Coronary Artery Graft Flow During Nonpulsatile and Pulsatile Extracorporeal Perfusion

Veikko O. Laaksonen, M.D., Ollli A. Meretoja, M.D.; Matti K. Arola, M.D.; Markku V. Inberg, M.D.; Jukka K. Irjala, M.D.; Esko Vänttinen, M.D.

From the Departments of Anesthesiology and Surgery, University of Turku, Turku, Finland

Abstract

The effects of ECG-triggered pulsatile extracorporeal perfusion on saphenous vein coronary graft mean and instantaneous flow patterns were determined. Ten consecutive coronary bypass surgery patients were studied during the period of weaning from extracorporeal circulation as and when the patients' sinus-rhythm allowed synchronization of diastolic counterpulsation.

We found no differences either in the mean or in the peak graft flows during pulsatile and nonpulsatile artificial perfusion, but during pulsatile supportive perfusion the instantaneous graft flow tended to increase towards the end of the diastole—as in a spontaneously beating heart—whereas nonpulsatile perfusion generated maximum graft flow at the beginning of the diastole. The combined influence of the techniques used and patients' well-being on the graft flows is discussed. Pulsatile perfusion may reduce the duration of the partial and total supportive perfusion in coronary bypass surgery.

Introduction

Open-heart surgery inevitably brings about subendocardial ischaemia,[2] and the incidence of perioperative acute myocardial infarction ranges from 5% to 40%[1] despite the remarkable progress made in methods of myocardial preservation during the open-heart procedure. Following the reestablishment of normal coronary blood flow, during the period of weaning from extracorporeal circulation, the elevation of diastolic blood pressure augments the coronary flow. This, in turn, may improve the myocardial pump function and energy metabolism.

Intra-aortic balloon counterpulsation (IABP) has emerged as the single most important clinical adjunct in the treatment of refractory left ventricular power failure after open-heart surgery. During IABP there is an improvement in the retrograde diastolic coronary flow because of an elevation in the mean aortic diastolic pressure.[3] The IABP procedure is traumatic, and the catheter must be in place for some time. In open-heart surgery, however, often supportive perfusion is needed only a short-time. During the weaning period, the synchronized counterpulsation achieved with ECG-triggered diastolic pulsatile perfusion, can be expected to provide the most satisfactory supply of blood to the coronary arteries.

Because of the above considerations, we have used the recently developed commercial Cobe/Stöckert pulsatile system to provide an ECG-triggered flow to coronary artery bypass grafts (CABG) after revascularisation. With a square-wave electromagnetic flowmeter* we measured and compared the effects of the pulsatile and nonpulsatile perfusion systems on CABG mean and instantaneous peak flow patterns.

Material and Methods

Ten consecutive patients subjected to aortocoronary bypass surgery were chosen for the present study. There were nine males and one female. The age of the patients

Address reprint request to Dr. V. Laaksonen, Department of Anesthesiology, University of Turku, SF-20520 Turku 52, Finland

* Model 372, Nycotron, Oslo, Norway

ranged from 36 to 57 years, the mean age being 49 years.

The anesthesia was induced with neurolepts, thiopentone and pancuronium. The patients were connected to a volume pre-set ventilator, and the anesthesia was maintained with nitrous oxide and 30% oxygen, fentanyl and pancuronium.

Moderate normovolemic haemodilution was carried out pre-bypass by withdrawing 15 ml blood per kg of body weight; the shed blood was replaced in a 1:1 ratio by 4.0% albumin-plasma protein solution. Concomitantly, systemic, pulmonary and venous pressures were carefully monitored.

For extracorporeal circulation, a Rygg-Kyvsgaard bubble oxygenator**, nonhaemic priming, moderate hypothermia (30 °C), and a Stöckert roller pump*** were used. The pump was controlled by a control module, which generated the nonpulsatile or pulsatile flow, either from the internal trigger or from the patient's electrocardiogram. For perfusion, the arterial cannula**** was connected to the ascending aorta, the tip being directed distally from the aortic valve. One blood filter***** was used in the arterial line between the roller pump and the patients. For myocardial protection, we used the cold cardioplegic arrest technique, together with continuous topical cooling with ice-cold saline solution. The mean perfusion time was 156 min (range 100–198 min), and the mean total aortic cross-clamp time was 69 min (range 25–105 min). Three patients received three saphenous vein grafts, six patients two grafts, and one patient a single graft.

After completion of the surgical procedure on the heart, when left ventricular ejection had recommenced towards the end of the bypass, ECG-synchronized 1:1 counterpulsation was used.[5] The run time was set at around 30% of the total cardiac cycle, and the timing was adjusted on the basis of the arterial wave form. Both the nonpulsatile and the pulsatile flows were pre-set at 2.4 $l/m^2/min$. The roller settings were totally occlusive in both modes of function similar to a conventional roller pump.

After the rewarming period, during the last phase of partial bypass, the continuous nonpulsatile, and pulsatile modes of perfusion were used alternately. The graft which had the highest and most stable flow was chosen for the flow measurements. Both the mean and instantaneous flow patterns were recorded on a multichannel recorder, using an electromagnetic square-wave flowmeter*. In order to produce zero flow, the grafts were occluded proximally to the measuring site. In some cases, for comparison of the flow patterns, the graft flow was also recorded after decannulation.

TABLE 1
Average mean and peak instantaneous CABG flow values during nonpulsatile and pulsatile extracorporeal circulation at the end of bypass during the weaning period.

Average flow measurements	Pulsatile ± SD	Nonpulsatile ± SD	p value
Mean CABG flow	87.1 ± 43.6	88.9 ± 50.6	N.S.
Peak instantaneous flow	167 ± 96.2	168 ± 96.3	N.S.

Results

The mean CABG flow, measured from the graft with the highest volume flow during continuous extracorporeal circulation, was 88.9 ± 50.6 ml/min (Table 1), and during ECG-triggered, pulsatile counterpulsation it was 87.1 ± 43.6 ml/min. The mean flow values are identical irrespective of the nature of the perfusion. We did not observe any important differences in the peak maximal instantaneous flow values, which were 168 ± 96.3 ml/min with continuous and 167 ± 96.2 ml/min with pulsatile extracorporeal perfusion.

The instantaneous CABG flow increased slightly towards the end of the diastole when pulsatile perfusion was used. During nonpulsatile perfusion the maximum instantaneous flow was at the beginning of the diastole and slightly decreased thereafter. After decannulation the instantaneous flow pattern was like that with augmented pulsatile diastolic perfusion, that is, it increased towards the end of the diastole. In arterial pressure recordings, diastolic augmentation was observed, but, in general, was rather limited, despite the generation of a 30–40 mmHg pulse wave during the periods of total perfusion.

Figure 1 shows the pressures proximal and distal to the arterial-line filter during continuous and pulsatile perfusion. The filter caused a pressure gradient of over 100 mmHg during pulsatile perfusion, but only a 10–20 mmHg gradient during continuous flow.

** Polystan AS, Copenhagen, Denmark

*** Stöckert Instrumente, Munich, West Germany

**** Model Argyle[R] 8888.570531, 24 Fr, Sherwood Medical Industries LTD, London, England

***** Model PF-427, Bentley Laboratories, Inc., Santa Ana, Calif. Ana, Calif.

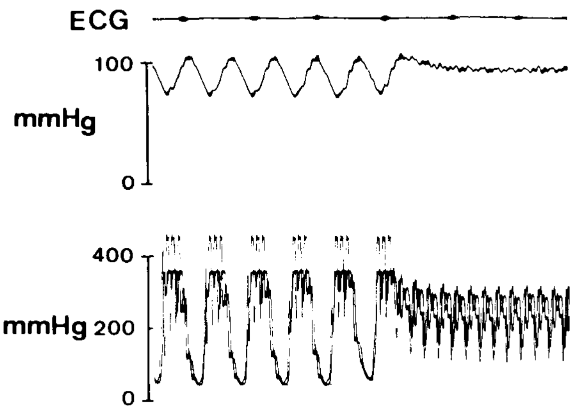

FIGURE 1. The pressures registered proximal and distal to the arterial-line filter during pulsatile and nonpulsatile extracorporeal circulation.

Discussion

Numerous investigations have been carried out with the object of achieving the best possible protection for myocardial energetics and function during aortic cross-clamping,[2] but still the discontinuation of normal coronary flow is most often associated with subendocardial ischaemia, and subendocardial necrosis remains the most common serious complication of open-heart surgery.[2]

Any method that will augment the coronary arterial flow, or diminish myocardial oxygen consumption in the working heart, is likely to improve the myocardial oxygen supply/demand ratio and facilitate the recovery of myocardial energetics and function during the weaning period at the end of bypass. Accordingly, both intra-aortic balloon pumping and vasodilator therapy have been used successfully to offset deteriorated myocardial metabolism and performance.[3,8,9] Furthermore, the potential importance of pulsatile cardiopulmonary bypass has been recognized for several years, and the Datascope pulsatile-assist device was one of the first clinical in-line systems with which it was possible to generate atraumatic synchronized pulsatile extracorporeal flow. This device functioned as an arterial counterpulsator and augmented the coronary graft flow by about 25%.[4]

We utilized an ECG-triggered roller pump in our heart-lung machine to synchronize the extracorporeal flow to the diastole of the beating heart in order to compare the effects of pulsatile and nonpulsatile perfusion on the saphenous vein coronary graft flow during the last phase of bypass. The pulsation during cardiopulmonary bypass was produced by rapid acceleration and deceleration of the roller pump and the synchronization through the patients ECG triggering similar to an intra-aortic balloon pump. Although the pulsatile mode created an average pulse pressure of 30 mmHg during aortic cross-clamping, and although the flow was totally diastolic (mean 2.4 and maximum 7 l/m^2/min), we were unable to observe any change in mean or peak graft flows when we changed from nonpulsatile to pulsatile perfusion, or vice versa. The only difference between the recorded flows was in the instantaneous flow patterns: during nonpulsatile perfusion, the graft flow reached its maximum at the beginning of the diastole, whereas during both pulsatile perfusion and spontaneous circulation the graft flow tended to increase towards the end of the diastole. Consideration should be given to the above findings.

Having ourselves had three years' experience of the Datascope intra-aortic balloon pump, we are of the opinion that none of the patients included in the present study would have needed the support of the balloon pump. Consequently, the possibility cannot be ruled out that the average myocardial function and graft flows were already adequate during continuous extracorporeal perfusion, and that the graft flows could not be expected to derive any benefit from pulsatile diastolic perfusion or from diastolic augmentation even with a balloon pump. Two technical points also deserve attention: first, the straight arterial cannula which we introduced into the ascending aorta was not directed towards the coronary ostia, but towards the aortic arch. Secondly, according to our general practice, we used a Bentley arterial-line filter during the flow recordings and, at the times of the measurements, it created a pressure gradient of over 100 mmHg during pulsatile perfusion. If the arterial filter is used, it is possible that it limits the diastolic augmentation; also the length of the arterial line may affect the timing of the pulsation. In this study we did not measure the graft flows without an in-line arterial filter.

The evidence makes it plain that pulsatile flow produces improved perfusion of the subendocardium, even in the presence of critical coronary stenosis.[6,7] We conclude nevertheless, that the Cobe/Stöckert ECG-triggered pulsatile perfusion system employed was incapable of augmenting either the mean or the peak coronary graft flows during the period of weaning from extracorporeal circulation after open-heart surgery. Considerable further experience and an improvement of techniques will be necessary before we can expect to achieve maximal diastolic augmentation. Pulsatile perfusion may, however, reduce the periods of partial and/or total supportive perfusion in coronary bypass surgery.

References

1. Mundth, E. D. and Austen, W. G.: Surgical Measures for Coronary Heart Disease. *N. Engl. J. Med.* 293: 13-19, 75-80, 124-130, 1975.
2. Buckberg, G. D.: Left Ventricular Subendocardial Necrosis. *Ann. Thorac. Surg.* 24: 379, 1977.
3. Bregman, D.: Dual-Chambered Intra-Aortic Balloon Counter-pulsation. In *Current Techniques in Extracorporeal Surgery,* M. I. Ionescu and G. H. Wooler (Eds), London, Butterworth and Co., Ltd., 1976, p. 407.
4. Bregman, D.: Hemodynamic Effects of Pulsatile Blood Flow. In *Clinical Application of Intra-Aortic Balloon Pump,* H. Bolooki (Ed), New York: Futura Publishing Company, Inc., 1977, p. 29.
5. Taylor, K. M.: Pulsatile Flow During Cardiopulmonary Bypass. Theoretical Basis and Clinical Experience. Technical Report. Cobe Laboratories Inc., Lakewood, Colorado, U.S.A. 1979.
6. Schaff, H. V.; Ciardullo, R.; Flaherty, J. T.; and Gott, V. L.: Effect of Pulsatile Perfusion during Cardiopulmonary Bypass in Reducing Regional Myocardial Ischemia Distal to a Critical Coronary Stenosis. *Circulation 53-54:* Suppl. II, 1976 (Abstract).
7. Watson, J. T.; Willerson, J. T.; Fixler, D. E.; Browning, R. M.; and Sugg, W. L.: Changes in Collateral Coronary Blood Flow (CCBF) Distal to a Coronary Occlusion During Intra-Aortic Balloon Pumping (IABP). *Trans. Am. Soc. Artif. Intern. Organs* 19: 402, 1973.
8. Sturm, J. T.; Fuhrman, T. M.; Igo, S. P. and Norman, J. C.: Efficacy of Nitroprusside Therapy in Postcardiotomy Low-Output Syndrome Necessitating Intra-Aortic Balloon Counterpulsation. *J. Thorac. Cardiovasc. Surg.* 78: 254, 1979.
9. Meretoja, O. A. and Laaksonen, V. O.: Hemodynamic Effects of Preload and Sodium Nitroprusside in Patients Subjected to Coronary Bypass Surgery. *Circulation* 58: 815, 1978.