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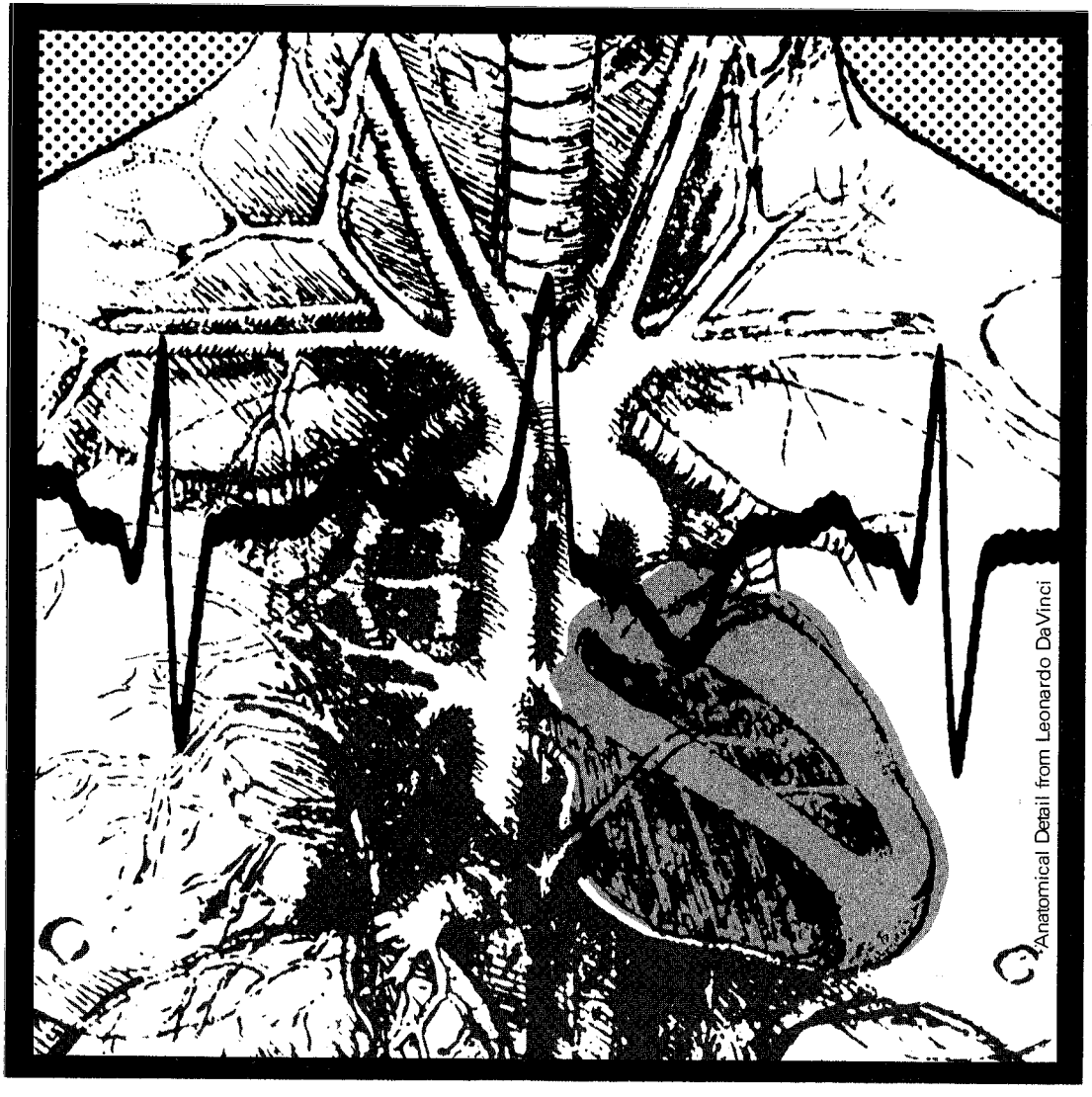

COMPUTER ASSISTED EVALUATION OF ERGOSPIROMETRIC PARAMETERS AND CENTRAL HEMODYNAMICS IN EXERCISE TESTING*)

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Summary

The method and the technical equipment of a system supervising invasive ergometric investigations is presented, which proved to be feasible in stress-testing for various demands. Strict observation of objective criteria and subjective parameters of physical performance constitutes the principle of a feedback system that integrates peripheral preprocessing, on-line computation of derived parameters with time-triggered and keyboard controlled print-out, audiovisual display and graphic documentation. On-line computation and rating of ergospirometric variables and derived parameters proved to be very useful in evaluating limiting factors of the cardio-respiratory function in quantitative terms.

Introduction

To assess the function of the cardio-pulmonary system in qualitative and quantitative terms stress-testing serves as a useful diagnostic tool. Our procedure includes various techniques stepwise, which are more and more invasive.

We are applying a standard program consisting of (A) the Rectangular-Triangular Bicycle Ergometry, (B) the Ergospirometry and (C) the Evaluation of Central Hemodynamics in Static and Dynamic Exercise.

In stress testing abnormal reactions of the patient and alarming symptoms should not escape the physician's notice, as he has to break off the test. But the exercise test should not be interrupted at a too low level of work intensity, as valuable information might be lost.

The primary goal is to guarantee absolute safety to the patient at a tolerable risk. That is to say, all parameters measured should be evaluated and interpreted immediately and documented in quantitative terms. These data and the patient's subjective complaints have to be integrated into a feed-back system to assist the physician, who is supervising the test. Peripheral preprocessing of primary signals and computer assisted data processing and calculation of derived parameters, as well as display, actually offer information easy to survey. The results of the test are promptly obtained, documentation and data retrieval for statistical analysis is less time-consuming and the exchange-rate of data and information for other medical departments is accelerated.

Methods

The patients exercise in a sitting or recumbent position (for catheterization only) on an electrically braked bike (Ergo-test, Fa Jäger, Würzburg, FRG). ECG analysis is based on the 12-lead-standard-program or on the Frank system (vector). The heart rate is analysed beat-to-beat or averaged; the QRS-signal is presented auditorily. Expired air volumes and gas concentrations are analysed in an open circuit system (Ergo-pneumotest, Fa Jäger). Arterial pressure waves of the fluid-filled catheter system are fed to pressure transducers (Statham P23) and preamplifiers; the mean pressure values are electrically integrated. Averaged peak systolic and diastolic pressure values may be stored for AD-conversion. Any analog signal can be documented on a six-channel pigment-tape-writer (EK-22) or watched on a four-channel screen (MS 203; Fa Hellige, Freiburg, FRG).

Blood samples of arterial and mixed venous blood are withdrawn for blood-gas-analysis (pH, pCO2, pO2; AVL-Gas Check, Graz, Austria). Derived parameters such as base excess and oxyhemoglobin concentration are computed by recently designed routines. By means of the Physio-Control In Vivo Oximeter mixed venous oxyhemoglobin saturation can be monitored continually (Physio-Control Corporation, Redmond, Washington, USA).

After preprocessing of primary ergospirometric and pressure data an external program control unit feeds the digitized and stored data (up to eleven parameters) via interface into a minicomputer (Olivetti P 652; hardware and software systems, Fa Jäger). The programs are stored on magnetic cards and on a magnetic disc. Software programs (Fa Jäger) have been adapted or recently developed to meet special requirements, such as to calculate hemodynamic parameters, to compare actually measured parameters with normal ranges, to calculate an index of anaerobic power and to improve blood-gas-analysis for assessing oxygen saturation.

(A) Ergometry

The procedure of the rectangular-triangular bicycle exercise test is described in detail elsewhere. The concept of the test is maximal stress limited by symptoms. The work loads are incremented every two minutes by 25 to 50 watts. The test is terminated by standard criteria to interrupt an exercise test, such as severe fatigue or perceived exertion rate 19 (PER), unless alarming symptoms of exertional intolerance arise (ECG/ rhythm disturbances, ST-T-alterations; extremely high blood pressure or fall in exercise blood pressure; complaints of angina pectoris and severe dyspnea).

Two groups of parameters must be checked continually: a) Objective criteria: the work load tolerated in relation to the predicted maximal load, the ECG with reference to rhythm disturbances and ST-T-changes, the heart rate, the blood pressure (auscultatory method) and the type and rate of respiration and b) Subjective criteria: symptoms of cardiopulmonary discomfort (angina pectoris, dyspnea), the perceived exertion rate (PER) and the patient's motivation.

Both criteria represent data which play an important role as simple feed-back mechanisms to the physician when he is rating the patient's response to a given load.

The ECG is documented graphically via a six-channel writer and displayed on the screen. The documented beat-to-beat analyzed analog signal of the heart rate and the audibly displayed QRS-signal will make the physician aware of any heart rate and rhythm abnormality.

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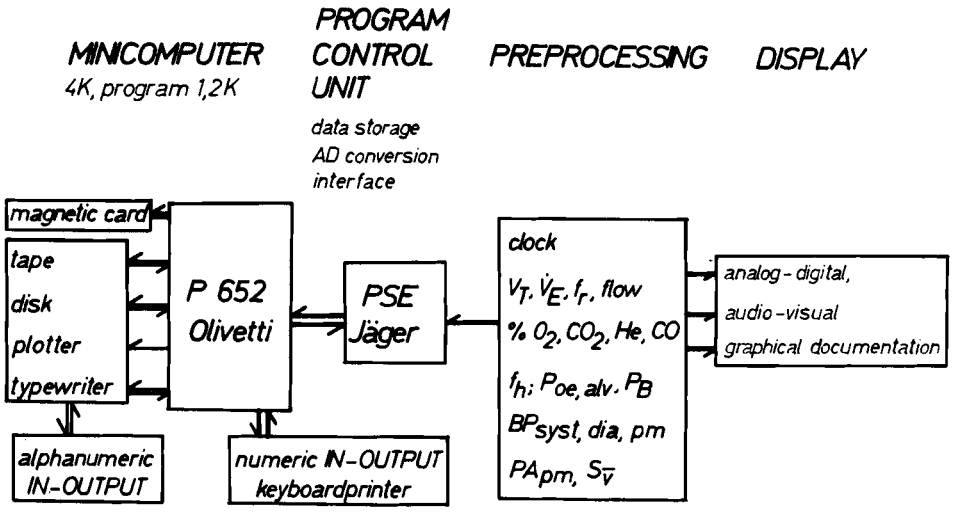


Figure 1

Hardware configuration. On-line analysis of lung function, ergospirometry and pressure values.

(B) Ergospirometry

The next step in evaluating the physical performance in patients with cardio-pulmonary impairment will be the rectangular-triangular ergospirometric bicycle test with the on-line analysis of respiratory function and gas-exchange.

Table 1
Criteria of Physical Performance

(1) AEROBIC POWER and ADAPTATION to increasing work rates
(2) ANAEROBIC POWER

(3) TOLERANCE of METABOLIC ACIDOSIS

After peripheral preprocessing of the expired air volumes, the rate of respiration and the CO2 and O2 concentrations, the minicomputer will calculate and document parameters as follows: expiratory volume per minute, tidal volume, breathing frequency, the concentration of CO2 and O2, oxygen uptake per min. and per kg body weight, oxygen pulse, respiratory quotient and heart rate. The data may be averaged over a predetermined period (e.g. resting period). At the first and second minute per load the oxygen uptake actually measured is compared with reference values. The difference is expressed as a multiple of the standard deviation of the regression line. In elderly subjects and patients with impaired myocardial pump function (hypokinetic circulation) oxygen uptake evidently stays below the standard values (- 1,0). In particular, evaluating oxygen uptake during short time intervals (0,5 min) provides information about adequate adaptational forces of the cardio-circulatory system.

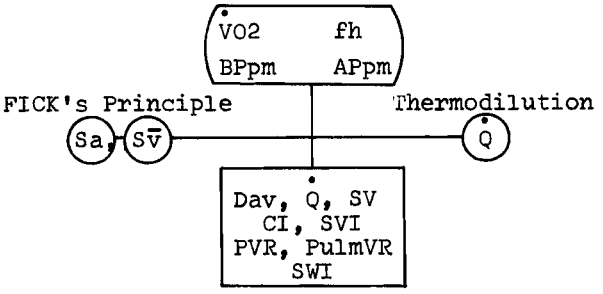
Energy that is not accounted for by reactions involving the VO2 measured is computed by subtracting the caloric equivalent of oxygen uptake during work exceeding the steady state level during rest from the energy demand to sustain a given work load aerobically. This INDEX of ANAEROBIC POWER is defined in kcal, cal/kg body wt. and as a percentage of the total amount of energy required. A close relationship to parameters of metabolic acidosis (base excess, pH) exists.

Physical performance of sedentary people, athletes and patients with impaired cardio-pulmonary function can be more precisely assessed in quantitative terms by means of computer assisted rectangular-triangular ergospirometry. Results obtained in patients with diseased conditions must be carefully interpreted, their condition suggesting the use of more invasive investigations to reveal the underlying pathophysiologic mechanisms.

(C) Central Hemodynamics

To assess the pump function of the heart, the systemic pressure regulation and the pressure changes in the pulmonary vascular bed (PAEDP), invasive techniques are absolutely necessary. Evaluating from a functional point of view we study the effects of steady state levels of dynamic work and the non-steady state responses to static stress in patients with coronary heart disease, chronic obstructive lung disease and abnormal blood pressure regulation.

Table 2
Central Hemodynamics on-line



To calculate the cardiac output ($\dot{Q}$) and derived parameters we prefer the Fick-principle rather than the thermodilution technique.

While blood samples are withdrawn (mixed central venous and arterial blood samples), the oxygen uptake, the heart rate and the systemic and pulmonary pressure values are stored, averaged and documented via keyboard printer. As soon as the oxygen saturation has been calculated, the hemodynamic calculation routine is started and data such as work load, arterial and venous oxygen saturation and conditionally LVET are entered via keyboard. The derived hemodynamic parameters are computed by a standard program (Q, CI, SV, SVI, Dav, PVR, LVWI, SWI, MSER, TTI). The main routine program is restarted via keyboard and via external

control unit for the time-triggered (every 30 second) output of respiratory function data (see ergospirometry) as well as blood pressure values.

Table 3

Central Hemodynamics - Subroutines

- Calibration
- Ergospirometry
- Pressure Values
  Oxygen Saturation
  Dav
- Central Hemodynamics
  (Fick's Principle or
  Thermodilution)
- Blood Gas Analysis
- Data of Patient
- Selection of Subroutines and Interrupt-Conditions
- Averaging (steady-state)

By means of fiberoptic catheters mixed venous oxygen saturation can be monitored continually (Physio Control In Vivo Oxymeter). Applying this technique, on-line evaluation of derived hemodynamic parameters (every 30 second) has been realized.

This procedure offers a great number of objective criteria in quantitative terms to the supervising physician. The actual values and the changes and variation of parameters such as heart rate, oxygen uptake, oxygen pulse, cardiac output, stroke volume, arterio-venous oxygen saturation difference, pulmonary artery enddiastolic pressure, and mean systemic and pulmonary pressure values proved to be precise and outstanding information to evaluate response and adaptation to work loads in patients with impaired cardio-pulmonary function.

Because of the complex reactions of cardiovascular and respiratory dynamics - besides abnormal electrocardiographic signs of myocardial ischemia, rhythm irregularity and subjective symptoms such as chest pain, dyspnea and perceived exertion rate - we believe at the moment that the trained physician has to decide which work load the patient should tolerate and when the test has to be interrupted.

By integrating peripheral preprocessing, online computation of derived parameters with time-triggered and keyboard controlled printout, audio-visual and graphic documentation, our ERGOMETRY-SUPERVISING-SYSTEM has proven to be an optimal assistance to invasive stress testing.

Table 4

Invasive Techniques in Stress Testing

PARAMETERS	DOCUMENTATION DISPLAY	CON	INT
Work load	ana	X	
ECG	ana, graph	X	
fh	ana, aud, prin	X	X
VE, VT, fr	ana, graph, prin	X	X
% CO2, O2	dig, graph, prin	X	X
VO2, O2-pulse, RQ	prin		X
Systemic pressure	ana, graph, prin	X	X
Pulm. art. press.	ana, graph, prin	X	X
Q, CI, SV Dav	prin		X
SWI, PVR, PulmVR	prin		X
pH, pCO2, pO2, Sa, $S\bar{v}$	dig, prin		X

(CON = continually, INT = intermittently, ana = analog, dig = digital, graph = graphical, prin = printout, aud = audible).

References

1. Astrand P.O., K. Rodahl: Textbook of Work Physiology. McGraw-Hill Book. New York, 1970.
2. Eklund L.G., A. Holmgren: Central hemodynamics during exercise. Circulat. Res. (Suppl I) 20/21, 1-33 (1971).
3. Marsoner H.J., K. Harnoncourt: Die Berechnung der Sauerstoffsättigung als Funktion von pO2, pH und Basenabweichung. Submitted.
4. Reiterer W.: Methodik eines rektangulär-triangulären Belastungstestes. Herz/Kreisl. 7, 457-462 (1975).
5. Reiterer W.: On-line Analyse von anaerober Energiebereitstellung und Sauerstoffschuld während rektangulär-triangulärer Fahrradergometrie. Wien. klin. Wschr. 88, 527-530 (1976).
6. Reiterer W.: Evaluation of physical performance by rectangular-triangular bicycle ergometry and computer assisted ergospirometry. Basic Res. Cardiol. 71, 482-503 (1976).