PRESSURE-VOLUME MEASUREMENTS BY CONDUCTANCE CATHETER METHOD IN THORACIC SURGERY AND INTENSIVE CARE STUDIES

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1. CARDIOMYOPLASTY and AORTOMYOPLASTY

In cardiomyoplasty dilated cardiomyopathy is treated by surgically wrapping the right latissimus muscle around the heart.The purpose of this is to stimulate the muscle, after having been conditioned for several months, in order to assist the ventricle in ejection during selected heart beats. The clinical success of this method is still debated. One of the important issues is how to evaluate the effects of the procedure in terms of improved pump function of the left ventricle. One of the most useful (or even the only) ways of assessing changed hemodynamics and contractile performance is the registration of left ventricular pressure-volume loops. Such loops may be constructed on a continuous basis during preload reduction (by transient vena cava occlusion) using the conductance catheter as has been done in several animal studies (1, 2, 3, 4). The general conclusion of these studies was that the proper stimulation protocol of the wrapped muscle effectuated an increase in contractility expressed by a leftward displacement and/or steeper slope of the end-systolic pressure-volume relation (ESPVR). A similar analysis, applied in human patients after undergoing cardiomyoplasty, has been published recently (5). Although no load reduction was performed in this multi-clinical study, it was shown convincingly that a stimulated heart beat when compared to unstimulated beats, resulted in an increased stroke volume mainly effectuated through a decrease in end-systolic volume, provided an optimal stimulation setting was utilized. A limited study of 3 patients, concerned with long term effects of cardiomyoplasty was published last year (6). These investigators found that the P-V loops of treated patients had shifted substantially to the left after 6-12 months, indicating increased EF and reversal of remodeling. More clinical studies of the intriguing question concerning how and under what conditions cardiomyoplasty appears to work are currently under way, all of which apply the conductance catheter method.

Aortomyoplasty also utilizes latissimus dorsi muscle to assist the failing heart. However, in contrast to cardiomyoplasty, the muscle is wrapped around the aorta and provides internal diastolic assist in a way analogous to aortic balloon pumping. To test the efficacy of the procedure, left ventricular pressure-volume loops utilizing the conductance catheter were measured in animal studies. Both normal hearts (7) and failing hearts (8) of dogs were investigated. Heart beats immediately following diastolic muscle stimulation compared to heart beats without previous stimulation showed a sizeable improvement of contractile performance as exemplified in a steeper ESPVR or a leftward displacement of the P-V loop.

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2. PARTIAL LEFT VENTRICULECTOMY

Severely dilated hearts commonly have a radius to wall mass ratio far exceeding normal and this consideration has led Batista to apply a surgical procedure existing of excising a substantial part of the left ventricular wall in eligible patients (1). In the case report described by him it is reported that ejection fraction increased from a pre-operative value of 17% to 37% and, 2 months later, to 44%, effectuated through the substantial reduction in cavity volume. Reportedly, Batista has treated several hundreds of patients so far, many of whom were studied perioperatively by recording pressure-volume loops with the conductance catheter method. It is obvious that this method is to be preferred over other ways of assessing ventricular volume in the operating room.

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3. CARDIAC TRANSPLANTATION

One of the key issues in cardiac transplantation is the suitability of the donor heart in terms of its pump function. An optimal way of testing the contractile performance of the left ventricle before the donor heart is excised consists of measuring pressure-volume relations during preload reduction. Three studies utilizing the conductance catheter for this purpose have been published: one assessed the value of core-cooling in dogs (1) while a second canine study investigated the effects in terms of (irreversible) changes in the slope of the ESPVR after increasing duration of cold storage of the heterotopically transplanted heart (2). A clinical study of the hearts of brain dead subjects employed evaluation of the slope of the ESPVR in comparison to the afterload (arterial elastance) (3).
Another clinical study has applied the conductance method to assess the behavior of cardiac pump performance (in terms of the slope of the ESPVR) in transplant patients in response to enoximone administration (4). More studies will be required to fully evaluate the need for and the effectiveness of assessing myocardial performance of donor hearts before or after being transplanted. There is little doubt, however, that such an assessment may be done rather easily by measuring P-V loops during load reduction with on-line pressure and volume registration.

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4. CARDIOPULMONARY and LEFT HEART BYPASS

Total or partial bypass of the heart is unavoidably accompanied by global ischemia of one or both ventricles. Assessment of the damage caused by ischemia using pressure-volume analysis obtained by the conductance catheter method has been performed by several groups. Matsuwaka et al have studied the changes in left ventricular pump performance in dogs subjected to 20 min of global ischemia followed by 80 min of reperfusion under total CPB and found that parameters related to preload recruitable stroke work (PRSW) were significantly reduced even after slope and intercept of the ESPVR had recovered to pre-ischemic values (1, 2). P-V relations of the left ventricle during inflow occlusion were measured pre- and post CPB in humans undergoing coronary artery bypass surgery (3). It was concluded that these relationships may be recorded repeatedly and quite easily in the operating room, but that changes in slope and intercept are related to a complex interplay of variations in loading conditions, body temperature and initial myocardial performance. The use of the conductance catheter peroperatively was advocated also by Urbanowicz (4).
The pump performance of the right ventricle in response to left heart bypass (LHB) was studied by two groups: Park et al obtained the RV contractile parameters ESPVR and 'force-velocity relationship' in both normal and failing canine hearts subjected to LHB (5, 6). They found that the decrease in RV performance was related to the assist ratio of LHB, depending upon the RV afterload. Somewhat at variance with these findings, Kitano et al found that LHB in dogs did not change the slope of the ESPVR of the RV and improved its compliance because of RV afterload unloading (7).

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5. CARDIOPLEGIA and CARDIAC ARREST

Effects of various components added to cardioplegic solution, its temperature or route of administration have been investigated with the use of the conductance catheter measuring P-V relations in many experimental studies. Thus, effects of adding acadesine (1), the nitric oxide donor SPM-5185 (2), adenosine (3) to cardioplegic solution (CPL) and variations in the blood to CPL mixing ratio (4) were studied in dogs or mini-pigs. In one of these studies, coronary endothelial function was assessed in addition to LV performance (2). The general conclusion was that post-cardioplegia dysfunction was improved by the various additions or modifications. Ko et al found that continuous warm cardioplegia in dogs did not provide benefits over single injection of cold cardioplegia in neither myocardial function (assessed by P-V relationships), myocardial energetics (assessed by the 'PVA' concept) nor endothelial or smooth muscle function (5). The effects of calcium administration in relation tot the problem of CPL-induced myocardial depression was studied quantitatively in dogs by conductance catheter-obtained P-V loops by Mathru (6). They concluded that the use of calcium should depend on initial serum levels of ionized calcium. A study by Caspi et al also involved the role of calcium concentration in CPL in newborn piglets and found that systolic as well as diastolic LV function was better preserved by low ionized calcium concentrations in the pre-ischemic period (7).
The safety of simultaneous arterial and coronary sinus perfusion was confirmed experimentally in mini-pigs employing ESPVR-derived parameters of contractility with the conductance technique by Buckberg's group (4, 8, 9). A clinical study in 30 patients undergoing CABG studying the effects of cold cardioplegic cardiac arrest on LV systolic and diastolic function was published recently by Wallace (10). The conclusion of this study was that CPL induces decreases in both modes of LV function, which could be quantified by P-V relationships.
Ventricular dysfunction after resuscitation following cardiac arrest, finally, was studied in pigs (11). As quantified by conductance method-obtained P-V relations, dysfunction (especially increases in LV volumes) was clearly related to time after resuscitation.

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6. PEDIATRIC SURGERY

Cardiac surgery in infants to correct congenital defects is associated with significant postoperative dysfunction. The infaust effects of high levels of circulating catecholamines on myocardial function were investigated experimentally in newborn piglets by Caspi using pressure-volume analysis by conductance catheter (1, 2, 3). Another study investigated the protective effect on catecholamine-induced LV dysfunction by magnesium (4). The study of calcium concentrations in CPL in the newborn by the same group cited above (5) is also of importance in this respect.
The question as to whether surgery-related reoxygenation of the heart after - often long - periods of hypoxemia associated with many forms of congenital defects, is the subject of a sizeable number of experimental studies by Buckberg's group (6). Using pressure-volume analysis of LV function (ESPVR and Starling curves), among other methods, in newborn piglets subjected to hypoxemic periods, these investigators:

a. Found evidence for reoxygenation damage, due to reducing anti-oxidant reserve capacity and excessive lipid peroxidation (7, 8, 9);

b. Compared hypoxemia/reoxygenation damage to damage by ischemia/reperfusion (10);
c. Counteracted reoxygenation injury by exogenous antioxidants, showing recovery of LV contractility, often in a dose-dependent fashion (11, 12, 13);
d. Provided evidence for the advantages of normoxic vs. hyperoxemic management during CPB (14);

e. Elucidated the role of nitric oxide production in the question of normoxic vs. hyperoxemic reoxygenation (15, 16);
f. Investigated the role of the iron-catalyzed pathway of oxygen-mediated myocardial injury by deferoxamine and showed its beneficial effect (17).

In all of these studies, contractility was assessed through P-V loops by the conductance catheter method.

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7. VARIOUS SURGICAL and CRITICAL CARE-RELATED STUDIES

Employing the conductance catheter for pressure-volume analysis of the left ventricle, studies were performed on the following topics:

1. Pericardectomy for constrictive pericarditis, showing its beneficial effects on P-V loops (1);
2. Acid aspiration-induced lung injury (2);
3. Effects of jet ventilation on heart failure, showing its negative inotropic influence (3);
4. Endotoxemia in (porcine) septic shock and the role of NO synthase inhibition (4), anti-tumor necrosis factor-α (5) and ibuprofen, a cyclooxygenase inhibitor (6) to prevent a decrease in myocardial contractility. Also, the role of myocardial oxygen extraction during endotoxemia in pigs was investigated by this group of investigators (7).

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