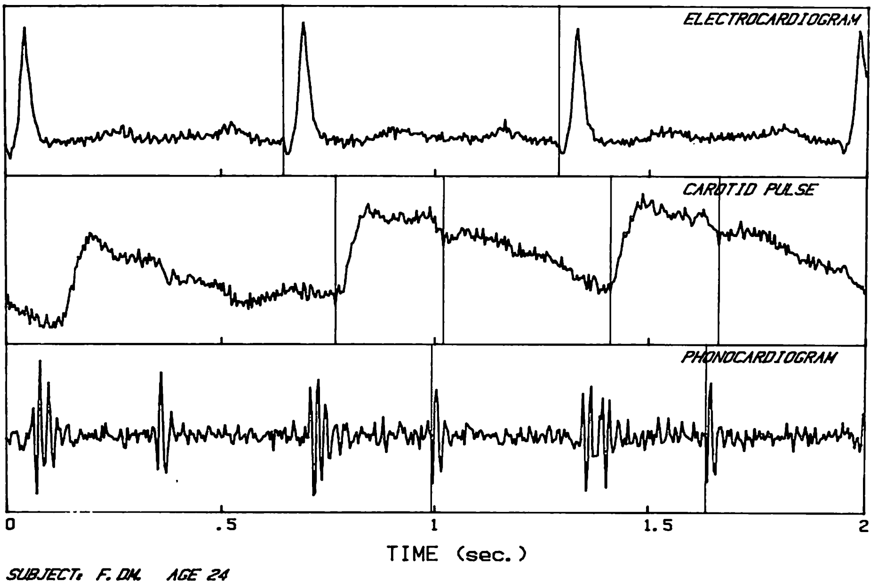

Fig. 5. Computer plot showing acquired signals and points automatically identified.
An example of poor quality data from a 24-year-old subject is shown.

multiprocessing. The software consisted of a main program written in interpreted BASIC for the general organization (menu, options, final printout), and of several subroutines written in 6502 or 68000 assemblers. The procedure is completely automatic: the operator is only required to select from the main menu one of various options: enter patient's personal data, select single or multiple six second recordings, and store results on disk. The acquired signals are displayed on the computer screen and the operator is given the option of accepting or rejecting the recorded signal, then the program outputs a written report for each six second record or a trend of successive records.

The improvement in speed achieved by the combined use of two assembled programmed microprocessors, allowed virtually real time digital filtering, fast signal display with autoscaling, application and comparison of multiple successive-approximation searching algorithms. Algorithms for automatic identification self-adapt to the noise level and to the irregularities of the signals: together with the results, the computer outputs the level of noise recorded for each signal, thereby giving an estimate of the reliability of the results obtained. If the quality of the signal is considered unacceptable, one or more beats are rejected; if more than half or 2/3 of the beats are rejected, the entire six second sequence is considered unacceptable and the operator is invited to check the channel(s) of poor quality. Optionally, signals may be printed on a digital plotter to check the positions of the markers automatically found. Although the program usually computes the STI immediately after acquisition (part of the computations may also be completed during acquisition), to blind the procedure, the signals were first stored on floppy discs, and processed by the computer program after the manual computations. Thus, automatic analysis program analyzed the same 56 six-second sequences processed manually, and gave the correspondent means of the same STI.

Statistical analysis

Pearson's linear correlation coefficient and regression analysis were computed for each couple (manual versus automatic) of indices.

Confidence limits were established for $p<0.001$. A one-way analysis of variance design for repeated measures[4] was used to test the differences between manual and automatic methods.

Results

Mean results of the manual and automatic STI obtained in the 56 consecutive subjects are shown in **Table 1**. All measured intervals were in close agreement by the two methods. However, a small but highly significant difference was observed between the manual and automatic Q-S2 ($p<0.001$), and between the manual and automatic LVET ($p<0.001$).

In all indices, both the manual and automatic methods correlated closely. Regression equations were: $y=-13.70+1.01x, r=0.995$ for Q-Q interval; $y=6.53+0.99x$, $r=0.975$ for Q-S2; $y=-3.55+1.04x$, $r=0.985$ for LVET; $y=8.01+0.98x$, $r=0.973$ for PEP; and $y=-0.007+1.02x$, $r=0.981$ for PEP/LVET ratio. See **Figs. 1 & 2** for the scatter plots.

Examples of the capability of the automatic method of identifying STI are shown in **Fig. 3** (good quality signals, end systolic click), **Fig. 4** (mid-systolic click on phonocardiogram), and **Fig. 5** (sequence recorded with high level noise).

No differences were observed between subjects of different ages, with or without systolic murmurs and/or the fourth heart sound, in the program's ability of identifying the STI.

Discussion

Several previous reports have described methods for the automatic identification of STI. However, most of them[5~10] were based on medium-size computers and were therefore impractical in size, cost and ease of use. Others were based on smaller computers and/or analog devices[12~14] and used simple algorithms which may decrease their reliability with signals of non-ideal quality, likely to occur with bedside use. Moreover, some of these methods require arbitrary corrections, for example in the identification of the Q wave. A recent report describes the use of an esophageal accelerogram[15] for determining the onset and the end of left ventricular ejection, but this is to be regarded experimental and is not a practical clinical tool.

In the present study the combined use of a simple personal computer and a new 32-bit microprocessor, allowed implementing several additional features with respect to previous methods (preliminary analysis of the noise, application of multiple successive approximations searching algorithms readjusted to the noise level, and comparison of results obtained) without substantially affecting the complexity of the hardware and the computation time. The reliability of this method is especially demonstrable by the specific operational experimental procedure: along with acceptable quality tracings (see **Figs. 3 & 4**), poor quality tracings with abnormally high signal to noise ratio were evaluated (see **Fig. 5**), in order to challenge the capability of this automatic system, without substantially affecting the manual reading capability which relies upon the experience, rather than on absolute features. The results obtained showed excellent agreement between manual and automatic STI computations, and there were little human versus machine differences in the elaborative process, substantiating the validity of the algorithms applied.

In conclusion, the results obtained confirm the technical validity and the clinical applicability of a personal computer-based system for automatic evaluations of STI.

References

1) Weissler AM: Noninvasive Cardiology. Grune & Stratton, New York, 1974
2) Lewis RP, Rittgers SE, Boudoulas H: A critical review of the systolic time intervals. *in* Weissler AM, Reviews of Contemporary Laboratory Methods. American Heart Association, Dallas, 1980, p 73–110
3) Martin CE, Shaver JJA, Thompson ME, Reddy PS, Leonard JJ: Direct correlation of external systolic time intervals with internal indices of left ventricular function in man. Circulation **44**: 419–431, 1971
4) Bruning JL, Kintz BL: Computational Handbook of Statistics. Scott-Foresman, Palo Alto, 1968
5) Divers RT, Katona PG, Dauchot PJ, Hung JC:

Continuous real-time computation and display of systolic time intervals from surgical patients. Comput Biomed Res **10**: 45–59, 1977

6) Zoneraich S, Zoneraich O, Rodenrys J: Computerized system for noninvasive techniques: I. Its value for systolic time intervals. Am J Cardiol **33**: 643–649, 1974
7) Kyle MC, Freis ED: Computer identification of systolic time intervals. Comput Biomed Res **3**: 637–651, 1971
8) Bachy JL, Marchand E, Col J: Effect of premature ventricular depolarization on the arterial pulse wave analysed by an on-line algorithm. Acta Cardiol (Suppl) **26**: 43–48, 1981
9) Mannebach H, Bechtloff L, Mertens HH, Przybilla L, Gleichmann U: A computer program for evaluating systolic time intervals at rest and during intervention tests. *in* List WF, Gravenstein JS, Spodick DH: Systolic Time Intervals, Springer, Berlin, Heidelberg, 1980, p 88–94
10) Donders JJH: Computer algorithms for automatic determination of systolic time intervals. *in* List WF, Gravenstein JS, Spodick DH: Systolic Time Intervals, Springer, Berlin, Heidelberg, 1980, p 100–109
11) Abelson D, Kamens EA: Bedside measurement of systolic and diastolic time intervals using the stethometer. Cardiovasc Res **11**: 270–274, 1977
12) Blackburn JP, Conway CM, Leigh JM, Lindop MJ, Reitan JA, Robbins R: An analogue device for measuring the pre-ejection period (PEP). Cardiovasc Res **6**: 444–448, 1972
13) Schalck HV, List WF, Marsoner HJ: Automatic versus visual evaluation of systolic time intervals. *in* List WF, Gravenstein JS, Spodick DH: Systolic Time Intervals, Springer, Berlin, Heidelberg, 1980, p 95–99
14) Marsoner HJ, Savora C, Moser W, List WF: An instrument for the on-line determination of systolic time intervals. *in* List WF, Gravenstein JS, Spodick DH. Systolic Time Intervals, Springer, Berlin, Heidelberg, 1980, p 110–116
15) Wiley RS, Wolferson LB, Shepard LS: A computerized system for monitoring systolic time intervals from esophageal accelerograms. Comput Biomed Res **16**: 44–58, 1983