A critical look at currently used indirect indices of myocardial oxygen consumption*)

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With 6 figures and 1 table

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Summary

Myocardial oxygen consumption indices that are frequently applied to man such as tension-time index (TTI), pressure-rate product (P·HR) and triple product (TP) have not been fully validated so far. These easily obtainable indices and a modified TTI (P·\sqrt{HR}) therefore, were examined in 10 closed-chest dogs with very broad variations of hemodynamics and oxygen consumption (3–36 ml/min · 100 g) analyzing 162 steady states. Myocardial blood flow was directly measured by a differential pressure coronary sinus catheter. \( \text{MVO}_2 \) was varied by administration of catecholamines and other inotropic drugs, atropine, beta-blocking agents and hypovolemia. Over a wide range of hemodynamic states, correlations with directly measured \( \text{MVO}_2 \) of TTI (r = 0.63), P·HR (r = 0.87), TP (r = 0.65) and P·\sqrt{HR} (r = 0.80) are not satisfactory due to neglect of contractility and cardiac volumes by these terms. Better correlations are obtained when relating these indices to \( \text{I/V[O}_2 \) under different inotropic states. At normal and moderately increased contractility, correlations with \( \text{MVO}_2 \) rose as follows: TTI (r = 0.96), P·HR (r = 0.91), TP (r = 0.96) and P·\sqrt{HR} (r = 0.94). Significant rises in correlation are due to the close relationship between peak pressure and dP/dt\text{max} at only moderately increased contraction velocity. Correlation differences within this inotropic range must be related to incorporation or neglect of ejection time as a partial determinant of \( \text{MVO}_2 \). At markedly increased contractility, however, results for these indices are in part very poor: TTI (r = 0.40), P·HR (r = 0.81), TP (r = 0.38) and P·\sqrt{HR} (r = 0.76). Within this inotropic state neglect of dP/dt\text{max} as a major determinant of \( \text{MVO}_2 \) and the inverse relationship between ejection time and dP/dt\text{max} mainly account for these correlation shifts. It is concluded that non-invasively obtainable indices, currently in use, are no reliable predictors of actual overall \( \text{MVO}_2 \) if the contractile state of the myocardium is not checked invasively before. The broad variability of the relation of the energy demand of velocity of tension development to maintenance of systolic wall tension is not sufficiently considered by these terms. Appropriate caution, therefore, is necessary when applying these indirect indices of \( \text{MVO}_2 \) to humans.

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Introduction

Direct measurement of myocardial oxygen consumption as a routine method is not practicable in patients with cardiovascular diseases due to the required coronary sinus catheterization and the ethical limitations. In a recent paper about all published oxygen consumption indices (1) it has been demonstrated that the application of an indirect method yields a high accuracy in determining left ventricular oxygen consumption. The hemodynamic parameter of Bretschneider (2) consisting of five additive components and requiring an invasive determination of $dP/dt_{max}$ showed a close relationship to myocardial oxygen consumption over a very broad test range ($r = 0.96$).

Frequently applied oxygen consumption indices, both in clinical cardiology and cardiovascular research units, are tension-time index, double product and triple product (3, 4). Comparative investigations on the reliability of these indices are rather few and incomplete (5, 6). Their measurement accuracy has not been examined hitherto by a valid reference method of measuring overall myocardial blood flow for direct determination of oxygen consumption. Former comparative reports on oxygen demand indices give little information upon the preconditions for the application of those easily obtainable indirect indices. Furthermore, the good results for tension-time index, double and triple product, reported previously, have been achieved on an insufficient number of data points covering only a small test range without reference to maximal changes of hemodynamics and oxygen consumption. Therefore seven easily determinable oxygen demand indices were tested experimentally in intact dogs with left ventricular weights comparable to humans, both under moderate and under extreme changes of hemodynamics and oxygen consumption.

In addition a further aim of this study was to examine the accuracy of all readily measurable and in part non-invasively obtainable indices in predicting myocardial oxygen consumption under various clinically important states such as sympathetic stimulation, hypertonus and heart failure.

Methods

Ten mongrel dogs of either sex weighing 30–48 kg with left ventricular weights ranging from 130 to 200 g were anesthetized with 5 mg/kg · h piritramide and ventilated with nitrous oxide and oxygen (70 % : 30 %). Closed-chest conditions were kept in all experiments. Catheterization of cardiac cavities and vessels was carried out in clinical heart-catheterization technique. Figure 1 shows the final position of cardiac catheters and measurement probes in the heart. The following parameters were recorded continuously on a 10-channel recorder (Hellige GmbH, Freiburg, Germany): 1. electrocardiogram (extremity lead II); 2. left ventricular pressure (catheter tip pressure transducer, Millar Instr., Inc., Houston, Texas, USA); 3. first derivative of left ventricular pressure (differentiating amplifier, Fischer, Göttingen, Germany); 4. aortic pressure (pressure transducer PV 120, U-ONICS Laboratories, Wayland, Mass., USA); 5. left ventricular diastolic pressure; 6. myocardial blood flow with differential pressure catheter (7) positioned in coronary sinus; 7. expiratory CO₂ content (Uras, Hartmann and Braun, Frankfurt, Germany). Steady state conditions were determined by stability of ventricular and aortic pressure, $dP/dt_{max}$, myocardial blood flow and electrocardiogram over 3–5 minutes.