CHAPTER 17
Intraoperative Transluminal Angioplasty

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Historical Development

Transluminal balloon catheter treatment of occlusive vascular disease had its origin in the operating room. In contrast to the several large incisions typically required to perform operations at the time, small incisions were made, and local, rather than general, anesthesia was used to extract emboli and thrombi from obstructed vessels (1).

In 1964 Dotter directed catheter-mediated therapy of chronic occlusive disease by employing coaxial dilatation. These initial procedures were performed in the angiographic suite (2). The limitations of coaxial catheter dilatation were recognized early by Dotter, enabling him to investigate other dilatation methods. In an attempt to improve the dilatation technique, in 1965 he utilized a Fogarty balloon catheter to successfully dilate an iliac artery stenosis (3). In general, though, he found the compliant embolectomy balloon unsuitable for dilating atherosclerotic plaque. He realized that catheters of a constant shape and size were needed for successful arterial dilatation. Using coaxial technology, van Andel subsequently treated arterial lesions using separate tapered dilators (4). Portsmann, on the other hand, attempted to adapt the balloon catheter to the purpose; he used an external meshwork to cage the latex balloon thus controlling the shape of the balloon in the inflated state (5).

None of these designs proved satisfactory for transluminal angioplasty. The coaxial tapered catheters and the caged balloon catheters resulted in a high rate of embolic complications, and early thrombosis occurred following their use.

Transluminal angioplasty did not develop into an effective procedure until Gruntzig designed a constant-volume balloon catheter constructed of a nondistensible plastic material. This catheter employed techniques commonly applied in diagnostic angiography (6). The initial passage of a spring guidewire through the stenosis was followed by the coaxial passage of the balloon angioplasty catheter over the guidewire (Fig. 17.1). If the lesion proved too tight to allow the passage of the Gruntzig balloon catheter, a tapered van Andel catheter was initially used to enlarge the lumen.

The guidewire and coaxial balloon dilatation catheter system has also been applied in the surgical suite as an intraoperative procedure. Concern over the possibility of guidewire and catheter dissection and perforation in severely stenotic lesions led Fogarty and Chin to introduce the linear extrusion catheter (7) (Fig. 17.2). This catheter does not require prior guidewire placement, and the balloon does not need to be accurately centered within the stenosis for effective dilatation. Consequently, less elaborate radiographic control is suitable to perform the intraoperative angioplasty. Recent changes to the original linear extrusion catheter...
Physical Principles

Successful application of transluminal angioplasty relies on an understanding of several underlying physical principles.

Mechanism of Dilatation

Transluminal angioplasty involves the development of fracture planes through the plaque and the intimal surface. These fractures allow the diseased vessel to distend under physiologic pressure, with a resultant increase in lumen diameter (Fig. 17.3). This mechanism of transluminal angioplasty has been documented using histopathologic studies, as well as quantitative materials analysis (8–10). These studies demonstrate that minimal plaque compression occurs during balloon dilatation. From our observations, plaque fractures occur more frequently along the longitudinal direction. This may account for the relative scarcity of intimal flap formation following transluminal angioplasty, because the blood flow is less apt to lift the leading edge of a longitudinal tear.

Balloon Sizing

Angioplasty balloons are constructed of a nonelastomeric material. A constant balloon shape, regardless of inflation pressure, is necessary to prevent overdistention and vessel rupture during dilatation. Arterial dilatation should never be attempted with an embolectomy balloon. The elastomeric embolectomy balloon bulges out on either side of a stenosis, exerting a greater stress on the normal than on the diseased portions of the vessel.

The angioplasty balloon's diameter should not exceed the native vessel's diameter adjacent to the stenosis. The largest appropriate balloon size should be used to achieve the maximal dilating force, as illustrated in Figure 17.4, which depicts a cross section of an angioplasty balloon inside a stenotic artery. The inflation pressure stretches the balloon surface against the raised plaque, exerting tension and leading to dilatation. This tension, also known as hoop stress, is directly proportional to the inflation pressure multiplied by the radius of the balloon (Laplace's law). Thus for a given inflation pressure, a larger balloon diameter leads to a greater dilatation force.

Transluminal dilatation is effective because of the resultant increase in the lumen's cross-sectional area. It is important to realize that a small percentage of reduction in the degree of stenosis may result in a large percentage of improvement in the amount of blood flow. This result occurs because arterial flow is related to the fourth power of the lumen diameter (Poiseuille's law) (11). For example, an 8-mm iliac artery with a 95% stenosis and a 60 mm Hg gradient is partially dilated to an 80% stenosis and a 20 mm Hg gradient. A 100%

Design permit through-lumen capabilities, which allow 1) administration of diagnostic or therapeutic fluids such as heparin solution, lytic agents, or contrast media, 2) precise control of the balloon eversion, and 3) a delivery route for other intravascular imaging instruments such as angioscopes and intravascular ultrasound (Fig. 17.2).
improvement in flow rate would result from this mild decrease in the degree of stenosis. Thus dilatation to the full native diameter may not be necessary—or advisable. In lesions with concentric calcification, for instance, dilatation to the native diameter may cause arterial rupture.

**Shear Force**

Shear force is another physical principle of importance in transluminal angioplasty. Shear force is the frictional force exerted between two surfaces in contact, moving with respect to one another. In tight stenoses, centering a coaxial balloon dilatation catheter within the lesion may apply significant shear force to the plaque surface. This shear force may cause plaque dislodgment or vessel dissection.

The linear extrusion catheter minimizes shear force by unrolling a balloon through the stenosis. The force exerted by the balloon remains perpendicular to the contours of the plaque. There is no axial movement of the balloon with respect to the artery, decreasing the possibility of plaque dislodgment. Previous measurements in models of high-grade stenoses have shown that linear extrusion catheter use may decrease shear force up to a magnitude of 40 times when compared with coaxial balloon angioplasty catheter passage (12) (Fig. 17.5).

**Balloon Inflation**

Once properly situated, coaxial angioplasty balloons are inflated to 4 to 6 atm (approximately 60 to 90 psi) for several minutes to achieve adequate dilatation. Under fluoroscopy, the balloon may have an initial hourglass shape that converts to a cylindrical outline, indicating that dilatation has occurred.

Linear extrusion balloon eversion requires a high initial inflation pressure to overcome the internal balloon friction present in the fully inverted balloon. Once the balloon has begun to evert, much less inflation pressure is required to unroll the balloon. The inflation pressure rises again as a stenosis is reached. When a single syringe is used for inflation, the high initial inflation pressure followed by the lower pressure requirement causes sudden eversion of the linear extrusion balloon. The use of a specialized inflation device allowing repeated high-pressure injections of a 0.5-ml volume helps control the eversion process.

To avoid balloon failure, inflation pressures should not exceed the maximum inflation pressures recommended by the manufacturer for the specific catheter system being used (Fig. 17.6).
Patient Selection

Intraoperative balloon angioplasty is performed in three modes of application: 1) as a primary procedure, 2) as an adjunct to scheduled vascular reconstructions, and 3) as a staged procedure following percutaneous transluminal angioplasty.

Primary Balloon Angioplasty

Primary intraoperative balloon angioplasty is used in situations in which percutaneous transluminal angioplasty is potentially unsafe because of, for example, patient obesity or calcification at the site of dilatation. Introduction of the balloon dilatation catheter into an open vessel in an operative setting decreases the chance of complications in these circumstances.

In some situations, increased vessel control during transluminal angioplasty is necessary. For example, balloon angioplasty of carotid fibromuscular lesions should be performed intraoperatively. This allows the surgeon to obtain adequate proximal and distal control, and to backflush the vessel after dilatation. Primary operative transluminal angioplasty is also useful for treating life-style-limiting claudication caused by an isolated lesion in the iliac or superficial femoral artery. When applied in this situation, transluminal angioplasty is a low-risk procedure and may be of benefit to debilitated patients in whom formal reconstruction would be difficult.

Adjunctive Balloon Angioplasty

Adjunctive intraoperative balloon angioplasty is used to decrease the magnitude of a surgical procedure. Thus dilatation of inflow iliac lesions during the course of a femoropopliteal bypass graft may serve to avert an aortobifemoral reconstruction. Similarly, outflow stenoses in the femoral or popliteal arteries may be dilated in conjunction with the placement of an aortobifemoral bypass graft. This may spare the patient a staged femoropopliteal bypass procedure. In addition, this procedure may relieve the claudication that would ordinarily be present postoperatively if the aortofemoral reconstruction alone were performed in a patient with concomitant proximal and distal disease.

Adjunctive balloon dilatation may also allow the placement of an extra-anatomic bypass graft in otherwise unfavorable situations. For example, a patient may have bilateral iliac disease with an occlusion on one side and a localized stenosis on the other. Balloon dilatation of the localized lesion may allow that side to be used as the donor limb for a femorofemoral graft (Fig. 17.7).
Transluminal angioplasty, when used as an adjunct to a scheduled vascular reconstructive procedure, may enhance flow through a newly placed graft. Correction of inflow or outflow lesions is accomplished with little additional operative time.

In cases of acute thrombosis due to a significant arterial stenosis, adjunctive balloon angioplasty may give the patient maximal benefit with the application of a minimal procedure. Intraoperative balloon dilatation is performed after balloon catheter embolectomy. The dilatation procedure protects the patient from rethrombosis due to underlying occlusive disease. It may be used as the primary mode of correction or as a temporary maneuver in the acute stage of sudden arterial occlusion. Combined embolectomy and balloon angioplasty buys the surgeon precious time, which may be used to stabilize the patient and to plan the best tactic for future revascularization.

**Staged Balloon Angioplasty**

Staged transluminal angioplasty may be useful in certain situations. Percutaneous transluminal angioplasty may be performed on an inflow lesion, days or weeks before a scheduled vascular reconstruction. During surgery the dilated lesion is reevaluated, with intraoperative balloon dilatation of the lesion repeated if necessary. In this case, the primary purpose of staged balloon angioplasty is to allow the success of the inflow dilatation to be determined before one embarks on a possibly complex distal procedure.

In general, staged percutaneous dilatation is useful for complex lesions, including total occlusions or severe stenoses greater than 5 cm in length. On the other hand, lesions that appear circumferential on the arteriogram can usually be managed with adjunctive intraoperative dilatation.

**Contraindications**

The same conditions that preclude the use of percutaneous transluminal angioplasty also contraindicate intraoperative balloon dilatation. These contraindications include severe stenoses greater than 10 cm in length, lesions located at critical bifurcations, and ulcerative or thrombosed lesions. Lesions greater than 10 cm in length represent a relative contraindication. These lesions have a low probability of successful improvement after transluminal dilatation. When applying the balloon dilatation to bifurcations, one must exercise caution. Balloon angioplasty of one branch at a bifurcation may result in occlusion of the other branch. Ulcerated or thrombotic lesions have significant embolic potential when subjected to transluminal angioplasty. However, an acute thrombosis may be treated with a combination of balloon embolectomy and balloon angioplasty as discussed previously.

**Technique**

**Coaxial Balloon Dilatation Catheter**

A spring guidewire is introduced through the arteriotomy and is passed across the stenosis. A floppy, or J-tipped, guidewire is used to decrease the possibility of perforation during guidewire passage. After successful negotiation of the guidewire through the lesion, the coaxial balloon dilatation catheter is threaded over the guidewire and under fluoroscopy is centered within the stenosis. The balloon is inflated to its rated pressure for several minutes. When viewed on x-ray film, the dilatation balloon may initially assume an hourglass configuration and then resolve into a normal cylindrical conformation, suggesting that successful dilatation has occurred.

In tight lesions or tortuous vessels, initial guidewire passage may be difficult or impossible. In other cases, successful guidewire passage may be followed by
unsuccessful placement of a coaxial balloon angioplasty catheter within the stenosis. In both of these situations, the linear extrusion catheter has been useful in crossing the lesion without causing arterial dissection.

**Linear Extrusion Catheter**

The linear extrusion catheter is introduced through an arteriotomy. In adjunctive intraoperative dilatation, this may be the arteriotomy used for the proximal or distal graft anastomosis.

Before dilatation catheter insertion, the distance between the arteriotomy and the stenosis site is determined, as well as the diameter of the native vessel immediately proximal to the stenosis. These measurements are made using a Fogarty balloon calibrat or. The calibrat or is inserted into the arteriotomy, and the balloon is partially inflated with saline. The calibrat or is advanced until the balloon meets the leading edge of the stenosis (Fig. 17.8). This distance is measured using length markers on the calibrat or body. The calibrat or balloon is then inflated until it contacts the wall of the artery proximal to the stenosis. The volume of saline required for this inflation is noted. The balloon is deflated, and the calibrat or is removed from the artery. Reinflation of the balloon is conducted with the measured volume of saline, and the diameter of the balloon is determined using a circle template. This method yields an accurate measurement of the native vessel diameter.

Selection is made of a Fogarty-Chin linear extrusion catheter whose inflation diameter most closely approximates, but does not exceed, the calibrated arterial diameter. The linear extrusion catheter is purged of air and is connected to a high-pressure inflation device.
The dilatation catheter is inserted into the arteriotomy and is advanced 2 cm short of the calibrated distance to the stenosis (Fig 17.9). The movable silicone marker on the catheter body is advanced to the arteriotomy site and is grasped with a pair of forceps or a clamp. This prevents the catheter from backing out of the vessel during balloon extrusion.

Initial inflation of the linear extrusion catheter requires a high pressure to overcome the internal friction of the fully inverted balloon. This pressure typically exceeds the maximum rated balloon pressure at full inflation. This excess should not cause alarm—balloon rupture will not occur during this initial pressurization. Once the balloon begins to evert, an immediate drop in pressure is noted. As a stenosis is approached, a moderate pressure rise again occurs. When the balloon has been fully extruded, the catheter is pressurized to the recommended value and left in place for several minutes to achieve full dilatation. During adjunctive dilatation procedures, we keep the linear extrusion balloon inflated while the graft anastomosis is being completed. The dilatation balloon is used as an occlusion device during the reconstructive procedure, with arterial flow restored immediately after dilatation catheter removal. Immediate restoration of arterial flow in the newly dilated vessel prevents collapse of disrupted vessel wall segments and possible early arterial occlusion. After linear extrusion catheter removal, a completion arteriogram is obtained without repeated balloon calibration.

**Pharmacologic Therapy**

No additional anticoagulation is used with intraoperative transluminal angioplasty, aside from the regimen normally applied to routine reconstructive procedures. Postoperative heparin use is indicated for patients who are initially seen with preoperative embolism or acute thrombosis.

Antiplatelet agents are used for all reconstructions below the inguinal ligament. We commonly prescribe a half tablet (2.5 grains) of aspirin per day postoperatively, to be continued on a long-term basis. Dipyriramole (Persantine) may also be added, although we do not routinely do so.

Thrombolytic agents such as streptokinase, urokinase, and tissue plasminogen activator have been applied in conjunction with balloon angioplasty for the treatment of acute thrombosis and embolism (13,14). We do not use these agents. Rather, we find the most expedient method of treating acute arterial occlusion involves balloon embolectomy followed by adjunctive transluminal angioplasty as needed for underlying atherosclerotic disease.

**Results**

In general, the results achieved with intraoperative balloon dilatation parallel those experienced with percutaneous transluminal angioplasty. After transluminal dilatation, lesions in larger-diameter vessels have a better patency rate than lesions in smaller-diameter vessels. An isolated common iliac stenosis is the most favorable lesion to dilate (15,16). In comparison with aortofemoral bypass grafts, isolated common iliac artery dilatations have slightly lower long-term patency rates. Femoral and popliteal lesions are also amenable to balloon dilatation. Long-term patency rates are superior with reversed saphenous vein grafts in the femoropopliteal region. However, when prosthetic graft material is used, transluminal dilatation yields better results than femoropopliteal bypass grafting (17-22) (Table 17.1).

The following are the results of a long-term follow-up of 77 patients who underwent intraoperative transluminal dilatation of 96 sites. The mean follow-up for this series was 17.5 months. Lesions dilated in this study ranged from 1 to 9 cm in length. The superficial femoral artery was dilated in more than one-half of the cases, with the next largest group comprising iliac artery dilatations. Fewer popliteal and profunda
Complications

Complications that may occur with the use of coaxial or linear extrusion balloon dilatation catheters include vessel rupture, thrombosis, and embolism (23–25). Because vessel rupture may result from the use of an oversized dilatation balloon, careful balloon sizing is important in preventing overdistention. Thrombosis may occur after dilatation, particularly if a good flow rate is not established immediately after balloon removal. Also, embolism may occur during and after balloon angioplasty. Therefore lesions containing thrombus should not be dilated.

Other complications are more prone to occur with one catheter system versus the other. The coaxial balloon dilatation catheter requires prior guidewire placement. The possibility of arterial dissection and perforation related to the guidewire or dilatation catheter increases in severely stenotic lesions. After guidewire placement, the force required to center the coaxial balloon within the lesion may cause plaque dislodgment.
Future Directions

Catheter treatment of intravascular disorders continues to advance. The use of balloon catheters, popularized first for embolectomy and now for dilatation, has initiated the trend toward less invasive vascular surgical procedures.

Recent advances in intravascular catheter technologies include the development of the adherent clot catheter and the graft thrombecatomy catheter for aggressive removal of adherent thrombotic material in native and synthetic vessels. Use of these catheters is described further in Chapters 21 and 34. Further developments in intravascular catheter technology include deployment of intravascular stents and synthetic vascular grafts and atherectomy devices. This expansion of catheter usage is enhanced by continued advances in vascular imaging via angioscopy, intravascular ultrasonic imaging, and intraoperative C-arm fluoroscopy.

It is important that vascular surgeons, who best appreciate the pathophysiology of arterial occlusive disease, become familiar with the proper use of these new devices and endovascular techniques. The scope and shape of future vascular interventions will be determined by utilizing information gleaned from the less invasive, more discriminating assessment modalities recently made available to the vascular surgeon. The prognosis is bright for improving current surgical approaches because of superior methodologies now available to implement and monitor these catheter-based techniques.

References