Interventional Cardiology — Where Are We Ballooning?

W. URBASZEK
Department for Cardiology, Clinic for Internal Medicine, University of Rostock, Rostock, Germany

Introduction

Since the introduction of PTCA by Grüntzig in 1977, the interventional cardiology has seen revolutionary changes with outstanding qualitative and quantitative developments that have been achieved through:
- improved imaging techniques
- better quality PTCA balloons, modified interventional techniques and introduction of stents
- new therapeutic strategies and antithrombotic drugs
- platelet inhibitors.

In the following some aspects revisiting the advances in biomedical techniques and also the need for new developments in interventional sector are reviewed.

Imaging techniques

The new digital cine-angiographic units and film techniques with their computerized methods have enriched the qualitative and quantitative information obtained through coronary angiography and ventriculography. The picture quality of the conventional cine-angiography with 1024x1024 picture matrix, the quick analog-digital switchover and the ECG triggered digital radiography and high storage capacity have become the standard in cardiovascular diagnostics.

The storage medium of the past, namely the cine-film, was largely replaced by CD-ROM techniques based on DICOM (Digital Imaging and Communication for Medicine) standard. Accurate measurements of coronary vessels up to even one tenth of a millimeter are achievable by the very high resolution. Quantitative Coronary Angiography (QCA) with automatic detection and delineation of borders were done using cine-film and digital cardioangiographic units.

The calculated minimal vessel diameter in stenotic areas allows for better therapy strategies, more reliable assessments of restenosis rate after PTCA and extended informations on long-term consequences. The need for important informations related to the extent of coronary stenosis, the assessment of wall irregularities, the local plaques and estimation of lumen gain after PTCA and therapy induced vessel wall changes have led to the device and technical development of Intravascular Ultrasound (IVUS) [7]. An extensive validation of histological and IVUS information and analysis followed. Presently available IVUS systems provide information regarding lumen dilatation and local wall structure after intracoronary interventions. The echo-transducer with a diameter of approximately 2.9 French is introduced over a 0.014" guide wire into the artery. The transducer frequency is 30 MHz and the radius of the image is around 4 mm. The axial resolution is around 150-200 µm in-vivo; the radial about 200-600 µm. As a principle, there are mechanical systems with a single rotating transducer and so called solid state devices with five integrated echo ranges and one phased array incorporated with 64 transducers. These are activated in tandem manner achieving a 360° radiation. Diagnostic ultrasound catheters, incorporated with angioplasty possibilities, integrated in these solid state devices are currently available. The role of such combined angioplasty-ultrasound catheter systems, currently evaluated in clinical trials, is not yet well defined.

Despite contributing to improved qualitative and quantitative information regarding coronary sclerosis and better understanding of local changes after coronary intervention, it has also shown its limitations. IVUS analysis has helped evolving better therapy strategies in only 20% of the examined. Adequate experience, good interpretation of obtained data and reliable analytical techniques are important and necessary before assessing the extent of restenosis and optimizing IVUS-controlled stent application in cases of difficult and complex stenting as also stenting of small vessels. Newer analytical systems function on ECG triggered, three-dimensional IVUS gained picture data [33]. Major clinical experience has been gained with an acoustical quantification system (Echo Quant) and a contour detection system, developed at the Thoraxcenter in Rotterdam, Netherlands [34].

Reconstructed images of vessel segments cut along longitudinal planes can be displayed and the luminal area of these regions in both longitudinal and transverse directions can be calculated using computer-assisted contour detecting algorithms. Such quantitative methods help identifying suboptimal dilated regions and allow repeated and reproducible assessment of minimal stent lumen. However, wide clinical and practical usage is still wanted. Smaller imaging catheters and improved computer technology would be the mainstay of technical developments in future. Apart from vessel geometry, picturization of plaque deposition and vessel wall contour have been realized through usage of the biplane angiography coupled with three-dimensional intracoronary ultrasound (ANGUS system) thus enabling a real reconstruction of atherosclerotic coronary wall and lumen.

During this age of stent implantation under high pressure, IVUS-controlled optimization of stent expansion in unclear and hazy angiographic picture and in prevention of subacute stent thrombosis is needed. Complex stent implantations as in longer lesions, lesions with unfavorable morphology, unstable coronary syndromes and small vessel lesions are special indications for the beneficial use of IVUS analysis.

Several developments will increase the future indications for IVUS imaging and increase also the amount of information.

The further online radiofrequency analysis of ultrasonic backscatter from the arterial wall enhances the ability to discriminate between fixed plaque and thrombus as well as differentiating between different subtypes of plaques.

High pressure or focal balloon angioplasty catheters with on-board ultrasonic transducers are commercially available. These combined devices may reduce the need for up-sizing to larger balloons and may help identify patients who require additional intracoronary stenting.

A catheter combining a cutting device (DCA) with an ultrasound transducer is also being developed.

A novel development directs the ultrasound beam axially towards the target lesions over a 120° sector that may be rotated. This instrument may have a particular role in directing guide-wire through a tight eccentric lesion and in chronic total occlusions.

A prototype has been developed of a mechanical transducer element mounted on an angioplasty guidewire. This may widen the utility of intravascular ultrasound by providing continuous imaging in the index artery and reducing the amount of instrumentation.

With solid state intracoronary imaging technology it is possible to measure blood flow using advanced radio frequency signal processing. This allows for assessment of vessel morphology and additional blood flow with a single catheter. Further it may be possible to display regional blood flow in the form of a color map superimposed on a two dimensional tomographic image.

Coronary angioscopy provides supplementary information about the status of coronary artery. The angiography portrays the lumen (Lumenology) and the IVUS describes the vessel architecture, plaque structure, and plaque load. The superficial changes in the native vessel lumen before and after intervention could be analyzed using angioscopy. The angioscopy data based on ERMENONVILLE classification are descriptive and diagnostic [3]. The diagnostic focus is on atherom, dissections and thrombosis. Angioscopic results are in tandem with data obtained from pathology and research findings on atherosclerosis. The local information provided by the coronary angioscopy are more relevant than that obtained through angiography. Angioscopic pictures correlate well with the clinical manifestation of ischemic heart disease. In stable angina pectoris, smooth, white intima was seen. In cases of instable angina pectoris, yellow colored irregular surface with partially red colored ruptured plaques was visualized. The acute myocardial infarction related artery showed mostly red occluding thrombus. Acute closure after PTCA presented mostly as dissection of the vessel wall and less related to occluding thrombus formation. In future, progressive development of this technique (vessel blockade, flushing system, optical fiberglass system with 3000 glass fibers and lenses, mostly 4.5 French catheter) and further experience would challenge the present fundamental understanding of coronary lumen and vessel wall processes as also therapy results.

Coronary interventional techniques

The particulars corresponding to coronary interventional techniques relate mostly to balloon dilatation and stent implantation. Table 1 gives a global overview without going into method particulars and their values.

- **Percutaneous Ballon Angioplasty**
- **Intracoronary Stents**
- **Directional Coronary Atherectomy**
- **Transluminal Extraction Atherectomy**
- **Rotational Burr Atherectomy**
- **Ultrasound Thrombolysis**
- **Laser Angioplasty**

Table 1. Coronary interventional techniques.

Guiding Catheters

French Size	Inner Diameter
6 F	0.066 "
7 F	0.075 "
8 F	0.098 "
9 F	0.101 "
10 F	0.112 "

Table 2. Inner lumen of guiding catheters.

PTCA (Balloon angioplasty)

Developments in guiding catheter and balloon technology have resulted in stable intubation of coronary arteries with passage of guide wire through every stenosis thus making balloon dilatation of stenosis possible. The good steerability of guide catheters and wires, the low profile of balloon catheter, special surface of balloons (covering, specially folded) have contributed much to the present 90% success rate. The low recanalization rate is basically a problem arising out of difficult guide wire passage and much less due to balloon dilatation.
The thrombogenicity of PTCA guide wires is different. Teflon-based (PTFE), silicon-based and hydrophilic coated (Phosphorylcholine) guide wires were evaluated by scanning electron microscopy after PTCA. Of them, only the hydrophilic coating was consistently thromboresistant. Thrombus formation occurs frequently on guide wires despite systemic heparinization. The phosphorylcholine provides a hemocompatible coating for guide wires and decreases surface friction therefore reducing the amount of force required for advancing guide wires through catheters [19].
The much better success rate of PTCA using modern balloons have elevated balloon dilatation to levels of gold standard in angioplasty procedures. Being practicable and user friendly, Monorail system has become the forerunner amongst balloon catheters. The ability to pass through the stenosis by manipulating it in guiding catheters with smaller inner lumen diameter namely in 6 and 7 French guiding catheters is advantageous because of the retained stability despite a reduced shaft diameter (Pushability, Trackability and Crossability). The flexible balloon tip should have low entering profile (e.g., 0.020"). The diameter of balloon should vary depending upon the extent of expansion (0.024" - 0.033") and the diameter of the catheter shaft should be around 2.5-2.8 French. The increasingly seldom used perfusion balloons for autoperfusion in occlusive dissection situations measure 3.7 F (1.22 mm) in the shaft region and about 4.2 F (1.39 mm) in the region of perfusion holes. This turns out to be disadvantageous in guiding catheters with small lumen. On the other hand, quick and optimal gain of lumen achieved through stent implantation in bail-out situations has virtually removed the perfusion catheter from the mainstream. The interventionist should however take into consideration the compliance of presently used balloons especially the rated burst pressures (around 16 atm) and the average burst pressure (over 20 atm). The restenosis rate of conventional balloon dilatation is around 30-40% in long-term observation. The available alternative interventional methods provide no obviously better results in the daily routine as seen from the restenosis rate after stent implantation (20-30%). The coronary stent reduces the local recoil phenomenon but promotes vessel proliferation. The so called "In-Stent Restenosis" is mostly therapy refractory.
The development in balloon technology appears to have reached its zenith. Principal improvements related to mechanical load and steerability through stenoses appear bleak. The balloon surface has caught the attention of researchers. Direct application of compat-ible and relevant drugs and/or brachytherapy with isotopes mounted on such specialized balloons seem to influence the restenosis rate but studies and trials to this effect are still underway.
Fundamental for the quality of guiding catheters are good pushability, torque strength, broad inner lumen (Table 2) and pliable shape. No major developments in this sphere are however expected. As out-patient interventions slowly become a reality, the size of the guiding catheters with diminishing outer diameter and a wider inner diameter would play an essential role. These improvements would really be a boon

Classification based on stent strukture

		Design	Prototype	Comments
1	·	Slotted tube	PALMAZ-SCHATZ	inhomogenous expansion
		Hybrid design	CROWN (slotted tube + multicellular)	
2	·	Monofilamentous	Wiktor-i	low spatial stability
3	·	Modified monofilamentous	FLEX	larger stent recoil
4	·	Modular	GFX-2	flexible but stable
		Hybrid design	(multicellular module)	inequal longitudinal flexibility
5	·	Pseudomodular	NAVIUS	no recoil, good shield
6	·	Multicellular	MULTI LINK, NIR, DUET	flexible, tight, high radial strength
7	·	Self expanding	WALL STENT, MAGIC-WALL STENT	Bypass vessel stenosis, long lesions
8	·	Composite	JO STENT-Coronary Stent graft	PTFE covered
9	·	Bifurcation	BARD-XT CARINA, JO Stent group	different mesh strukture

Table 3. Overview on construction principles of commercially available coronary stents.

especially in transbrachial procedures.

Intracoronary Stents

Coronary stenting has already revolutionized the practice of interventional cardiology. Stent application results in an optimal lumen gain even at long stenoses, strong vessel wall changes and curved vessel areas. Stents prevent the menacing occlusion (< 95%) in bail-out situations. They function as stabilizing elements after recanalization of chronic coronary occlusions and reduce restenosis at acute vessel occlusion. The rate of restenosis in coronary sclerosis is decreased by stenting to about the half. High pressure dilatation after stenting and in critical cases the IVUS controlled optimization of stent segments contributed essentially to these positive outcomes. Subacute stent thrombosis could be reduced to less than 1 % by additional medication with acetylsalicylicacid and Ticlopidine. In acute coronary syndrome the application of glycoprotein IIb/ IIIa receptor blockers improved the acute and long-term results after stent application (EPILOG study, 9).

The BENESTENT-I, the STRESS, and START studies provided significantly higher survival rates without events at significant De-novo stenoses and stable angina pectoris. The elective indication for stenting at restenosis after balloon dilatation is among others based on the positive data of the REST stenosis. Thus, the primary indication for the coronary stent implementation to manage symptomatic dissections and acute vessel occlusions caused by balloon angioplasty was extended (STENT-BY study). The prospective randomized SAVED study tested the stent implementation in aorto-coronary bypasses. After 6 months, the restenosis rate, parameters for revascularization and the event-free survival were significantly better. Conclusively, the SICCO study evaluated the stent implantation after recanalization of chronically occluded coronaries. Here also, the results were obviously better than from pure balloon dilatation [11].

In the course of these studies the stents were implanted almost exclusively in large coronary arteries with lumen diameters of more than 3 mm. At elective implantations mostly circumferential short stenoses were treated. For smaller vessels around 2.5 mm and less diameters with additional curved sites, long-term results are a matter of discussion.

The current percentage of stent application in coronary interventions can be estimated with 40 to 80%. Biomedical engineering did enormous efforts in development within the last 12 to 13 years of coronary stenting to conduct the mechanical behavior and phenomena at the interface between stent material and vessel wall in a way, that the excellent acute results could be conserved permanently. Some overview on construction principles is given in Table 3 [30]. From that table it can be concluded that the search for an optimal stent design leads to different solutions. The flexibility demanded by the user is necessary to meet the needs of the curved vessel track, the rough wall zones, the plaques and dissections within the passage. Essential is the delivery system. Modern balloons for PTCA can be well mounted with stents. For physicians more easy to handle are by the manufacturers premounted stents on balloon catheters, which normally allow very good implementation.

In older coronary stenoses the radial force expression as well as the good longitudinal stability is of importance. At complex stenoses and different shapes of bifurcative stenoses the special design with varying mesh width and the good radioopacity have a decisive role (Table 4: example of JOSTENT group). Especially, the IVUS guided balloon angioplasty assisted with focal stenting has a higher, procedural success rate than former success rates reported with traditional PTCA.

The balloon angioplasty of a stenosing coronary plaque causes primarily a plastic deformation with vessel dilatation and dissections as well as plaque compression. Due to the dissection accompanied by tears of the intima and media, sub-intimal vessel zone are laid bare. They carry thrombogenic factors and support the adhesion and aggregation of thrombocytes. This first stage of the vessel wall within the first days after intervention covers the risk of thrombus formation. In the second stage, the forming of the neointima takes place accompanied by the proliferation of smooth muscle cells. These processes cause restenosis apart from the so called lumen remodeling with the tendency for lumen reduction. This explains the effort for an optimal post-interventional lumen. The application of stents takes the cardiologist closer to the goal to avoid the acute recoil and later remodeling. That gives the reason for the growing interest in prepared stents for further reduction of the restenosis rate. The development is directed to influence the thrombogenicity as well as hyperplasia of neointimal tissue, and to obstruct the proliferation of smooth muscle cells and fibroblasts. Table 4 points in its last 3 rows to coated stents, which shall solve these aspects beside of its function of vessel support. Blood and tissue elements shall be restricted in their local activities.

The following concepts are subjects of discussion for biomedical engineering:

- Coating of stents with anti-thrombotic and anti-proliferative substances
- Coating with polymer substances to hold large amounts of drugs for vessel wall treatment
- Endovascular brachytherapy with radioactive drugs
- Local drug delivery
- Genetic therapy to change the genetic program of vessel wall cells

These basic concepts particularly are in an early experimental state and shall not be explained in detail but summarized.

Genetic-therapeutic approaches use coated stents with endothelial cells manipulated by genetic engineering. They secrete therapeutic proteins with anti-thrombotic and antiproliferative effect [14][20][29].

The principle of local drug delivery makes use of the application of drugs by modified balloons or needle catheters. The spectrum of possible drugs reaches from steroids, anticoagulative drugs with anti-proliferative effect, calcium channel blockers, antioxidants up to cytostatics [21]. Established experiences are not available until now. The coating of stents with polymeric substances being able to hold drugs in an extended scale for later deposition hunt for the same objective.

The coating of stents with antithrombotic and anti-proliferative substances seems to be especially successful. The PARAGON stent coated with phosphorylcholine will be judged for this outcome. The Reopro and Taxol coating are expected to influence the frequency of restenosis.

Experimentally stainless steel stents, plated with a pure gold surface have been associated with lower thrombogenicity. Additional better fluoroscopic visibility of gold-plated stents may improve procedural results. In a randomized trial coating of a stainless-steel stent with a gold surface showed a negative impact on the outcome of patients during the first year [24].

Amorphous silicon carbide (a-SiC:H) is a ceramic semiconductor with favorable haemocompatible properties shown experimentally. Scanning electron microscopy demonstrates complete coverage of stent surface with endothelial cells. Long-term data on clinical experiences with the TENAX coronary stent are till now not available.

The heparin coating of stents allows positive and negative effects. Heparin shows an antithrombotic effect and works anti-proliferative. On the other hand, heparin promotes the aggregation of thrombocytes. The BENESTENT II study [26] yielded good results from the heparin coated group in case of optimal stent expansion with high pressure and following therapy

Stent types	Radio opacity	Delivery platform	Flexibility	Radial strength	Long stability	Biocompatibility	Antithrombogenicity	Antiproliferative properties
Palmaz Schatz Crown - 316L stainless steel	++	++	++	++	+++	-	-	-
Palmaz Schatz Stent with cov. bonded heparin (BENESTENTII) - Tantalum	++	+++	++	++	+++	+	++	+
Magic Wallstent - cobalt-based alloy with platinum core	+++	++	+++	++	+	-	-	-
Gianturco-Roubin II (GRII) - 316L stainless steel	+++	++	+++	++	++	-	-	-
Wiktor-GX, -I - tantalum (Hepamed Wiktor)	+++	+++	+++	++	+	- future: Taxol/Reopro-coating	++	+
Multilink coronary stent - 316L stainless steel	+	+++	++	+++	+++	-	-	-
Crossflex - 316LVM stainless steel	++	+++	+++	++	++	-	-	-
Freedom - 316L stainless steel	++	++	+++	++	++	-	-	-
Paragon - martinsitic nitinol	++	+++	+++	++	++	+ (Phosphorylcholine)	+	+
TENSUM - tantalum coated with a-SiC:H	+++	++	+++	+++	+++	+	+	+
TENAX - 316L coated with a-SiC:H	++	+++	+++	+++	+++	+	+	+
NIR stent - stainless steel	+	+++	+++	+++	+++	-	-	-
NIROYAL - stainless steel plated with gold	+++	+++	+++	+++	+	-	-	-
BARD XT - 316 LVM stainless steel	++	+++	+++	+++	+++	-	-	-
beStent - 316L stainless steel with terminal gold	+++	+++	+++	+++	+++	-	-	-
JOSTENTs - 316 L stainless steel	+	+++	+++	+++	+++	-	-	-
NAVIUS - 316L full hard stainless steel	+	++	+++	+++	+++	+	+	+

JOSTENTs (316 L stainless steel):
JOSTENT Plus
JOSTENT Flex
JOSTENT Side Branch allow access for side branches
JOSTENT Asymmetric Side Branch
JOSTENT Bifurcation
JOSTENT Coronary Stent Graft

+++ excellent, ++ good, + sufficient, - not reported

Table 4. Stent overview (selected).

with ASS and ticlopidine (6% restenosis vs. 20 % in BENESTENT I).
Endovascular brachytherapy holds promise to become an important tool in the prevention and treatment of restenosis. However while there is a basic foundation of knowledge about its function and mechanisms of action [35][37] more information regarding clinical effectiveness, long-term results and safety is required. Specifically, there remains the issue of long-term adverse effects associated with intravascular irradiation. Other questions relating to choice of isotope (gamma or beta emitters), dosing, mode of delivery, need for source centering, among other points, need to be answered as well [27,28]. The results of the ongoing multi-center trials (Beta-CathTM system trial in the USA and the BRIE trial in Europe) will contribute to the medical acceptance of intracoronary radiation for prophylaxis and/or therapy of restenosis [10][37]. Radioactive stents are of value, especially in large vessels, because of their low activity and proximity to the vessel wall [37]. Adventitial labeling and immunostaining have suggested that the mechanisms by which radiation reduces restenosis are inhibition of smooth muscle cell proliferation in the adventitia and favorable effects on vessel remodeling.
Future developments especially in connection with stents seem to contribute to new approaches to get good long-term results and a low level of coronary restenosis.

Directional Coronary Atherectomy (DCA)

The directional coronary atherectomy causes the Dotter effect to the stenosis. A larger amount of plaque can be removed and the elastic recoil is reduced. Classically, the indication is for eccentric lesions near the mainstem in larger vessels. Proximal RIVA stenoses can be treated most effectively as well as stenotic areas in bifurcations. Restenotic lesions after balloon dilatation and within stents can be treated. Several studies confirm the effectiveness of this method (CAVEAT, CCAT, OARS, BOAT). The profit of the technique is restricted by the required wide guiding catheters and the stiff cutting catheters. But in combination with an additional stenting good acute results can be achieved. The rates of restenosis are comparable to the gain of balloon dilatation. Due to the comfortable situation where dissections can be supplied with stents, the DCA nowadays is almost not performed at larger coronary dissections with intracoronary flaps. The method of the DCA requires technologically high sophisticated catheter systems. Further technical developments can be expected in future.

Transluminal Extraction Atherectomy (TEC)

The on the wire design of the transluminal extraction atherectomy system assures intraluminal position and rotational stability (750 rpm). The unique TEC guidewire combines flexibility and steerability. A precise designed distal bushing allows the apical positioned cutter (Microtome-sharp TEC blades) to move and rotate freely over the TEC guidewire. The indication is given in thrombotic lesions in bigger coronary arteries, in ostial lesions and in case of degenerated grafts with thrombotic content. Is a plaque excised, it is quickly and continuously extracted through the central lumen of the coronary TEC catheter. The potential for distal embolization is minimized. Unprotected left main coronary arteries, heavily calcified lesions, diffuse disease greater than 20 mm long with total occlusions in native coronary arteries are contraindications. The clinical experiences of this interventional principle are limited.

Rotational Burr Atherectomy

The Rotablator is a unique mechanical atherectomy system that utilizes a rapidly rotating diamond coated burr (160.000-180.000 rpm) to selectively remove atheromatous plaque. The guidewire directs the rotablation. The abraded minute particles traverse the coronary microcirculation and are removed by the reticuloendothelial system. The established uses are fibroelastic lesions, complex lesions, bifurcation stenoses, ostial lesions, long and diffuse lesions, also with calcification and intra-stent restenosis. The restenosis rate is similar like other catheter-based coronary interventions in patients with severe coronary sclerosis. The potential advantages of using the rotablation together with coronary stenting evaluated the SPORT-Study (Stent Implantation Post Rotational Atherectomy Trial) [17]. Rotational atherectomy with adjunctive balloon angioplasty leads to better acute angiographic results and improved long-term clinical outcomes than balloon angioplasty alone for the treatment of in-stent restenosis (BARASTER Registry) [5]. The technological quality of the rotablator system is far advanced.

Differential interventional therapy modalities

Ostium stenosis	:	DCA, PTCRA, Balloon, ELCA
Calcified proximal stenosis	:	PTCRA, Stent, Balloon
Hard distal stenosis	:	PTCRA, Balloon
Eccentric stenosis	:	DCA, Stent, PTCRA, Balloon
Elastic stenosis	:	Stent, Balloon
Long lesions	:	PTCRA, Balloon, Stent, ELCA
Thrombosed stenosis	:	US-Lysis, DCA, TEC, Balloon, Stent
Bypass vessel stenosis	:	Stent, Balloon, TEC, DCA (?)
Angular vessel stenosis	:	PTCRA, Balloon, Stent
Vessel occlusion	:	ELCA, Balloon, PTCRA, Stent
Occlusive dissektion	:	Stent, DCA (?), Balloon

[modif. after KOBER, Z. Kardiol. 85: Suppl. 1 (1996)]

ELCA = Excimer Laser-Angiplasty
DCA = Directional Coronary Atherectomy
TEC = Transluminal Extrac tion Atherectomy
PTCRA = Rotational Burr Atherectomy
US-Lysis = Ultrasound Thrombolysis

Table 5. Overview of possible applications of different interventional methods.

Ultrasound Thrombolysis

The ultrasound thrombolysis device is a 140 cm long, solid-metal probe, ensheathed in a plastic catheter and connected at its proximal end to a piezoelectric transducer. Ultrasonic energy (45 kHz) is transmitted from the transducer as longitudinal vibrations of the probe, which direct the energy into the arterial system. The last 18 cm of the device is a three-wire flexible segment with a 1.6 mm tip. When activated through an integrated computer designed to ensure constant power output at the distal tip the probe produces cavitation and a resulting vortex which pulls the thrombus toward the distal tip of the probe. The fibrin holding the thrombus together is selectively lysed leaving basic blood components, which pass the microcirculation. The clinical results till now suggest that ultrasound thrombolysis has the potential to be a safe and effective catheter based therapeutic modality in reperfusion therapy for patients with acute myocardial infarction and other clinical conditions associated with intracoronary thrombosis [4][8][22]. Till now the clinical experience is small. Case reports are available in saphenous vein grafts, unstable angina, acute myocardial infarction, subacute thrombosis of stent.

Laser Angioplasty

There are numerous potential sources of laser energy, each with different effects on plaques and arterial tissue, and different delivery requirements.

The LASTAC®-System (LASer Transluminal Angioplasty Catheter) delivers continuous wave argon laser energy via a bare fiber. The Eclipse® laser employs a pulsed, solid state holmium/Tm: YAG system. The current catheter design is an over-the-wire system with multiple fibers arranged around the central lumen. The excimer laser coronary angioplasty (ELCA) have been, in comparison with the earlier mentioned types, extensively used due to their ultraviolet wavelength which allow high absorption by proteins, precise control of ablation, low thermal effects and the ability to ablate calcified plaques. Most clinical experience with ELCA is derived from the 308 nm XeCl system, which utilizes a fairly flexible over-the-wire coaxial multifiber catheter (sizes ranges from 1.3 to 2.0 mm, a laserwire is also available for the first use in totally occluded arteries) introduced through any conventional 8F guiding catheter [2][18][31]. Especially with the ELCA wire coronary recanalization is possible. Additional balloon dilation or stenting after recanalization is necessary. The rate of restenosis is high and the laser procedure is very expensive [1][15][32]. The ARBAC and AMRO studies could not demonstrate better results with the laserangioplasty in comparison to the balloon angioplasty. Further randomized studies are of interest. The TOTAL Trial used the laser wire (0.018") in chronic occlusions. The EXACTO study compared the success rate between mechanical and laserguided recanalizations. The LARS trial examinated the effects of the laser angioplasty in-stent restenosis. In such cases eccentric laser catheters (1.7 and 2.0 mm) sometimes were used. The long-term results of these studies will contribute data for the position of laser angioplasty in interventional cardiology.

In the last years the Transmyocardial Revascularization (TMR) and the Percutaneous Myocardial Revascularization (PMR) stands in evaluation. Especially the catheter based PMR seems to be a useful tool to treat patients with advanced coronary stenosis and heavy angina pectoris if the bypass surgery or other interventional treatment is impossible. Under fluoroscopic visualization the laser catheter is positioned against the ischemic endocardium under control of a 9F guiding catheter.

The Ho:YAG laser is fired synchronous to the ECG. Nitinol petals near the tip of the lens limit penetration into the myocardium. During the procedure, channels are spaced one centimeter apart throughout the ischemic region. Preliminary clinical results are promising [13][23][36]. Till now there is no sufficient scientific based explanation for these clinical results. Although improvement in angina pectoris is still evident, sustained clinical improvement does not persist in all patients. A multicenter study is going on to proof the safety and clinical effectiveness.

Conclusions

The field of interventional cardiology stands under permanent development of balloon catheters and especially of stents. The promising hopes in the field of laser angioplasty are not fulfilled till now. It is quite difficult to give a survey of a preferable method from the clinical point of view. Table 5 gives an overview about possible applications of different interventional methods depending on the nature of the diseased coronary arteries. Until now there are different opinions, depending on the different experiences of the interventionists. Special aspects and requirements are necessary in radial artery approach to manipulate coronary stenosis. The transradial approach can be used as an alternative entry site for coronary angioplasty [16]. Here we need a special equipment selection with further claims on the biomedical research to obtain smaller and save devices.

References

[1] Appelman Y.E., Piek J.J., Strikwerda S,. Tijssen J.G., de Feyter P.J., David G.K., Serruys P.W., Margolis J.R. Randomized trials of excimer laser versus balloon angioplasty for treatment of obstructive coronary artery disease. Lancet 1996; 347: 79-84

[2] Bittl J.A., Sanborn T.A.: Excimer laser facilitated coronary angioplasty: Relative risk analysis of acute and follow up results in 200 patients. Circulation 1992, 86: 71-80

[3] Den Heijer P., Foley D.P., Escaned J., Hillege H.L., van Dijk R. B., Serruys P.W., Lie K.I.: Angioscopic versus angiographic detection of intimal dissection and intracoronary thrombus. J Am Coll Cardiol 1994; 24: 649-654

[4] Fajadet J., Calderon L., Thomas M. et al: Coronary ultrasound thrombolysis in acute coronary syndroms: The first 100 patients from Acolysis Registry., Circulation, Abstracts From the 71 st Scientific Sessions 1998; 98 (Suppl): 439

[5] Goldberg S.L., Berger P., Cohen, D.J. et al: For the BARASTER Registry, Swedish med Ctr, Seatle, WA: Balloon angioplasty versus rotational atherectomy for in-stent restenosis. Circulation, Abstracts From the 71st Scientific Sessions 1998; 98 (Suppl): 1907

[6] Gruentzig A.: Transluminal Dilatation of Coronary-Artery Stenosis (letter). Lancet 1978; 1: 263

[7] Gussenhoven W.J., Bom N., Roelandt J.: Intravascular Ultrasound 1991, Kluwer Academic Publishers, Dordrecht, The Netherlands

[8] Hartnell G.G., Saxton J.M., Friedl S.E., Abela G.S., Rosenschein U.: Coronary ultrasonic thrombus ablation: in vitro evaluation of a novel device. J Intervent Cardiol 1993; 6: 69-76

[9] Kerekas D.J., Lincoff A.M., Miller D.P., Tcheng J.E., Cabot C.F., Anderson K.M., Weisman H.F., Califf R.M, Topol E.J.: For the EPILOG Trial investigators: Abciximab therapy and unplanned coronary stent deployment. Circulation 1998; 97: 857-864

[10] King S.B., Williams D.O., Chougule P. et al: Endovascular ß-radiation to reduce restenosis after coronary balloon angioplasty: Results of the Beta Energy Restenosis Trial (BERT). Circulation 1998; 97: 2025-2030

[11] Kloner R.A., Birnbaum Y.: Cardiovascular Trials Review, Third Edition, Le Jacq Communications, Inc., Greenwich, CT 06830, USA, 1998

[12] Kober G.: Alternative Techniken der koronaren Intervention - Eine neue Differentialtherapie ? Z. Kardiol 1996; 85 (Suppl 1): 1-7

[13] Lauer B., Junghans U., Stahl F., Oeserle S.N., Schuler G.: Percutane myokardiale Revaskularisation, ein neues Therapieverfahren für Patienten. Z Kardiol 1998; 87 (Suppl 1) 789

[14] Libby P., Ganz P.: Restenosis revisited - now targets, new therapies. N Engl J Med 1997; 337: 418-419

[15] Litvack, F., Eigler, N., Margolis, J. et al: For the ELCA Investigators: Percutaneous excimer laser coronary angioplasty - results in the first consecutive 3000 patients. J Am Coll Cardiol 1994: 23: 323-329

[16] Lotan, C.H., Hasin, Y., Salmoirago, E., Rozenman, Y., Mosseri, M., Admon, D., Nassar, H., Gotsman, M.S.: The radial artery: An applicable approach to complex coronary angioplasty. J Invas Cardiol 1997; 9: 518-522

[17] Moussa, I., Di Mario, C., Moses, J., Reimers, B., Di Francesco, L., Martini, G, Tobis, J., Colombo, A.: Coronary stenting after rotational atherectomy in calcified and complex lesions. Circulation 1997; 96: 128-136

[18] On behalf of the TOTAL investigators. Recanalization of chronic total coronary occlusions using PRIMA, 0,018 inch laser guide wire. The European Multicenter Surveillance Study. Eur Heart J 1995; 16: 2792

[19] Plante, S., Juneau, C.: Thrombogenicity of PTCA guide wires: A scanning electron microscopy study. Technology Update 1997

[20] Plautz, G., Nabel, E.J., Nabel, G.J.: Selective elimination of recombinant genes in vivo with a suicide retroviral vector. New Biol 1991; 3: 709-715

[21] Pratt, R.E., Dzau, V.J.: Pharmacologicial strategies to prevent restenosis. Lessons learned from blockade of Renin-Angiotensin System. Circulation 1996: 93: 848-852

[22] Rosenschein, U., Roth, A., Rassin, T., Basan, S., Laniado, S., Miller, H.I.: Analysis of coronary ultrasound thrombolysis endpoints in acute myocardial infarction (ACUTE Trial) Circulation 1997; 95: 1411-1416

[23] Sanborn, T. A., Oesterle, S.N., Heuser, R.R. et al: Percutaneous myocardial revaskularization (PMR) with a Holmium Laser. A Pilot Multicenter Feasibility Trial. Circulation, Abstracts From the 71st Scientific Sessions, 1998; 98 (Suppl) 441

[24] Schömig, A., Kastrati, A., Neumann, F.J., Elezi, S., Schühlen, H., Dirschinger, J.: Impact of gold plating on the outcome after coronary stent placement: results of a randomized Trial, Circulation, Abstract from the 71 " Scientific Sessions, 1998; 98 (Suppl) 4486

[25] Schryver, T.E., Popma, J.J., Kent, K.M., Leon, M.B., Eldredge, S., Mintz, G.S.: Use of intracoronary ultrasound to identify the true coronary dissection treated with intracoronary stenting. Am J Cardiol 1992; 69: 1107-1108

[26] Serruys, P.W., Emanuelsson, H., van der Giessen, W. et al: Heparin-coated Palmaz-Schatz Stents in human coronary arteries, early outcome of Benestent - II pilot study. Circulation 1996; 93: 412-422

[27] Serruys, P.W., Levendag, P.C.: Intracoronary brachytherapy: The death knell of restenosis or just another episode of a nevervending story ? Circulation 1997; 96: 709-712

[28] Soares, C.U., Halpern, D.B., Wang, C.K.: Calibration and characterization of betaparticle sources for intravascular brachytherapy. Med Phys 1998; 25: 339-346

[29] Steg, P.G., Tahlil Ou, Aubailly, N., Caillaud, J.M., Dedieu, J.F., Bertheldt, K., Le Roux, A., Feldman, L., Perricaudet, M., Denefle, P., Branellec, D.: Reduction of restenosis after angioplasty in an atheromatous rabbit model by suicide gene therapy. Circulation 1997; 96: 408-411

[30] Strupp, G., Schreiner, G., Bonzel, T.: Bauarten und Eigenschaften koronarer Stents. X. Seminar für angewandte PTCA, Fulda, 10. und 11. September 1998

[31] Tsheng, J. D.: Saline infusion in excimer laser coronary angioplasty. Seminars in Intervent Cardiol 1996: 1: 135-141

[32] Vandormael, M., Reifart, N., Preusler, W., Schwarz, F., Störger, H., Hofmann, M., Klöpper, J., Müller, S., Haase, J.: Six month follow - up results following excimer laser angioplasty, rotational atherectomy and balloon angioplasty, ERBAC-Study. Circulation 1994; 90: 213 A

[33] Von Birgelen, C., Mintz, G.S., De Feyter, P.J., Bruining, N., Nicosia, A., Di Mario, C., Serruys, P.W., Roelandt, J. R.T.C.: Reconstruction and quantification with three-dimensional intracoronary ultrasound. Eur Heart J 1997: 18: 1056-1067

[34] Von Birgelen, C., de Feyter, P.J., Erbel, R., Serruys, P.W.: Coronary stenting as assessed with qauantitative three-dimensional intravascular ultrasound. Stent 1998; 1: 114-121

[35] Waksman, R.: Local catheter-based intracoronary radiation therapy for restenosis. Am J Cardiol 1996; 78 (Suppl 3A) : 23-28

[36] Whitlow, P.L., Knopf, W.D., O'Neill, W.W., Kaul, U., Londero, H., Shawl, F.A.: Percutaneous transmyocardial revascularization in patients with refractory angina. Circulation, Abstracts From the 71st Sientific Sessions 1998; 98 (Suppl) 442

[37] Williams, D.O.: Radiation vascular therapy: A novel approach to preventing restenosis. Am J Cardiol 1998: 81: 18E-20E