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Review

Eyewitness to history: Landmarks in the development of computerized electrocardiography

Pentti M. Rautaharju, MD, PhD*

Division of Public Health Sciences, Wake Forest School of Medicine, Winston-Salem, NC

Abstract The use of digital computers for ECG processing was pioneered in the early 1960s by two immigrants to the US, Hubert Pipberger, who initiated a collaborative VA project to collect an ECG-independent Frank lead data base, and Cesar Caceres at NIH who selected for his ECAN program standard 12-lead ECGs processed as single leads. Ray Bonner in the early 1970s placed his IBM 5880 program in a cart to print ECGs with interpretation, and computer-ECG programs were developed by Telemed, Marquette, HP-Philips and Mortara. The "Common Standards for quantitative Electrocardiography (CSE)" directed by Jos Willems evaluated nine ECG programs and eight cardiologists in clinically-defined categories. The total accuracy by a representative "average" cardiologist (75.5%) was 5.8% higher than that of the average program (69.7, $p < 0.001$). Future comparisons of computer-based and expert reader performance are likely to show evolving results with continuing improvement of computer-ECG algorithms and changing expertise of ECG interpreters.

Keywords: ECG history; Computer ECG; ECG readers; Classification accuracy

Introduction

Medical electronics experienced a period of rapid growth in the late 1950s, some 15 years after the end of WW 2. At that time analog computers dominated electrocardiographic (ECG) and vectorcardiographic (VCG) research. In 1959 I came for my PhD research at University of Minnesota with Otto Schmitt, Professor of Biophysics, Zoology and Electrical Engineering. Schmitt was idolized by many as a 'guru' of medical electronics and VCG research [1]. A steady flow of visiting investigators came to meet Otto, including those who became active in the development of computerized ECG. Otto's gallery now in the archives of the University of Minnesota contains some 2000 Polaroid pictures of these visitors. I also worked with Ernst Simonson and Henry Blackburn to formulate standardized ECG classification criteria for epidemiological studies published in 1960 [2]. According to Citation Index, that publication was still in 2012 among the four most frequently cited articles in ECG literature. Standardization of clinical ECG classification criteria turned out to be an elusive goal. In an evaluation of the progress in 1966 Simonson et al. concluded that "computerized ECG interpretation will elude us until the next generation of cardiologists" [3].

Working with the Minneapolis group gave me an opportunity to learn about important developments and to meet leading investigators in computerized ECG field. These contacts turned out beneficial after I set up my own ECG research group in 1962 at Dalhousie University in Halifax, Nova Scotia. The present communication reviews some of the important landmarks in the development of computerized electrocardiography.

Early pioneering phase

By early 1960s there was a gradually growing expectation in the US that digital computers will play an important role in ECG processing. The application of digital computers in the US was pioneered in Washington, DC by two immigrants, Hubert Pipberger and Cesar Caceres. In the 1960s competitive spirit in Washington between the research groups of these two pioneers was almost tangible. The picture of Hubert Pipberger (Fig. 1a) is from 1986 when I visited him at his home in Washington, DC. Cesar Caceres can be seen in Fig. 1b.

The pioneering efforts of Pipberger [4] in computerized ECG are well known and his extensive contributions to VCG research were published in many cardiology journals. Pipberger got his MD in 1951 at Rheinische Friedrich Wilhelm University in Bonn. During WW2 he served as a medic in German air force and was taken as prisoner of war in France sometime after the 1944 Normandy invasion. In 1955 Pipberger immigrated to the US, working first with Prinzmetal in Los Angeles in basic

* Division of Public Health Sciences, Wake Forest School of Medicine, Winston-Salem, NC.

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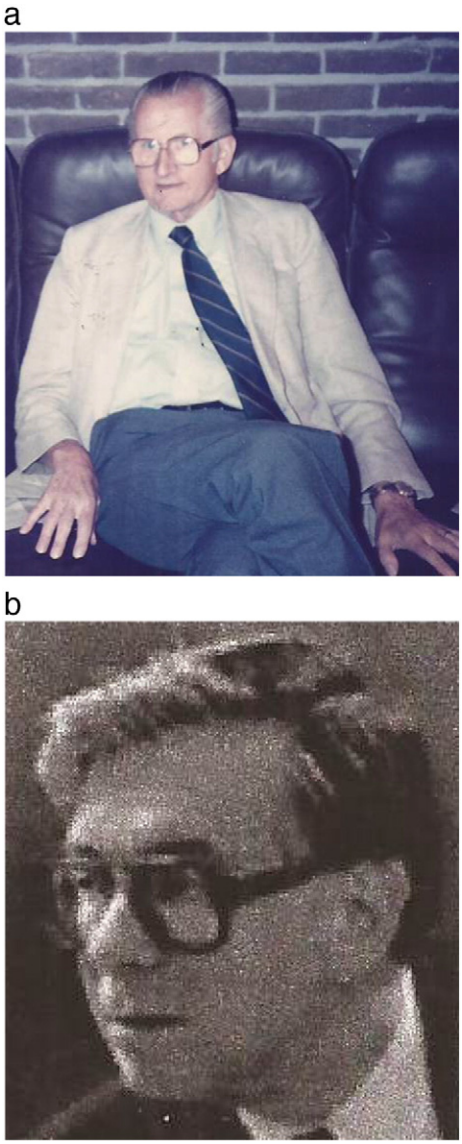

Fig. 1. a, Hubert Pipberger; b, Cesar Caceres.

cardiac electrophysiology projects. In 1957 VA established the Research Center for Cardiovascular Data Processing with Pipberger as the chief. In 1960, Pipberger obtained funding from the VA for computerized ECG development as a collaborative project with eight VA hospitals, with Alan Berson as an engineer for the project. Pipberger provided firm leadership for this pioneering collaborative project in acquisition of digital ECG diagnostic data base with diagnostic classification established using nonelectrocardiographic information. Pipberger also provided active leadership to interdisciplinary teams of investigators in formulating the American Heart Association's recommendations for ECG instrumentation published in 1967 and 1975.

Caceres, born in 1927 in Honduras, moved in 1933 to the US with his father who was the Ambassador to Washington. Caceres received his MD at Georgetown University. He was fascinated by electrocardiography and read widely about it already during his medical school and later during his post-doctoral years at Georgetown University. Caceres got a job at US Public Health Service (USPHS) and at the recommendation of Robert Grant of NIH he was asked to set up an ECG research laboratory. The laboratory was first established under NIH and after a couple of years under the Heart Disease Control Program of USPHS.

Those days the problem for digital ECG processing was the lack of commercial amplifiers and FM recorders for multichannel recording of the 12-lead ECGs. Caceres based his computer-ECG program development on the use of standard 12-lead ECG. Initial work to record and digitize one lead at a time was performed in part by Airborn Instruments Laboratory under USPHS contract. Pipberger contracted National Bureau of Standards to build a device for analog-to-digital conversion of the XYZ leads introduced by Frank in 1956 [5]. Caceres and Pipberger both used Otto Schmitt as a consultant for their systems design specifications. Pipberger's initial results from automatic ECG wave recognition were documented in 1961 [6]. The ECG program of Caceres evolved in an over a decade-long development effort by his large team from a primitive initial version to a more comprehensive ECG measurement and interpretation program (ECAN-D) [7,8]. In his 1969 book describing the achievement Caceres proclaimed that the first diagnostic computer was born for electrocardiography [8]. A remarkable event, though the baby had some birth defects. Another book edited by Caceres and Dreifus "Clinical Electrocardiography and Computers" in 1970 contains many important aspects of computer-ECG development and contributions by both pioneering 'camps' [9].

Limited acceptance of the ECAN program was mainly due to the inefficiency in single-channel recording and analysis of the 12-lead ECG and the inherent difficulty to obtain accurate global interval measurements. VA (Pipberger) program's acceptance was low because the Bayesian-type of classification into mutually exclusive diagnostic categories with probabilities adding to 1 without an option for combinations. Pipberger deserves credit for introducing the probabilistic concept to computer ECG classification. Cardiologists actually commonly make use of the probabilistic concept in modifying diagnostic classification when clinical data in addition to ECG become available. However, the heuristic-type decision-tree ECG criteria are easier to associate with pathophysiological mechanisms.

The role of IBM and Telemed

In the early 1960s Ralph Smith at the Mayo Clinic initiated a joint venture with IBM incorporating modified Frank leads as well and the standard 12-lead ECG. The Mayo-IBM diagnostic ECG program was initially implemented on IBM 360 computer. Collaboration between Ralph Smith and IBM's Clyde Hyde did not last long before Mayo and IBM started their separate ECG program development. In 1964 the IBM program was converted to IBM 1800 computer in my ECG research center at Dalhousie University by Clyde Hyde and Eugene Strand. IBM 1800, designed as a process-control computer for industry, was efficient also for ECG processing. The program was translated to high-level FORTRAN by my research group. After protracted negotiations IBM agreed to