Overview Of Angioplasty: Need For Imaging And Sensing

Borst, Cornelius, Rienks, Rienk, Verdaasdonk, Rudolf


Event: OE/LASE '89, 1989, Los Angeles, CA, United States
Overview of angioplasty: need for imaging and sensing

Cornelius Borst, Rienk Rienks, Rudolf M. Verdaasdonk

Heart-Lung Institute, Department of Cardiology, University Hospital Utrecht, and Interuniversity Cardiology Institute of the Netherlands, Catharijnesingel 101, 3511 GV Utrecht, The Netherlands

ABSTRACT

Balloon angioplasty is a well established non-surgical treatment of ischemic vascular disease. Balloon dilatation increases the lumen in a stenosed artery by overstretching the wall and fracturing the atherosclerotic plaque. Fluoroscopy is adequate to guide the proper placement of guide wire and balloon catheter. Fluoroscopy largely fails, however, when a different recanalization strategy is chosen to address the major problems associated with balloon dilatation. In the past few years, more than twenty different recanalization catheters have been developed that physically remove obstructing plaque. In the femoral artery, both mechanical and thermal methods appear to be quite successful in traversing total occlusions in spite of "blind" guidance by fluoroscopy. However, subsequent balloon dilatation is often needed. The femoral artery is large and runs a fairly straight course. Perforation of the femoral artery is a minor complication. In the coronary arteries, in contrast, the novel angioplasty methods have met with variable success. These arteries are small, tortuous and move continuously. The anatomy and composition of the plaque is complex and the remainder of the diseased wall may be thin. In the coronary arteries, the margin between recanalization and perforation is small. The latter is a potentially fatal complication. Thus, there is a great need for a catheter that is capable of high resolution imaging and tissue identification in obstructed arteries of small caliber. Intra-arterial echo imaging, possibly combined with laser fluorescence spectroscopy, seems a promising approach. The design of a catheter that combines these powerful diagnostic features with steerability, flexibility and controlled ablation is now the major engineering challenge in interventional cardiology.

1. PERCUTANEOUS ANGIOPLASTY

Recanalization of arteries by catheter (percutaneous angioplasty) was initiated in 1964 by Dotter and Judkins\(^1\) who used catheters of incremental diameter to widen peripheral artery stenoses.

1.1. Balloon angioplasty

Since the introduction of the balloon catheter in the human coronary arteries by Grünzig\(^2\) in 1977, balloon angioplasty has become a well established non-surgical treatment of ischemic disease. Balloon dilatation of coronary arteries is being performed in nearly 200,000 patients per year in the US only\(^3\). Fluoroscopy is adequate to position guide wire and balloon catheter properly in the stenosed segment\(^3\). Balloon dilatation increases the lumen by overstretching the wall and fracturing the plaque\(^4\).

Balloon dilatation is remarkably successful. In coronary arteries, the primary success rate is about 90-95 % in experienced centers\(^3\). However, the procedure has several limitations that are inherent to its mode of action\(^3,4\). First, sometimes the balloon catheter cannot be properly positioned in a subtotal occlusion. Segments that have been totally occluded for several months are often not amenable to balloon angioplasty due to the failure of the guide wire and/or the balloon catheter to traverse the occlusion. Secondly, overstretching the wall leads to intimal tears that may extend into the media. Intimal flaps and exposure of thrombogenic surfaces to blood leads to acute occlusion in about 5 % of cases. Thirdly, an excessive wall healing response to the overstretching injury leads to fibrocellular proliferation and restenosis in 20-50 % of cases. Fourth, heavily calcified plaque often cannot be dilated although the balloon has been positioned properly.
1.2. Alternative angioplasty methods

To address the limitations associated with balloon angioplasty a great number of alternative catheter methods have been developed in the past few years. The designs are based on two approaches: 1) stenting the segment after balloon dilatation, 2) physically removing obstructing plaque, rather than remodelling the wall. The former approach is guided adequately by fluoroscopy. The latter approach requires detailed information on the anatomy of the obstructed artery that fluoroscopy often cannot provide.

Plaque removing catheters include mechanical devices that cut, shave or drill and thermal devices that burn their way through the obstruction in contact mode.

The atherectomy device cannot deal with total obstructions, whereas the high speed rotary cam and rotary burr catheters are designed to recanalize total obstructions. The relatively selective attack of plaque by these three mechanical devices is partly attributed to lower compliance of atherosclerotic tissue as compared to normal arterial wall.

In the femoropopliteal arteries, the low risk of mechanical and thermal perforation (about 10%) and the high primary success rate (about 80%) of the metal laser probe and the sapphire contact probe in conjunction with a Nd-YAG laser is to a large extent due to the atraumatic, blunt shape of these modified fiber tips that allow tactile feedback. However, it is remarkable that the hot tip does not perforate more frequently because it delivers its energy both in forward and radial direction whereas the sapphire tip delivers its energy preferentially in the forward direction with limited heating of the sides of the sapphire. The 'blind' tracking of the occluded artery on pushing these probes may be attributed to fatty plaque liquefaction, to some preferential thermal ablation of plaque vs normal wall and to the relative resistance to heat of the internal elastic lamina. A mechanical dilatation effect seems to contribute to the safe and effective recanalisation of the femoropopliteal segment because the sapphire tip could traverse, without activating the laser, up to 15 cm long occlusions in one third of the first twenty patient treated in our institute.

The femoropopliteal artery can take a heavy beating, both mechanically and thermally. This artery is serving as the testing ground for novel devices that are to be used ultimately in the coronary arteries. Most devices seem to work quite well in this artery. However, the anatomy of the coronary arteries makes percutaneous recanalization there considerably more difficult and hazardous than the procedure in the upper leg.

2. CORONARY VS FEMORAL ARTERY

The femoropopliteal artery is 6-7 mm in diameter and runs a fairly straight course. Perforation is a minor complication. However, perforation of the iliac artery carries the risk of massive retroperitoneal bleeding. The one major risk of the novel recanalization techniques in the femoropopliteal artery is the creation of an embolus at the trifurcation that blocks the blood flow to the three conduit arteries in the lower leg.

The epicardial coronary arteries, in contrast, are small (2-4 mm), tortuous and continuously moving. Perforation is a major complication that is potentially fatal. The tortuosity of the arteries requires more flexible catheters. However, enhanced flexibility will limit axial force. Over the wire tracking of the artery will be hampered by its tortuous course. Clinical application of the metal laser probe in the coronary arteries met with variable success in the first 13 patients. In three cases the stenosis could not be improved, in two cases myocardial infarction was diagnosed in the course of the first day. The complex anatomy of coronary obstructions forms a basic problem in catheter recanalization.

3. ANATOMY OF OBSTRUCTION

The distribution of atherosclerotic plaque is highly variable and its composition is wildly heterogeneous. The distribution of atherosclerotic plaque in a diseased arterial segment is irregular and largely unpredictable,

SPIE Vol. 1068 Catheter-Based Sensing and Imaging Technology (1989) / 109
although bifurcations and other places where streamline flow is disturbed are predilection places. The extent of plaque formation is variable, both in the axial and in the radial direction. An eccentric stenosis is more common than a concentric stenosis. The lumen of a high grade eccentric stenosis may be lined in part with an almost normal wall. Consequently, ablation of the plaque requires careful aiming at a selected part of the cross-section of the artery. At places where the plaque is extensive, sometimes little remains of the tunica media, the originally thickest intermediate layer of the wall.

The composition of an arterial obstruction cannot be judged from fluoroscopy. It may consist of a) weak recent thrombus, b) firm organized thrombus, c) soft, yellow, fatty plaque, d) white, elastic, fibrous plaque, e) hemorrhagic, ulcerated plaque, f) any combination of these, g) with or without calcific deposits. The distribution of calcific deposits within plaque is variable. Calcific deposits present an added risk in most non-balloon methods. Thus, the conditions for complete and safe catheter removal of plaque from the coronary arteries are rather unfavorable. As a result, there is a great need for diagnostic information in addition to fluoroscopy.

4. IMAGING AND SENSING

4.1 Fluorescence spectroscopy

Soon after the initial experiments on laser angioplasty, the potential of atheroma identification by fluorescence spectroscopy was recognized. However, spectroscopic discrimination of plaque from normal vessel wall is not always unambiguous because 1) blood modifies the spectroscopic signals, 2) plaque composition is heterogenous, 3) laser ablation may degrade the spectral signature of plaque. Fluorescence spectroscopy probably cannot distinguish an obstruction due to intima proliferation (restenosis after balloon dilatation) from normal wall. Furthermore, the spectroscopic information is derived from fluorescence in the superficial layer, the depth depending on the excitation wavelength. Since the tunica media of the heavily diseased coronary artery may be virtually absent, ablation guided by fluorescence spectroscopy may leave only the adventitia in place.

4.2. Angioscopy

Thermal ablation guided by angioscopy has been tested by Abela et al. in the femoropopliteal artery. The major limitations to angioscopic guidance in the coronaries are a) angioscopy requires displacement of blood by a clear fluid, b) information is limited the visual appearance of the surface, c) proper visualization of the target area is sometimes difficult.

4.3. Intra-arterial ultrasound imaging.

In the past three years, intra luminal echo imaging is being investigated intensively to determine whether in depth information on the three layers of the wall can be obtained from high resolution ultrasound catheter imaging. Current designs produce transverse images close to the end of the catheter. It is likely that imaging in the forward direction will soon be feasible as well. The striking quality of recent images makes intra-arterial ultrasound the most promising modality to guide ablation of plaque.

5. CONCLUSIONS

Fluoroscopy largely fails as a guiding modality when most of the plaque is to be removed by catheter from a small and tortuous artery. Intraluminal echo-imaging shows the greatest promise as guiding modality for new catheter recanalization methods. Fluoroscopy is adequate for balloon angioplasty and stenting. If ultrasound imaging and fluorescence spectroscopy could be combined in one catheter, plaque discrimination might be enhanced because independent information would be obtained. The design of a catheter that incorporates these diagnostic features, as well as flexibility, steerability and the capability for controlled ablation, is now the major engineering challenge in interventional cardiology.
6. ACKNOWLEDGEMENTS

The research on laser angioplasty performed in our institute and Rudolf M. Verdaasdonk were supported by the Netherlands Heart Foundation (Grants nr. 34.001 and 87.037). We thank Mrs. A.I. Diepeveen for typing the manuscript.

7. REFERENCES