A Comprehensive Cardiac Exercise Stress Processor for Environmental Health Effects Studies*

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We have shown that an interactive microcomputer system using noninvasive cardiovascular measurements during exercise is both possible and practical. Experimental use of the system has verified our choice of variables as appropriate for automatic generation of a cardiovascular data base, but additional studies are required to determine the system's sensitivity for assessing health-effect decrements.

INTRODUCTION

The effects of air pollutants on the human cardiovascular system have not been well established in environmental medicine. A major reason for the lack of a scientific data base has been the absence of suitable biomedical instrumentation to document pollutant dose versus physiological response, especially when conducting exercise cardiovascular studies on the population at risk. Because such information is essential for devising standards for pollution exposure, the Environmental Protection Agency (EPA) has undertaken the design of a system that will allow systematic generation of a dose–response data base.

Our clinical objective, then, is to identify the dose–response relationships by analyzing ambient pollutant and physiological covariates. Cardiovascular data should be collected during exercise when airborne pollutant ingestion and tissue oxygen demand increase. Because small, yet cumulative, changes are expected, a comparative trend analysis of exercise response in clean and polluted air is preferred. Since physio-

logical compensation has been observed in some pollutant studies, a multiparameter trend analysis would be necessary to identify the mechanisms involved.

This paper reports on the design of a cardiac exercise stress processor (CESP) and its features that respond to these clinical objectives. The report is not a conclusive clinical study but an outline of an engineering development expressing the measured parameters, system algorithms, signal-processing techniques, and computations used in quantifying cardiac performance.

BACKGROUND

A system design philosophy was formulated to (1) monitor cardiac electrical and mechanical performance noninvasively during an exercise test; (2) incorporate automated test sequencing, data acquisition, and systems management; (3) employ interactive operation and measurement validation; and (4) implement hardware and software modules that can be modified or expanded.

Cardiac exercise response is usually estimated noninvasively by the electrocardiogram (ECG), which, under stress, may exhibit characteristic changes with cardiac muscle ischemia. Recently, the inaccuracies of assessing the complex cardiac response to exercise by a single measurement criterion (i.e., ST-segment depression ≥ 1 mm for 80 msec indicates abnormality) have been identified. Accuracy may be improved by including additional ECG measurements and independent measures of cardiac performance, such as blood pressure, duration of exercise, systolic time intervals, and thoracic fluid volume change by electrical impedance measurement.

Cardiac mechanical performance during exercise is measured by several methods; however, most are impractical for our research application. We chose to measure systolic time intervals (STI), which have been studied under a wide range of clinical conditions including exercise stress. The STI include the pre-ejection period (PEP), the left ventricular ejection time (LVET), and the total electromechanical systole (EMS = PEP + LVET). Other associated measurements are the isovolumic contraction time (ICT) and the ratio PEP/LVET.

Methods for obtaining STI measurements include echocardiography, carotid pulse and heart sound, and the first derivative of the thoracic electrical impedance cardiogram (DZ/DT). STI measurement by the impedance method has the advantage of eliminating mechanical transducers. Using only surface electrodes, then, changes in heart rate, rhythm, ischemia, cardiac muscle performance, and thoracic fluid volume can be monitored.

The synchrony of DZ/DT with the intracardiac systolic valvular events was examined by simultaneously recording the ECG, DZ/DT, mitral valve echogram, and aortic valve echogram (Figure 1). Electromechanical systole begins with the ECG Q wave. The anterior (AML) and posterior (PML) mitral valve leaflets close shortly thereafter (T1), which initiates the isovolumic contraction period. At time T2, the aortic valve leaflets (AVL) separate and remain apart until the end of ejection (T3). During ejection, the AVL appear as parallel lines adjacent to the aortic wall (Ao). Following aortic valve closure, the DZ/DT diastolic wave peaks simultaneously (T4) with the maximal mitral valve opening. These independent echocardiographic data illustrate the basis of our STI measurements and support CESP design.