Arq Bras Cardiol
56 (5): 407-412, 1991

TEMPORARY CIRCULATORY ASSIST DURING HIGH-RISK CORONARY ANGIOPLASTY. WHICH TECHNIQUE FOR WHICH PATIENTS?

ROBERTO V. HAENDCHEN, ELIOT CORDAY
Los Angeles, USA

Percutaneous transluminal dilatation of atherosclerotic obstructions in peripheral arteries was first described by Dotter and Judkins in 1964 [1] . In the late 1970s, Gruentzig et al[2] introduced the use of percutaneous transluminal coronary balloon angioplasty (PTCA) for the treatment of chronic stable angina pectoris associated with severe single vessel coronary artery disease[3].

Since that time, the use of PTCA rapidly expanded to other coronary anatomical as well as clinical situations, such as in patients with stable angina and multivessel coronary artery disease[4,5], and patients with unstable angina[6,7] and acute ischemic syndromes, including acute myocardial infarction[8-10]. PTCA has also been successfully used for recanalization of totally occluded vessels[11-13]. Impaired or even severely depressed left ventricular (LV) function no longer seems to be an impediment to coronary angioplasty[14-15]. More recently, a variety of alternative techniques to PTCA, such as laser angioplasty[16-17] and atherectomy[18], have been developed and successfully used in preliminary clinical trials. Other techniques such as ultrasound ablation of atherosclerotic lesions[19] are still in the developmental phase.

It has been well documented in experimental[20] as well as in clinical studies[21 22] that severe regional LV dysfunction develops very rapidly following complete interruption of coronary artery blood flow, usually within the first 10 to 20 cardiac beats after coronary artery occlusion in the absence of significant collateral flow (fig. 1). Regardless of the method used for coronary artery recanalization, occlusion of a major coronary artery during angioplasty may not be tolerated in a significant proportion of cases, depending upon the extent and severity of obstructive lesions in other coronary arteries, collateral blood flow, the amount of contracting myocardium supplied by the target vessel, as well as the extent of baseline LV dysfunction.

Because coronary angioplasty has been increasingly used in high-risk conditions[14,15], and in many cases is the only suitable revascularization procedure to be offered, there has been great interest in he use of circulatory supportive techniques during angioplasty in such patients. Furthermore, many of these techniques can be life saving in cases of failed angioplasty, particularly after abrupt coronary artery closure, which has been associated with high morbidity and increased mortality rates[23,24].

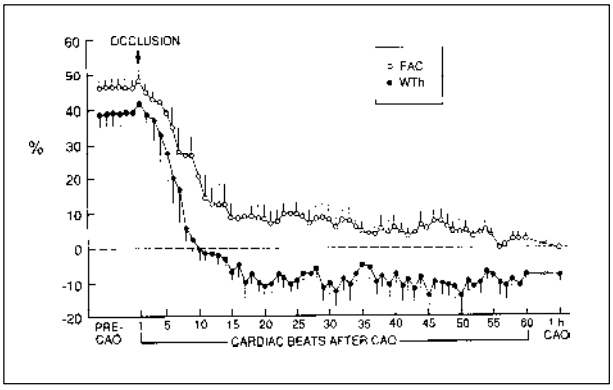

Fig. 1—Beat-to-beat changes in myocardial contraction in the center of the ischemic zone immediately prior to, during the first 60 beats, and 1 hour following acute coronary artery occlusion (CAO) in 5 dogs with limited collateral blood How (means ± standard error). Regional contraction was assessed by systolic cavity area change (FAC, fractional area change) and transmural systolic wall thickening (WTh) using two-dimensional echocardiography. Note absence of WTh 10 beats after coronary occlusion while some endocardial inward motion (FAC) was still present (from Haendchen et a/[20], with permission).

T**he dimension of the problem**. In 1987, approximately 200,000 PTCA procedures were performed in this country and abrupt coronary artery closure occurred in approximately 5% of these patients, resulting in more than 1,000 deaths[24-26]. Periprocedural occlusion occurs more frequently

This study was supported in part by Grants HL 14644-15 and HL 17561-15 from the National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, Maryland and the Medallion Group of Cedars-Sinais Medical Center, Los Angeles, CA.

Correspond: Roberto V. Haendchen—Cedars-Sinais Medical Center —Halper Bldg, Rm 325, 8700 Beverly Boulevard—Los Angeles, CA 90048-USA

Arq Bras Cardiol
56 (5): 407-412, 1991

while the patient is still in the cardiac catheterization laboratory, but 20 to 30% of occlusions take place outside the catheterization laboratory after an initially "successful" PTCA. It is estimated that in 1990 more than 350,000 intracoronary interventional therapeutic procedures will be performed in the United States alone. Because the indications and the demand for balloon angioplasty and other intracoronary interventions have consistently increased over the last few years, it is likely that the demand for supported angioplasty will also increase. In fact, angioplasty has been performed not only in a large percentage of patients with severe coronary artery disease who would otherwise be candidates for surgical revascularization, but many of these techniques have been used in patients in whom coronary artery surgery is either considered too risky or is actually contraindicated[15,27],

Although the vast majority of patients undergoing angioplasty are considered low risk candidates and most will do well without any support, acute complications and catastrophic events are not uncommon, and to some extent are unpredictable. Therefore, it seems well justified to develop a rational therapeutic approach to this problem, which includes the use of circulatory assist devices either prophylactically or as a standby procedure.

Whos is a high-risk candidate for angioplasty? Although the criteria for high-risk coronary angioplasty have not been clearly defined, several groups of patients can be readily identified as high-risk candidates for hemodynamic collapse, pulmonary edema or ventricular fibrillation during angioplasty one the basis of threatening coronary anatomy and/or extensive LV dysfunction. Table I summarizes such conditions.

Left main coronary artery dilatation has been clearly associated with high morbidity and mortality rates[25], particularly in the absence of a patent bypass to the left coronary system. Left main equivalent, deemed as stenosis > 70% in both the left anterior descending (LAD) artery before the first septal branch an in the circumflex artery before any branches in the absence of an intermediate branch, is also a high-risk anatomy for angioplasty[15] In many occasions, particularly during angioplasty of the proximal LAD or left circumflex artery, concomitant occlusion of a major side branch can significantly increase the procedural risk. These are anatomic situations requiring transient interruption of blood flow to large areas of myocardium and therefore prone to induce rapid hemodynamic deterioration and/or severe ventricular arrhytmias. Patients with more than 40 to 50% of viable contracting myocardium at risk for severe ischemia during the procedure have also been identified as high-risk candidates for angloplasty[27]. Other high-risk situations include angioplasty of the only remaining patent vessel, or a flow-limiting lesion in a major non-target vessel, whose perfusion territory might become severely ischemic if coronary perfusion pressure is transiently reduced during angioplasty.

Severe baseline LV dysfunction is clearly a situation that may require the use of supported or assisted angioplasty. Hartzler and coworkers have previously reported higher mortality rates in patients with LV ejection fraction < 40% undergoing PTCA[15]. Several investigators and angioplasters have advocated the use of prophylactic supportive techniques during angioplasty in patients with LV ejection fraction below 30% [27, 29], Severe transient reduction in ejection fraction in patients with normal or near-normal baseline LV function may also require temporary circulatory support. This most often occurs in patients with one or more of the conditions listed in Table I (A). Patients with acute ischemic syndromes or other cardiac abnormalities associated with elevated baseline LV end-diastolic pressure which cannot be successfully reduced with pharmacologic therapy should also be considered high-risk candidates for angioplasty.

Other conditions associated with high complications rates during angioplasty, particularly abrupt coronary artery closure, are mostly related to unfavorable location and/or adverse morphologic features of the lesions to be angioplasted (Table II). These include PTCA of ostial lesions, angled lesions >90º, bifurcation lesions, lesion lenght > 20 mm, exceedingly eccentric lesion morphology and presence of thrombi[30]. Some clinical variables have also been previously identified as high risk conditions such as acute ischemic syndromes, "high" surgical risk, combined diagnostic catheterization and angioplasty for unstable angina, age > 70 years, female gender and single session dilatation of 3 or more vessels[15 31].

Even though the conditions listed in Tables I and II have been helpful in identifying high-risk candidates for angioplasty, their predictive value have not been stablished.

Techniques for supported angioplasty. The concept of percutaneous or catheter-based circu latory assist for temporary support of the failing heart is not new[31 32] These techniques can be subdivided

TABLE I — Anatomic and physiologic conditions associated with righ risk for hemodynamic collapse, pulmonary edema or ventricular fibrillation during angioplasty.

A.Coronary Anatomy:
* left main as the target vessel
* ≥ 50% viable contracting myocardium at risk
* single remaining patent vessel
* occlusion of major side branch during angioplasty
* flow-limiting lesion in ≥ 1 major non-target vessel(s)

B.Left ventricular function:
* baseline EF < 40%
* baseline LVEDP ≥ 20 mmHg
* severe EF reduction during angioplasty

EF = left ventricular ejection fraction; LVEDP = left venticular diastolic pressure.

TABLE II Location and morphologic features of coronary artery lesions predictive of abrupt closure during angioplasty.

* ostial lesions
* angled (<90°) lesions
* bifurcation lesions
* thrombus
* extreme lesion eccentricity
* lesion lenght ≥ 20 mm

TABLE III Myocardial circulatory support techniques for high-risk coronary angioplasty.

* Autoperfusion balloon catheter (Stack)
* Non-phased antegrade active perfusion
* Antegrade phased diastolic perfusion
* Synchronized diastolic retroperfusion
* Perfluorochemical perfusion (Fluosol DA 20%)

into two general categories: 1) techniques which primarily provide myocardial blood flow, or " myocardial circulatory assist", and 2) techniques which provide hemodynamic support and peripheral organ perfusion, or "systemic circulatory assist".

Myocardial circulatory assist (Table III). Several techniques have been recently proposed to temporarily provide adequate blood flow or blood substitute to myocardial regions deprived of oxygen during angioplasty.

The autoperfusion balloon catheter provides distal coronary perfusion during angioplasty by passive blood flow through proximal perfusion side holes and holes distal to the dilating balloon[33,34]. Radiopaque markers proximal and distal to the perfusion holes as well as balloon markers facilitate adequate catheter positioning[35]. This technique has been tested in experimental models[36] as well as in variety of clinical situations[33-35]. Studies in the canine have demonstrated adequate distal perfusion and small infarcts during prolonged balloon occlusion of the coronary artery with concurrent maintenance of regional and global LV function[36]. More studies are needed, however, to clarify pressure-flow relationships with this catheter under variable hemodynamic conditions.

There has been no systematic study or controlled clinical trials on the efficacy of the autoperfusion catheter in preventing abrupt closure or as a stabilizing technique during high-risk angioplasty. This catheter, however, has been used in the catheterization laboratory not only to provide distal myocardial perfusion during high-risk angioplasty, but also to rescue patients with failed angioplasty and abrupt coronary artery closure[36]. More recently, the autoperfusion catheter has also been used to "seal" coronary artery dissections following angioplasty with prolonged balloon inflations[38].

The major advantage of the autoperfusion catheter is ease of implementation without the need for extracorporeal circuits. The disadvantages in some cases are inability to cross the lesion and appropriately place the catheter especially following abrupt coronary closure, lack of perfusion to territories supplied by occluded side branches, as well as inability to fully protect left main angioplasty. Other potencial limitations include the need for an adequate systolic blood pressure (> 80 mmHg) and reduced flow due to intraluminar catheter fibrin deposition and/or clotting of the side-holes distal to the balloon, particularly under low driving pressure or reduced cardiac output.

Perflurochemical perfusion with Fluosol 20% has been recently approved by the Food and Drug Administration to be used as an oxygen-transporting blood substitute during transient ischemia induced by angioplasty[39], including unstable and high-risk patients[40]. Fluorochemicals and particularly fluosol 20%, an emulsion mixture of perfluorodecalin and perfluorotripropylamine, were previously found to be safe in animal studies[41,42] Although fluosol has been considered safe in limited studies in the human[43], a major concern has been the hyperoxia required to enhance oxygen delivery to tissues[44], which can cause lung tissue damage[45,46]

Administration of fluosol has also caused anaphylactoid reactions[47,48] in humans, as well as severe transient hemodynamic alterations in both dogs[49] and humans[5] Transient elevations of transaminases and persistently elevated SGOT suggesting liver injury have also been reported in man [51].

The efficacy of oxygenated fluosol during angioplasty in human subjects has been controversial.

Reduction of ST segment elevations and time-to-peak ST segment changes with fluosol infusion during PTCA have been modest[52], and other studies have shown no significant improvements in diastolic or systolic LV function[53]. In a recent study, fluosol did not prevent an increase in pulmonary capillary wedge pressure or reduction in cardiac output usually seen in patients undergoing transient coronary artery occlusions during angioplasty without support, although there was some improvement in global LV function[40]. Additional limitations for the use of fluosol infusion during angioplasty include the need to warm up the solution to 37°C, time to oxygenate the solution to a PO_2 greather than 600 mmHg, and ST segment elevation during the infusion[54], which can preclude adequate assessment of ischemia during the procedure. Intravascular volume expansion may also be a limiting factor with the recommended infusion rates of 60-0- ml/minute, particularly in patients with high LV filling pressures. Furthermore, it is known that fluosol has a long blood and tissue half-life (13 hr and 8.9 days in rats, respectively)[55], and its long-term effects in humans have not been carefully studied, particularly liver toxicity. Perfluorochemicals are retained for long periods in the liver, spleen and bone marrow, and trace amounts may be found in these organs for up to 7 months after a single dose of 10 ml/kg. Therefore, repeated dosages should not be given at least during the first 7 months following the initial dose.

Coronary venous retroperfusion has been extensively investigated in animal models of acute coronary artery ocolusion[56-64]. It has been repeatedly demonstrated that synchronized diastolic retroperfusion (SRP) improves regional LV function and reduces infarct size in the canine[59-62] and in baboons[65 66], The technique consists of an ECG-gated pump connected to a triple-lumen balloon-tipped coronary venous catheter. Besides the infusion lumen, a second lumen is used for balloon inflation in diastole with a fixed CO_2 volume, and the third lumen is for monitoring of coronary venous pressure. The pump operates by piston displacement activated by a stepper motor. In this manner, autologous arterial blood (usually from the femoral artery) is pumped retrogradely in diastole and balloon deflation in systole allows normal coronary venous drainage.

Recent clinical studies in relatively low-risk patients undergoing elective PTCA have demonstrated that SRP is feasible and safe in human subjects[67]. Although the protocol used in these studies was not specifically designed to adequately test SRP efficacy, in the majority of patients there was moderate reduction in ST segment displacements and improved regional and global LV function during PTCA[67]. Berland and coworkers have also reported on the use of SRP-supported angioplasty in a similar patient population[68]. In their study the coronary sinus was successfully catheterized in 16 out of 17 patients within a mean of 140 seconds, and salutary effects of SRP on indexes of ischemia during 90 to 120 second LAD coronary occlusion were observed in the majority of patients. Constantini et al have recently demonstrated significant improvements in cardiac output, LV stroke work and ejection fraction during SRP-supported angioplasty in patients with acute ischemic syndromes[69]. Gore et al have previously shown beneficial effects of SRP in patients with rest angina refractory to maximal pharmacologic therapy[70].

SRP has been tested in only a few patients in the presence of ischemia in the left circumflex or right coronary artery perfusion territories[69 72]. It has been suggested that selective placement of the catheter in the regional coronary vein may enhance the efficacy of SRP[68], in which case improved catheter technology and stability would be critical for optimization of SRP, particularly for support of ischemic regions other than those supplied by the LAD coronary artery. If SRP efficacy can be confirmed in well designed clinical studies, a major advantage of this technique for temporary support of ischemic myocardium is that it does not interfere with the intracoronary artery interventional procedure. Another potential advantage is the possible concomitant use of coronary sinus pacing and retrograde drug infusion[72]. Recente studies have demonstrated pronounced accumulation of drugs in the ischemic myocardium following coronary occlusion and much higher tissue drug concentrations compared to simultaneous systemic intravenous infusions[73]. The disadvantages of SRP include inability to catheterize the coronary sinus or to appropriately position the catheter in the optimal location for SRP, which may occur in 5 to 10% of patients undergoing angioplasty, and unfavorable coronary venous anatomy, which may be present in as many as 5% of these patients. Therefore, emergency use of this technique during routine angioplasty may be difficult in some patients, unless prophylactic placement of the coronary sinus catheter is performed in anticipation of abrupt

coronary artery closure.

Antegradephased diastolic perfusion has also been proposed to protect the myocardium during angioplasty. This technique uses a principle similar to synchronized retroperfusion but arterial blood is pumped antegradely during diastole through the lumen of low profile PTCA catheters. Preliminary results in animal models and in humans[74] suggest that this technique might be an alternative to passive antegrade perfusion. Potential limitations of this approach are inability to cross the occlusion site, absence of perfusion to occluded side branches and possible damage to red cells or platelets due to high driving pressures and high blood velocities through the relatively small lumen of the angioplasty catheter.

Non-phasic antegrade perfusion of autologous arterial blood by infusion through the central lumen of PTCA catheter has been also proposed to mitigate ischemia during transient coronary artery occlusion[75]. Blood infusion at a rate of 60 ml/minute has been reported to be safe and effective in reducing ischemia during coronary angioplasty. Potential limitations of this technique are similar to the ones mentioned above for antegrade phased active perfusion.

Systemic circulatory assist (Table IV). **Intra aortic balloon pumping (IABP)** has been extensively investigated as an assist device for the failing heart and was one of the first techniques used for support of high-risk angioplasty[76]. Among is advantages in the fact that IABP has been currently used as a circulatory assist technique in a variety of clinical situations and is an effective left ventricular unloading device. A recent report indicates that it can ben safely used in high-risk patients undergoing coronary angioplasty with good maintenance of hemodynamic status[29]. The major limitations of IABP are the rate of vascular complications, reported to range from 12 to 25% of patients[77], modest improvement in cardiac output, reduced efficacy during certain types of cardiac arrhythmias and lack of myocardial blood supply to the ischemic regions[78].

TABLE IV Systemic circulatory assist techniques for suppor ted coronary angioplasty.

* Intra aortic balloon pumping
* Femoro-femoral cardiopulmonary bypass (pump-oxygenator)
* Transaortic turbine pumping (Hemopump)
* Percutaneous left atrial-aortic bypass (roller pump)

Percutaneous femoro-femoral cardiopulmonary bypass (PCS) employing a system with active blood aspiration and a pump oxygenator has been recently investigated in high-risk patients undergoing angioplasty[79]. The current system uses size 18 to 20F arterial and venous cannulas and blood flows through a centrifugal pump by active aspiration. Output is independent of cardiac function and ranges from 4 to 6 liters/minute. Peripheral perfusion and mentation can be well maintained with PCS even during ventricular fibrillation or asystole [80].

A recently published study from the national registry on elective PCS-supported angioplasty reported a 7.ó% average hospital mortality rate in a very high-risk patient population. Mortality was 0% in patients with LV ejection fraction of less than 20%, whereas inoperable patients or those with their only remaining patent vessel had a hospital mortality of 4 and 7%, respectively[81]. Although this technique seemed to reliably provide systemic circulatory support, the use of exceedingly large cannulas (18 to 20 French) in the femoral artery (and vein) was associated with a prohibitive number of vascular complications. Out of the 105 patients who entered this multicenter study, 41 patients had significant complications mostly associated with cannula insertion or removal. In addition, 43% of the patients required transfusion of a mean of nearly 4 units of blood. In this series, 45% of the patients had PCS established by percutaneous cannula insertion and 55% by cutdown. In another series, Shawl et a/27 reported somewhat lower complication rates in a similarly high-risk group of 51 patients undergoing PCS-supported angioplasty with percutaneously inserted cannula.

In spite of effective peripheral organ perfusion and ventricular unloading, there seems to be no improvement in myocardial perfusion or function with PCS[82,83]. One of the major advantages of this technique is that it can maintain peripheral perfusion and mentation for up to 2 hours in patients with cardiac arrest[72, 80]. This, however, also raises some ethical questions such as the decision to discontinue perfusion in hopeless but conscious patients. It is known that after prolonged arrest it is difficult to resume spontaneous cardiac contractions even after surgical revascularization, unless the ventricles are vented early after arrest[84].

Percutaneous left atrial-aortic bypass has been proposed as s simpler alternative to the femoro-femoral bypass and pump oxygenator. This technique uses smaller (size 14 to 16.5 French)

venous and arterial cannula and a roller pump[85]. The system is capable of generating flow rates of 1.5 of 4.5 liters/minute, and significant reduction in preload and increase in cardiac output have been reported in a limited number of patients during angioplasty, without significant complications[85,86], Potential shortcomings of this technique for support of high-risk angioplasty include low flow rates, the need for transseptal catheterization with large cannula as well as prolonged time to implementation for rescue of patients with failed angioplasty and hemodynamic collapse. Also, there is no expected improvement in myocardial perfusion distal to an occluded coronary artery with this technique.

T**he hemopump, or trans-aortic turbine pumping**, is a 7 mm diameter ventricular assist device which is introduced through a femoral artery cutdown[87]. During pumping, blood is withdrawn from the left ventricle and pumped into the aortic root using an external motor connected to a drive shaft outside the patient. This system is capable of generating up to 3.5 liters/ minute of monpulsatile flow. Studies in animals have shown that the system can increase cardiac output and blood pressure as well as enhance myocardial perfusion during acute coronary artery occlusion[87]. Preliminary studies in humans have demonstrated feasibility and some efficacy of the hemopump during high-risk angioplasty [88].

Selection of technique for high-risk angioplasty A previosly stated, the vast majority of patients undergoing coronary angioplasty do not require circulatory assist devices. However, if the patient is indeed a high-risk candidate for angioplasty, and circulatory assist is indicated, the most adequate available technique should be selected and a decision made as to whether the system should be used prophylactically or as a standby procedure in case severe complications do occur. At the present time there are no specific guidelines as to which technique is most appropriate for each particular circumstance. What is clear is that high-risk candidates for angioplasty should be thorougly discussed between the cardiologist and the angioplaster prior to the procedure. Prior cardiovascular surgical consultation is also important, not only to aid in the selection of the most appropriate supportive technique, but also to develop an adequate strategy for a possible emergency surgical intervention. Such strategy is also critical when abrupt vessel closure occurs after support has been terminated. Surgical standby is certainly required for all these cases.

It is also important to recognize that myocardial and systemic circulatory assist devices are not necessarily mutually exclusive. For example, systemic circulatory assist with intraaortic balloon pumping or percutaneous cardiopulmonary bypass can be complemented by a myocardial circulatory assist such as anterograde active or passive perfusion or retroperfusion, and vice-versa. Obviously potential benefits of supported angioplasty must be weighted against the possible complications associated with such support measures.

On the other hand, realiance on support techniques should not disencourage careful case selection and appropriate referral to bypass surgery. Furthermore, complex high-risk procedures should be handled by the most experienced operator in individual centers, all of which can minimize catastrophic complications in these patients.

ACKNOWLEDGEMENT

We should like to thank Ron Arzaga for typing the manuscript and Jeanne Bloom for editorial assistance.

REFERENCES

1. Dotter CT, Judkins MP—Transluminal treatment of arterioselerotic obstruction. Description of a new technique and a preliminary report of its application. Circulation, 1964; 30: 654-70.
2. Gruentzig AR—Transluminal dilatation of coronary-artery stenosis. Lancet, 1978; 1: 263.
3. Gruentzig AR, Senning A, Siegenthaler WE—Nonoperative dilation of coronary artery stenosis: percutaneous transluminal coronary angioplasty. N Engl J Med. 1979; 301: 61-8.
4. Vilestra RE, Holmes DR Jr, Reeder GS et al—Balloon angioplasty in multivessel coronary artery disease. Mayo Clin Proc, 1983; 58: 563-7.
5. Dorros G. Stertzer SH, Cowley MJ, Myler RK—Complex coronary angioplasty multiple coronary dilatations Am J Cardiol, 1984-53 (Suppl C): 126C-130C
6. Williams DRo, Riley RS, Singh AK, Gewirtz H. Most AS—Evaluation of the role of coronary angioplasty in patients with unstable angina pectoris. Am Heart J. 1981; 103: 1-9.
7. Faxon DP, Detre KM, McCabe CH et al—Role of percutaneous transluminal coronary angioplasty in the treatment of unstable angina: Report from the National Heart, Lung and Blood Institute Percutaneous Transluminal Coronary Angioplasty and Coronary Artery Surgery registries. Am J Cardiol, 1984: 53 (Suppl C): 131C-135C.
8. Hartzler GO, Rutherford BD, McConahan DR et al—Percutaneous transluminal coronary angioplasty with and without thrombolytic therapy for treatment of acute myocardial infarction. Am Heart J. 1983: 106: 965-73.
9. O'Neill W. Timmis GC, Bourdillon PD et al—A prospective randomized clinical trial of intracoronary streptokinase versus coronary angioplasty for acute myocardial infarction: A 12-month follow up report. N Engl J Med. 1986:314: 812-8.
10. Rothbaum DA, Linnmeier TJ, Landin RJ et al—Emergency percutaneous transluminal coronary angioplasty in acute myocardial infarction: A 3 year experience. J Am Coll Cardiol. 1987; 10: 264-72.
54. Schaer GL, Kracoff MW, Green C, Visner MS—Dissociation of ST segment elevation and regional wall motion with open-artery intracoronary Fluosol. Am Heart J. 1989; 118: 679-85.
55. Geyer RP—Whole animal perfusion with fluorocarbon suspensions. Fed Proc, 1970; 29: 1758-63.
56. Andrealis P. Natsikas N,ArealisEG, Lazarides DP—The aortocoronary

11.Serruys PW,UmansV,Heyndriekx OR et al—Elective PTCA of totally occluded coronary arteries not associated with acute myocardial infarction: Short-term and long-term results. Eur Heart J. 1985; 6: 1-12.

12. Kereiakes DJ, Selmon MP, McAuley BJ, McAuley DB, Sheehan DJ, Simpson JB—Angioplasty in total coronary artery occlusion: experience in 76 consecutive patients. J Am Coll Cardiol, 1985; 526-33.

13. Stone GE, Rutherford BD, McConahay DR et al—Procedural outcome of angioplasty for total coronary artery occlusion: An analysis of 971 lesions in 905 patients. J Am Coll Cardiol, 1990; 15: 849-56.

14 Hartzler GO Complex coronary angioplasty: An alternative therapy. In J Cardiol, 1985; 9: 133-7.

15. Hartzler GO, Rutherford BD, McConahay DR et al—"High-risk" percutaneous transluminal coronary angioplasty. Am J Cardiol, 1988; 1: 330-370.

16. Karseh KR, Mauser M, Joelker W et al—Percutaneous coronary eximer laser angioplasty: initial clinical results. Lancet, 1989; 2: 647-50.

17. Litvack F. Grundfest WS, Goldenberg T. Laudenslager J. Forrester JS—Percutaneous eximer laser angioplasty of aortocoronary saphenous veins grafts. J Am Coll Cardiol, 1989; 14: 803-8.

18. Kautmann UP, Garratt KN, Vliestra RE, Menke KK, Holmes DR Jr—Coronary atherectomy: First 50 patients at the Mayo Clinic. Mayo Clinc Proc, 1989; 64 747-52.

19. Siegel RJ, DonMichael TA, Fishbein MC et al—In viva ultrasound arterial recanalization of atherosclerotic total occlusion. J Am Coll Cardiol, 1990; 15: 345-51.

20. Haendchen RV, Fishbein MC, Meerbaum S. Corday E—Sequential noninvasive assessment of left ventricular size, regional wall thickness and function during 3 hours of coronary artery occlusion and reperfusion: Differential effects of reflow in dogs with small vs. large areas at risk. Braz J Med Biol Res, 1989; 22: 1195-217.

21. Hauser AM, Gnagadharan J. Ramos RG, Gordon S. Timmis GC —Sequence of mechanical electrocardiographic and Clinical effeets of repeated coronary artery occlusion in human beings: Echocardiographic observations during coronary angioplasty. J Am Coll Cardiol, 1985; 5: 193-7.

22. Wohlgelernter D, Cleman M, Highman HA et al—Regional myocardial disfunction during coronary angioplasty: Evaluation by two-dimensional echocardiography and 12 lead electrocardiography. J Am Coll Cardiol, 1986; 7: 1245-54.

23. Cowley MS, Dorros A, Van Raden M, Detre KM—Acute coronary events associated with percutaneous transluminal coronary angioplasty. Am J Cardiol, 1984; 53 (Suppl C): 12C-16C.

24. Topol EJ—Emergency strategies for failed percutaneous transluminal coronary angioplasty. Am J Cardiol, 1989; 63: 249-50.

25. Chokshi SK, Meyers S. Asi-Mansour P—Percutaneous transluminal coronary angioplasty: Ten yearst experience. Prog Cardiovasc Dis, 1987; 30: 147-210.

26. Detre K, Holubkov R. Kelsey S et al—Percutaneous transluminal coronary angioplasty in 1985-1986 and 1977-1981. The National Heart, Lung and Blood Institute Registry. N Engl J Med. 1988; 318: 265-70. -

27. Shawl FA, Domanski MJ, Punha S. Hernandez TJ—Percutaneous cardiopulmonary bypass support in high-risk patients undergoing percutaneous transluminal coronary angioplasty. Am J Card, 1989; 64: 1258-63.

28. O'Keefe JH, Hartzler GO, Retherford et al—Left main coronary angioplasty: Early and late results of 127 acute and elective procedures. Am J Cardiol, 1989; 64: 144-7.

29. Kahn SK, Rutherford BD, McConahay DR, Johnson WR, Giorgi LV, Hartzler GO—Supported "high-risk" coronary angioplasty intraaortic balloon pump counterpulsation. J Am Coll Cardiol, 1990; 15: 1151-5.

30. Ryan TJ, Faxon DP, Gunnar Rm et al—Guidelines for Pereutaneous Transluminal Coronary Angioplasty. A report of the American College of Cardiology/American Heart Association task force on assessment of diagnostic and therapeutic cardiovascular procedures. J Am Coll Cardiol, 1988; 12: 529-45.

31. Goldman A, Boszormenyi E, Itsu F. Enescu V, Swan HJC, Corday E—Veno-arterial pulsatile partial bypass for circulatory assist. Dis Chest, 1966; 50: 633-41.

32. Corday E, Swan HJC, Lang TW et al—Physiologic principles in the application of circulatory assis for the failing heart. Intaaortic balloon circulatory assist and venoarterial phased partial bypass. Am J Cardiol, 1970; 26 595-602.

33. Hinohara T. Simpson JB, Phillips HE et al—Transluminal catheter reperfusion: A review technique to reestablish blood flow after coronary occlusion during percutaneous transluminal coronary angioplasty. Am J Cardiol, 1986; 57 684-96.

34. Collins TV, Ramirez NM, Hinohara T. Klopovic Z. Phillips HR, Stack RS—The perfusion balloon catheter A new method for safe prolonged coronary dilatation J Am Col Cardiol, 1987 (abstr); 9: 106A

35. Hinohara T. Simpson JB, Philips HR, Stack RS—Transluminal intracoronary perfusion catheter. A device to maintain coronary reperfusion between failed angioplasty and emergency coronary bypass surgery. J Am Coll Cardiol, 1988; 11: 977-82.

36. Turi ZCI, Campbell CA, Tottimukkala MV, Kloner HA—Preservation of distal coronary perfusion during prolonged balloon in Bation with an autoperfusion angioplasty catheter. Circulation, 1987; 75: 1273-80.

37. Smith JE, Quigley PJ, Teheno JE, Bauman RP, Thomas J. Stack RS—Can prolonged perfusion balloon inflations salvage vessel patency after failed angioplasty? (abstr) Circulation, 1989 (abstr); 80, suppl II, II-373.

38. Leitsehuh ML, LaRosa D, Currier JW et al—"Stack perfusion catheter" improves outcome following dissection during coronary angioplasty. J Am Coll Cardiol, 1990 (abstr); 15: 250A.

39. Cleman M, Jaffe C, Wholgelernter D—Prevention of ischemia during percutaneous transluminal coronary angioplasty by transcatheter infusion of oxygenated Fluosol DA 20%. Circulation, 1986; 74: 555-62.

40. Cowley MJ, Snow FR, Disciascio G. Kelly K, Guard C, Nixon JV—Perfluorochemical perfusion during coronary angioplasty in unstable and high-risk patients. Circulation, 1990; 8 (suppl IV): IV27-34.

41. Sloviter HA, Petkovic M, Ogashi S. Yamada H—Dispersed fluorochemicals as substitutes for erythrocytes in intact animals. J Appl Physiol, 1969; 27: 666-8.

42. Forman MB, Puett DW, Wilson H et al—Beneficial long-term of intracoronary perfluorochemical on infarct size and ventricular function in a canine reperfusion model. J Am Coll Cardiol, 1987; 9: 1082-90.

43. Mitsuno T. Ohyanagi H. Naito R—Clinical studies of a perfluorochemical whole blood substitute (Fluosol-DA). Ann Surg, 1982; 195: 60-9.

44. Meyer RP—Artificial blood now and the future. Am Acad Cardiovasc Perfusion, 1982; 3: 92-8.

45. Clark JM, Lambertsen CJ—Pulmonary oxygen toxicity: A review. Pharmacol Rev, 1971; 23: 37-133.

46. Deneke SM, Fanburg BL—Normobaric oxygen toxicity of the lung. N Engl J Med. 1980; 303: 76-86.

47. Tremper KK, Friedman AK, Levine EM, Lupin R. Camarillo D —The preoperative treatment of severely anemic patients with a perfluorochemical oxygen transport fluid, fluosol-DA. N Engl J Med. 1982; 307: 277-83.

48. Vercellotti GiM, Hammerschmidt DE, Craddock PR, Jacob HS —Activation of plasma complement by perfluorocarbon artificial blood: Probable mechanism of adverse pulmonary reactions in treated patients and rationale for corticosteroid prophylaxis. Blood, 1982; 59: 1299-304.

49. Mattrey RF, Hilper PC, Long CD et al—Hemodunamic effects of intravenous lecithin-based perfluorocarbon emulsions in dogs. Crit Care Med. 1989; 17: 652-6.

50. Tremper KK, Vercellotti CIM, Hammerschmidt DE—Hemodynamic profile of adverse clinical reactions to Fluosol-DA 20%. Crit Care Med. 1984; 12: 428-31.

51. Elliot LA, Ledgerwood AM, Lucas CE et all—Role of Fluosol-Da 20% in prehospital resuscitation. Crit Care Med. 1984; 17: 166-72.

52. Anderson HV, Leimgruber PP, Roubin GUS, Nelson DC, Oruentzig AR—Distal coronary artery perfusion during percutaneous transluminal coronary angioplasty. Am Heart J. 1985; 110: 720-6.

53. Bell ME, Nishimura RA, Bailey KR, Schwartz RS, Vliestra HE —Does intracoronary infusion of Fluosol-DA 20% ameliorate left ventricular diastolic dysfunction during coronary angioplasty? Circulation, 1989 (abstr); 80 (suppl II), II-372.

venous anastomosis in experimental acute myocardial ischemia. Vasc Surg, 1974; 8: 45-52.
57. Cibulski AA, Mardov A, Lehan PH et al—Retrograde radioisotope myocardial perfusion patterns in the dog. Circulation, 1974; 50: 159-66.
58. Chiu CJ, Mulder DS—Selective arterialization of coronary veins for diifuse coronary occlusion. J Thor Cardiov Surg, 1975; 70: 177-82.
59. Meerbaum S, Lang TW, Osher JV et al—Diastolic retroperfusion of acutely ischemic myocardium. Am J Oardiol, 1976: 37: 588-98.
60. Farcot JC, Meerbaum S, Lang TW, Kaplan C, Corday E—Synchronized retroperfusion of the coronary vensi for circulatory support of jeopardized ischemic myocardium. Am J Cardiol 1978; 41: 1191-1201.
61. Haendchen RV, Corday E, Meerbaum S et al—Prevention of ischemic injury and early reperfusion derangements by hypothermic retroperfusion. J Am Coll Cardiol, 1983; 1: 1067-80.
62. Drury JK, Yamazaki S. Fishbein MC, Meerbaum S, Corday E —Synchronized diastolic coronary venous retroperfusion: Results of a preclinical safety and eficacy study. J Am Coll Cardiol, 1985; 6: 328-34.
63. Yamazaki S, Drury JK, Meerbaum S, Corday E—Synchronized coronary venous retroperfusion: Prompt improvement of left ventricular function in experimental myocardial ischemia. J Am Coll Cardiol, 1985; 5: 655-63.
64. Taira Y. Kanaide H. Nakamura M—Coronary venous perfusion of the ischemic myocardium during acute coronary artery occlusion in isolated rat hearts. Circul Res, 1985; 56: 666-75.
65. Smith GT, Geary GG, Blanchar W. McNamara JJ—Reduction in infarct size by synchronized selective coronary venous retroperfusion of arterialized blood. Am J Cardiol, 1981; 48: 1064-70.
66. Geary GG, Smilh GT, Suchiro GT, Zehan C, Siu B. McNamara JJ—Quantitative assessment of infarct size reduction by coronary venous retroperfusion in babbons. Am J Cardiol, 1982; 50: 1424-30.
67. Kar S. and the Investigators for the Multicenter Retroperfusion Trial—Reduction of myocardial ischemia during PTCA by synchronized coronary venous retroperfusion. Results of Multicenter Clinical Trial. Circulation, 1989 (abstr); 80 (suppl II): II-273.
68. Berland J. Farcot JC, Barrier A et al—Coronary venous synchronized retroperfusion during percutaneous transluminal anfioplasty of left anterior descending coronary artery. Circulation, 1990; 81 (Suppl IV), IV35-42.
69. Constantini C, Sampaolesi A, Pieroni M et al—Coronary venous retroperfusion support during high-risk coronary angioplasty in patients with acute ischemic syndromes. Circulation, 1989 (abstr); 80 (suppl II): II-625.
70. Gore JM, Weiner BH, Benotti JR et al—Preliminary experience with synchronized coronary sinus retroperfusion in humans. Circulation, 1986, 74: 381-8.
71. Barnett JC and Touchon RC—Use of coronary venous retroperfusion in acute myocardial ischemia. Cardiovasc Rev & Rep, 1989; 100: 64-5.
72. Corday E, Meerbaum S. Drury JK—The coronary sinus: An alternate channel for administration of arterial blood and pharmacologic agents for protection and treatment of cute cardiac ischemia. J Am Coll Cardiol, 1986; 7: 711-4.
73. Ryden L, Takokoro H. Sjoquist P-O, Kar S. Ervik M, Corday E—Pronounced accumulation of metoprolol in ischemic myocardium after coronary venous retroinfusion. J Cardiovasc Pharmacol, 1990;15: 22-8.
74. Berland J. Farcot JC, Cribier A, Lefebvre E, Barrier A, Letac B—Evaluation of a new physiologic anteroperfusion synchronized system (PASS) during PTCA. Eur Heart J. 1989 (abstr); 10:236.
75. Lehmann KG, Atwood E, Snyder EL, Ellison RL—Autologous blood perfusion for myocardial protection during coronary angioplasty: a feasibility study. Circulation, 1987; 76: 312-23.
76. Alcan KE, Stertzer SH, Wallsh JE, DePasquale NP, Bruno MS —The role of intra-aortic balloon counter pulsation in patients undergoing percutaneous transluminal coronary angioplasty. Am Heart J. 1983; 105: 527-30.
77. Macoviak J, StephensonLW, Edmunds LH, HarkenA, MacVaugh III H—The intraaortic balloon pump: An analysis of five years' experience. Ann Thor Surg, 1980; 29: 451-8.
78. MacDonald RG, Hill JA, Feldman RL—Failure of intraaortie balloon counterpulsation to argment distal coronary perifusion pressure during percutaneous transluminal coronary angioplasty. Am J Cardiol, 1987; 59: 359-61.
79. Vogel RA, Tommaso CL, Gundry SR—Initial experience with coronary angioplasty and aortic valvuloplasty using elective semipercutaneous cardiopulmonary support Am J Cardiol, 1988; 62: 811-3.
80 Bhawl FA, Domanski MJ, Wish M, Davis M, Punja S, Hernandez TJ—Emergency cardiopulmonary bypass support in patients with cardiac arrest in the catheterization laboratory. Cathet and Cardiovas Diagn, 1990;19: 8-12.
81. Vogel RA, Shawl F, Tommasco C, O'Neil W et al—Initial report of the National Registry of elective cardiopulmonary bypass supported coronary angioplasty. J Am Coll Cardiol, 1990; 15: 23-9.
82. Geannopoulos C, Peters T, Leya F et al—Does percutaneous cardiopulmonary support protect the heart from ischemic dysfunction during coronary occlusion? Am Coll Cardiol, 1990 (abstr); 15: 42A.
83. 8tack RK, Pavlides GS, Justeson GT et al—Hemodynamic and metabolic effects of cardiopulmonary support during PTCA. J Am Coll Cardiol, 1990 (abstr); 15: 250A.
84. Cooley DA, Reul GJ, Wutasch DC—Ischemic contracture of the heart:,"stone heart". Am J Cardiol, 1972; 29: 575-8.
85. Babic U, Grujicic S, Djurisic Z, Vucinic M—Percutaneous left atrial-aortic bypass with a roller pump. Circulation, 1989 (abstr); 80 (suppl II): II-272.
86. Glassman E, Chinitz L, Levite H, S1ater J, Winer H—Partial left heart bypass support during high-risk angioplasty. Circulation, 1989 (abstr); 80 (suppl II): II-272.
87. Merhige ME, Smalling RW, Cassidy D et al—Effect of the hemopump left ventricular assist device on regional myocardial perfusion and function. Circulation, 1989; 80 (suppl III): III 158-66.
88. Loisance D, Dubois-Rande JC, Delenze PH et al—Prophylactic use of hemopump in high-risk coronary angioplasty. J Am CoU Cardiol, 1990 (abstr); 15: 249A.