Percutaneous Coronary Intervention (PCI)

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Dotter and judkins were the first to propose the concept of transluminal angioplasty enlargement of the lumen of a stenotic vessel by a catheter-technique in 1964. Their technique used a spring-coil guidewire over which a series of progressively larger rigid dilators were advanced to dilate the atherosclerotic arterial stenosis. While the Dotter technique proved effective in peripheral arteries, the need to insert large calibre rigid dilators through the arterial puncture (and the high shear forces applied by the dilators as they crossed the atherosclerotic lesion) ultimately restricted its clinical application.

Gruentzig's pioneering work in 1974 replaced the rigid dilators with an inflatable balloon mounted on a comparatively smaller catheter shaft which could be introduced percutaneously, advanced across a vascular stenosis in its smaller (collapsed) state, and then inflated with sufficient force to enlarge the stenotic lumen. This culminated in the first percutaneous transluminal coronary angioplasty (PTCA) of a stenotic coronary artery in a conscious human on September 16, 1977. Balloon angioplasty remained the only catheter-based revascularization technique in widespread use until the mid-1990s, when other modalities including atherectomy and were introduced. Accordingly, the technique is now more commonly referred to as percutaneous coronary intervention (PCI). Over time, progressive improvements in equipment and technique have produced dramatic growth in PTCA and transformed it into the dominant form of coronary revascularization.

Over the past 25 years or so, the role of balloon dilation has become much less prominent as a stand-alone treatment. In current practice, it serves predominantly as an adjunctive therapy for preparing (i.e., predilating) or optimizing (i. e., post dilating) stent placement. Despite the fact that PCI is being performed in increasingly more complex lesions and patients , the advent of the stents and other new interventional devices, as well as adjunctive antithrombotic pharmacology , has improved the procedural success rate of PCI to approximately 95%, the procedural mortality to approximately 1%, and the emergency bypass rate to <0.5% .

Equipment:

A coronary angioplasty system consists of three basic components

(a) Guiding catheter, which provides stable access to the coronary ostium, a route for contrast administration, and a conduit for the advancement of the equipment.

(b) Guidewire that can be passed through the guiding catheter, across the target lesion into the distal coronary vasculature to provide a rail over which therapeutic devices can be advanced.

© Balloon dilatation catheter filled with contrast medium.

Mechanism of Percutaneous Transluminal Coronary Angioplasty:

Compression of the atheromatous plaque akin to footprints in the snow. Extrusion of liquid components from the plaque does permit some compression of soft plaques but contributes minimally to improvement in more fibrotic. In fact, true plaque compression accounts for a minority of the observed improvement. Plaque redistribution more like foot prints in wet sand. Some of this takes place by longitudinal displacement of plaque upstream and downstream from the lesion .

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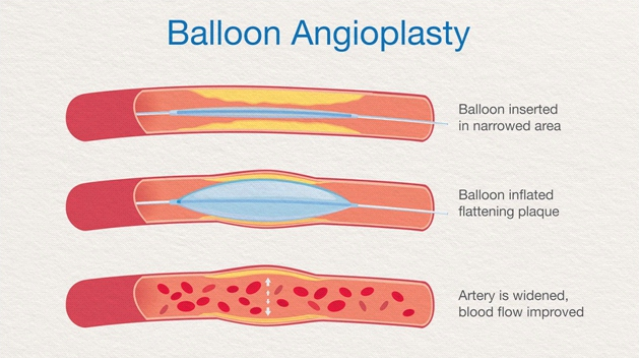
Stretching leads to fracture of the intimal plaque and partial disruption of the media and adventitia , with consequent enlargement of both the lumen and the overall outer diameter of the vessel. Although use of a full-sized balloon should theoretically eliminate all narrowing at the treatment site , the overstretched vessel wall invariably exhibits elastic recoil following balloon deflation and some degree of local vasospasm. These processes typically leave the stretched vessel with a residual stenosis. A typical balloon angioplasty result also shows evidence of localized trauma to more superficial plaque components, spiral dissections that may interfere with antegrade blood.

Stenting reduces or even eliminates this elastic recoil, dissection, and thereby provides lower (0% to 10% rather than 30%) postprocedural residual stenosis , and a smooth and uniform lumen.

Figure 1: Mechanism of action of "Balloon Angioplasty"



Limitations of Balloon Angioplasty:

The majority of vessels undergoing balloon angioplasty tolerate balloon dilatation and heal sufficiently to result in an adequate lumen; however, balloon-mediated injury to the vessel wall can at times be uncontrolled and excessive, resulting in balloon angioplasty's two major limitations: (1) Abrupt closure (occurring acutely, or within the first several days after angioplasty). (2) Re-stenosis - 50% (occurring later, within months after the procedure due to a combination of acute recoil and chronic constrictive remodelling) .

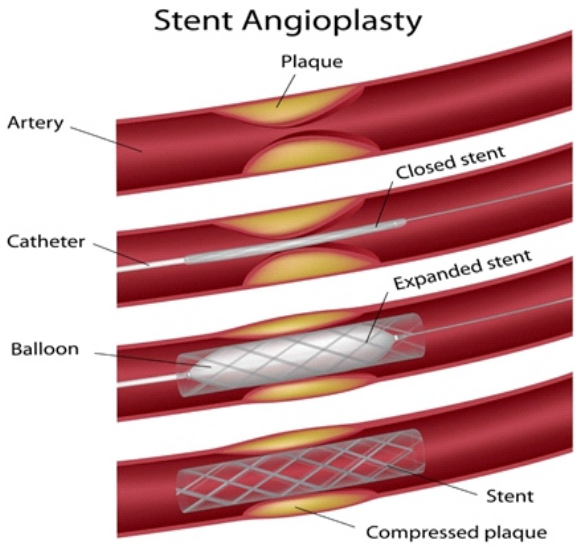
Bare Coronary Stents:

The coronary stent was thus devised as an endoluminal metallic scaffold to create a larger initial lumen, to seal balloon induced dissections , and to reduce vascular recoil & acute vessel occlusions and late vascular remodelling, thereby improving upon the early and late results of balloon angioplasty.

Design Features:

These devices can be divided into three different designs: coil, tubular mesh, and slotted tube. The coil design is characterized by metallic wire or strips formed into a circular coil shape. The tubular mesh design is characterized by wires wound together in a meshwork forming a tube. The slotted tube design is characterized by tubes of metals from which a design is laser cut. These devices differ from each other with respect to composition (eg, stainless steel, cobalt chromium alloy, nickel chromium alloy), architectural design, and delivery system (i.e. , a balloon catheter that delivers the stent, self-expanding, or balloon expandable). These devices also have different strut patterns and widths, stent diameters, stent lengths, radial strength, radiopacity, thrombogenicity, and magnetic resonance imaging (MRI) compatibility.

Figure 2: Mechanism of action for "Stent Angioplasty"



Drawback of Bare metal stents:

In about 30–40% of cases the smooth muscle cell activation leads to an untoward excessive intimal hyperplasia, which may result in clinically relevant restenosis and need for repeat revascularization.

Restenosis mechanism:

The initial stage (30 days) includes platelet adhesion, mild luminal thrombus formation, fibrin deposition, and a focal inflammatory cellular infiltrate consisting of polymorphonuclear leukocytes and macrophages. T-lymphocyte infiltration starts around 2 weeks and persists for several months. The early process of vascular healing (2–4 weeks) is followed by smooth muscle cell migration, proliferation, and matrix formation (proteoglycans/collagen type III). Completion of vascular repair in humans is usually achieved by re-endothelialization 3–4 months after BMS implantation. Neointimal formation peaks at 6–12 months, with collagen I.

Drug Eluting Stents (DES):

Contrary to the inability of systemic therapy to inhibit restenosis after angioplasty or stenting , the local release of antiproliferative drugs (e.g. , sirolimus, paclitaxel, zotarolimus, everolimus) from a polymer matrix over the first few months after stent implantation can substantially reduce inflammation and smooth muscle cell proliferation within a stent. Since drug eluting stents have delayed endothelialization as compared with bare-metal stents , the duration of dual antiplatelet therapy must be extended (minimum 12 months). In contrast, bare metal stents or PTCA alone should be considered in patients who have a high bleeding risk, inability to comply with prolonged dual antiplatelet therapy , or have the potential need for a planned surgical procedure following the PCI which will require interruption of the dual antiplatelet therapy

Design of DES:

DES platforms consist of 3 main components:

(1) stent metallic platform or scaffold,

(2) stent polymer coating that allows for controlled drug release,

(3) antiproliferative drug.

Evolution of Coronary Stents:

First-Generation DES:

First-Generation DES has thick struts & polymer coating, showing a significant increase in late stent thrombosis (LST) in DES because of delayed arterial healing and impaired re-endothelialization were strongly associated with the frequently fatal LST. Pathologic findings showed the development of unstable features like neoatherosclerosis within the neointima as a frequent finding in first-generation DES, which may partly contribute to events of LST

Second Generation DES:

The first-generation DESs were another leap forward compared with BMS; however, there was still concern about LST and reduced deliverability with the 140µ strut/polymer thickness. The second generation DESs were designed to overcome these flaws using for example thinner cobalt chromium alloys, new cell cycle inhibitors (everolimus/zotarolimus), and more biocompatible polymers (fluoropolymers/ phosphorylcholine). Whereas the first-generation DES continued to release drug for a prolonged duration, the release kinetics of the second-generation DES was generally shorter

Stent with biodegradable polymer:

DESs with completely biodegradable polymer coatings were designed with the goal of early neointimal hyperplasia inhibition, followed by polymer absorption, with the hope of minimal long-term inflammatory responses similar to the BMS vascular interaction. Biodegradable polymer (PLA and PGA) SES demonstrated a reduction of neointimal formation and a reduced cellular inflammatory response when compared with permanent polymer SES and BMS.

Bioresorbable vascular scaffolds (BRS):

Bioresorbable vascular scaffolds (BRS) represent a significant evolution in stent technology. They offer

multitude potential advantages over their metallic congeners including full restoration of vessel vasomotion, obviation of the need for prolonged dual antiplatelet therapy (DAPT), prevention of potentially deleterious effects of long-termmetal's presence, and possibility of future graft insertion in scaffold area. However, despite the anticipation and initial enthusiasm, reports of scaffold thrombosis emerged with bioresorbable vascular scaffolds too. The rate of subacute or probable scaffold thrombosis was higher with bioresorbable vascular scaffolds vis-à-vis metallic DES. The incidence was from 0.42% to 1.37% with the highest rates seen in patients of ACS (1.42%). Abbott Vascular recalled of the Absorb Bioresorbable Vascular Scaffold (BVS) System due to elevated rates of major adverse events, specifically, myocardial infraction and scaffold thrombosis when compared to patients treated with the Xience metallic drug eluting stent.

Intravascular Imaging Techniques:

Introduction:

Intravascular imaging techniques with the ability to visualize both vessel wall structures and lumen provide valuable additional information and promise to cover the shortfalls of conventional angiography. Imaging guidance during PCI is one of the key determinants of procedural outcomes because it is an integral part of every stage of PCI including assessment of lesion severity, preprocedural planning (selection of appropriate stenting strategy, stent size, landing zones), optimization (stent expansion, malapposition, lumen gain), and management of immediate complications (dissection, thrombus, tissue prolapse, side-branch compromise). During follow-up, imaging helps in identification and management of mechanisms of stent failure (restenosis, thrombosis).

Imaging techniques:

Intravascular Ultrasound (IVUS):

Intravascular ultrasound (IVUS) catheters use reflected sound waves to visualize the arterial wall in a two-dimensional , tomographic format, analogous to a histologic cross section. They utilize significantly higher frequencies than utilized in non-invasive echocardiography (20 to 45 MHz as compared with 2 to 5 MHz) . This provides high resolution (100 to 200 μm for the coronary catheters) at the expense of beam penetration (limited to 4 to 8 mm from the catheter tip)

Optical Coherence Tomography:

The intravascular OCT imaging system consists of an optical engine emitting and receiving near infrared light signals .The optical engine includes a super-luminescent diode as a source of low-coherence, infrared light, with a wavelength of approximately 1,300 nm to minimize light absorption by vessel wall and blood cell components (protein, water, haemoglobin and lipids) .

Components of imaging system:

1. Catheter interface unit including a motor drive;
2. Fiberoptic imaging catheter; and
3. computer processor and display console for system control, image reconstruction, and digital recording.

Figure 3: Various presentations during Intravascular Ultrasound

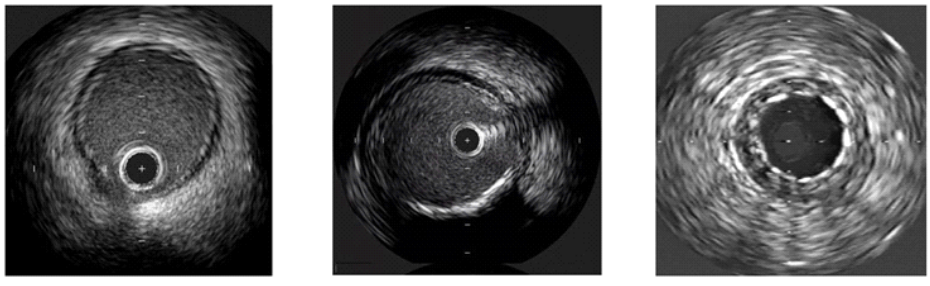
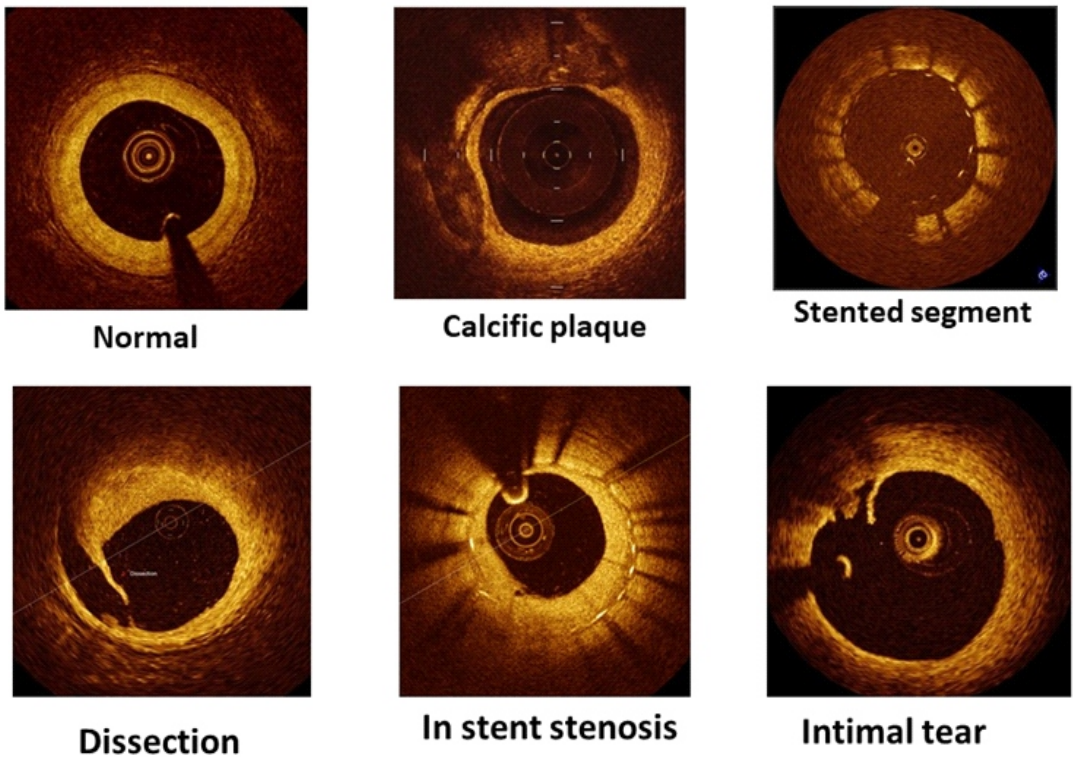


Figure 4 : Use of Optical Coherence Tomography



When to use imaging:

Complex lesions such as diffuse disease, chronic total occlusions, heavily calcified vessels and bifurcations (particularly the left main stem) benefit from an image-guided approach. Similarly, more complex patient subsets such as ACS presentation, significant renal dysfunction or those with unusual/atypical presentations benefit from enhanced diagnostic ability and optimisation of intervention to minimise the risk of stent failure. Routine imaging in simple lesions and stable clinical presentations does not provide a clear benefit.

Capabilities and limitations of IVUS & OCT:

OCT has approximately ten times superior resolution compared with IVUS, so is suited to detailed assessment of lesion characteristics less visible by IVUS. Strut-level detail and automated 3D rendering make OCT the modality of choice for stent visualisation. Compared with IVUS, OCT image acquisition is faster and interpretation is aided by reliable automated analysis of lumen contour. However, image generation by near-infrared light requires blood clearance with contrast injection, limiting the use of OCT in renal insufficiency, aorto-ostial lesions and traumatised vessels at risk of hydraulic dissection. Despite the lower resolution provided by IVUS, compared with OCT, it offers a greater depth of vessel penetration. Consequently, IVUS provides more accurate assessment of deeper vessel structures, such as the external elastic membrane, delineating vessel size and plaque burden. IVUS is preferred in larger vessels (>5mm) and aorto-ostial lesions as there is no requirement for blood clearance. This makes IVUS well suited to LM lesions. So, IVUS can provide a comprehensive anatomical and haemodynamic assessment and guide optimal LM treatment. IVUS is also preferred for CTO lesions and renal insufficiency as there is no reliance on contrast injection. The development of high definition IVUS allows improved spatial resolution combined with imaging depth.

Utility of Intravascular imaging techniques in coronary interventions:

Plaque composition:

As discussed earlier, OCT & IVUS provide differing evaluation of coronary plaque composition. The penetration depth of IVUS provides deep structure identification, particularly the external elastic membrane, allowing estimation of true vessel size and an appreciation of plaque burden (discussed later). OCT's superior resolution and the specific nature of near-infrared light's interaction with individual tissue components facilitates identification of calcium, macrophage, neovascularisation and lipid/necrotic core. With recent advances in modification techniques for calcification, there has been an increased focus on identification of calcium and detection of characteristics associated with poor stent results. Specific markers suggesting the need for calcium modification are a calcific arc over 180 , calcium thickness >0.5mm, and length >5mm. Modification may require use of non-compliant or cutting balloons, rotational atherectomy, intravascular lithotripsy or laser and algorithms are being developed to guide the treatment of severely calcific plaque. It is essential that repeat imaging is undertaken to confirm adequate calcium modification before considering stent implantation, to avoid under expansion and poor long term PCI outcomes.

Stent selection and optimisation:

Use of upfront imaging provides an accurate assessment of lesion length and vessel size. Identification of healthy vessel 'landing zones' (<50% plaque burden) are important to avoid unnecessary vessel injury that may compromise the long term result. Distal landing zones within an area of residual plaque burden >50% or lipid-rich plaque are associated with stent-edge restenosis, and a landing zone within a lipid pool is associated with increased peri-procedural MI. IVUS and OCT can detect under expansion, mal apposition, geographic plaque miss, and stent edge dissection which are all associated with adverse PCI outcomes. OCT is superior at detecting mal apposition and stent edge dissections, and has particular utility in detecting plaque protrusion/thrombus which may indicate a mechanical or pharmacological problem.

Stent Expansion:

Both techniques can precisely measure stent expansion .Minimal stent area/distal reference lumen area >90% was associated with improved long-term hard clinical outcomes.

Stent Malapposition:

Malapposition refers to lack of contact of stent struts with the vessel wall and can co-exist with under expansion or occur independently. Malapposition can occur acutely post-procedure due to inadequate dilatation or acute stent recoil, or may develop later as a result of positive (outwards) remodelling of the vessel (late acquired malapposition), or resolution of thrombus. Acute stent mal apposition does not predict stent thrombosis in prospective studies. However, late acquired stent malapposition is associated with late and very late stent thrombosis. Extensive malapposition should be corrected where feasible.

Dissection:

Large edge dissections are markers of major adverse cardiovascular events, in particular those with lateral extension >60°, length >2mm, or involvement of deeper layers (media or adventitia). Dissection at the distal edge may be clinically more relevant than the proximal edge.

Haematoma:

Haematoma on imaging is an important indicator of dissection which can appear as stent edge stenosis on angiography, with a tendency to be misclassified as spasm or size mismatch. Progression of uncovered haematoma may lead to early stent thrombosis so consideration should be given to correcting this. More minor stent edge dissections and those without haematoma are unlikely to be clinically relevant and may not require correction..

Stent thrombosis:

OCT is the preferred technique for assessing stent thrombosis, however in large volumes of thrombus the attenuation of OCT signal may prevent strut and

deeper vessel wall visualisation. The main markers of early stent thrombosis are under expansion and edge dissection. Markers of very late stent thrombosis are under expansion, late acquired stent malapposition, and neoatherosclerosis.

Acute coronary syndrome:

Intra-coronary imaging can assist identification of the culprit lesion and understanding of the mechanism of acute coronary syndrome (ACS) where there is clinical uncertainty. Imaging can delineate luminal discontinuity, plaque disruption and thrombus which are the hallmarks of a culprit lesion. Confirmation of plaque erosion may have implications for treatment as the aetiology is distinct from plaque rupture. A 'definite' plaque erosion is confirmed on OCT where there is a fibrous lesion with no evidence of fibrous cap disruption and overlying luminal thrombus.

Vulnerable Plaque detection:

The unique capabilities of OCT for the assessment of a lipid pool, a thin fibrous cap , macrophage accumulations, and other detailed surface morphologies suggest OCT as a suitable research and clinical tool for vulnerable-plaque investigation.

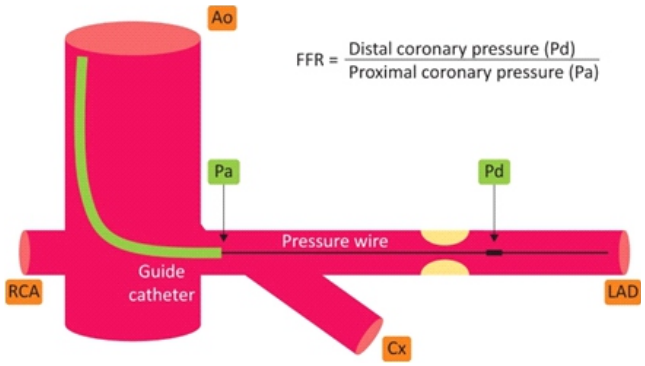
In OCT, Thin Cap Fibroatheroma (TCFA) is defined as an OCT-delineated lipid or necrotic core with an overlying fibrous cap where the minimum thickness of the fibrous cap is less than 65 micron .These plaques are vulnerable for plaque rupture / fissuring with clot formation, resulting into acute coronary syndrome.

Fractional Flow Reserve:

Fractional Flow Reserve, or FFR, is a guide wire-based procedure that can accurately measure blood pressure and flow through a specific part of the coronary artery. FFR is done through a guiding catheter at the time of a coronary angiogram. The special guide wire crosses the lesion and is able to measure the flow and pressure of the blood, after infusion of a hyperaemic agent, such as adenosine. Results are displayed on a special monitor along with the "FFR value". Studies have shown that an FFR value less than 0.75 or 0.80 corresponds to inducible ischemia, and most likely will require interventional treatment. Blockages that score above this threshold can be safely and adequately treated by medical therapy without the need for angioplasty. The measurement of Fractional Flow Reserve has been shown useful in assessing whether or not to perform angioplasty or stenting on "intermediate" blockages.

The point of opening up narrowings or blockages in the coronary arteries is to increase blood flow to the heart. But a number of studies have shown that if a "functional measurement", such as Fractional Flow Reserve, shows that the flow is not significantly obstructed, the blockage or lesion does not need to be revascularized (angioplasty) and the patient can be treated safely with medical therapy. A new physiologic measurement, called IFR or Instant wave-Free Ratio, was recently approved by the FDA for use in coronary stent guidance. IFR does not require the use of adenosine or otherhyperaemic agent.

Figure 5: Estimation of Fractional Flow Reserve



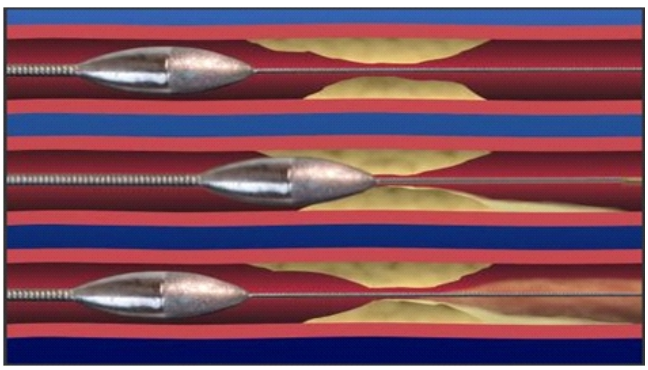
Rotational Atherectomy:

Coronary stenosis with circumferential or significant vessel calcification is rigid and frequently not dilatable with use of conventional balloon angioplasty. Often stent dilation and maximal vessel wall apposition are compromised in extensively calcified coronary lesions; stents deployed in heavily calcified vessels without atherectomy tend to thrombose, restenosis, and could cause stent fracture. Significant calcification remains a major limitation of balloon angioplasty as well as successful stent delivery to severely affected vessels.

In cases with heavily calcified lesions, high-pressure, non-compliant balloon inflations may still fail to dilate adequately and prepare a heavily calcified vessel for stent delivery. Atherectomy refers to the removal of the obstructing material, and in our case this is calcium. By removing significant calcification or modifying the calcified atherosclerotic plaque vessel wall compliance in calcified or fibrotic lesions is increased, and the lumen diameter gained from using this device will be much improved as compared to the use of simple balloon angioplasty. Rotational atherectomy is one of several ways to perform atherectomy in a coronary vessel. It is the most commonly used atherectomy device and removes atheromatous plaque by differential cutting, that is removing the inelastic calcified plaque with microscopic (20 to 50 μ) diamond chips embedded on the surface of a rapidly rotating (150,000 to 200,000 rpm) olive-shaped burr . Such abrasion generates 2 to 5-micrometer microparticles that propagate through the coronary microcirculation and are removed by the reticuloendothelial system. The burr travels over a specialized 0.009-inch guidewire and is available in diameters ranging from 1.25 to 2.50 mm. In the setting of severe calcification, smaller burr sizes should be used initially, followed by larger burrs in 0.25 to 0.50-mm increments up to 70% of the reference vessel diameter.

Rotational Atherectomy is most effective in calcified, inelastic lesions; it will not be effective in soft and thrombus containing lesions as present in acute myocardial infarction or saphenous vein graft lesions with heavy thrombotic burden where its use is contraindicated. One of the potentially disastrous complications of rotational atherectomy is the development of slow coronary flow or no flow phenomena. This is defined as a decrease or cessation of blood flow in the absence of an apparent occlusive dissection or spasm. Slow flow and coronary no flow phenomena are thought to occur as a result of distal microparticle embolization that occurs during rotational atherectomy. It is usually treated with intracoronary administration of verapamil, diltiazem, nicardipine, adenosine or nitroprusside. These medications have their effect at the microcirculation level.

Figure 6: Procedure of Rotational Atherectomy

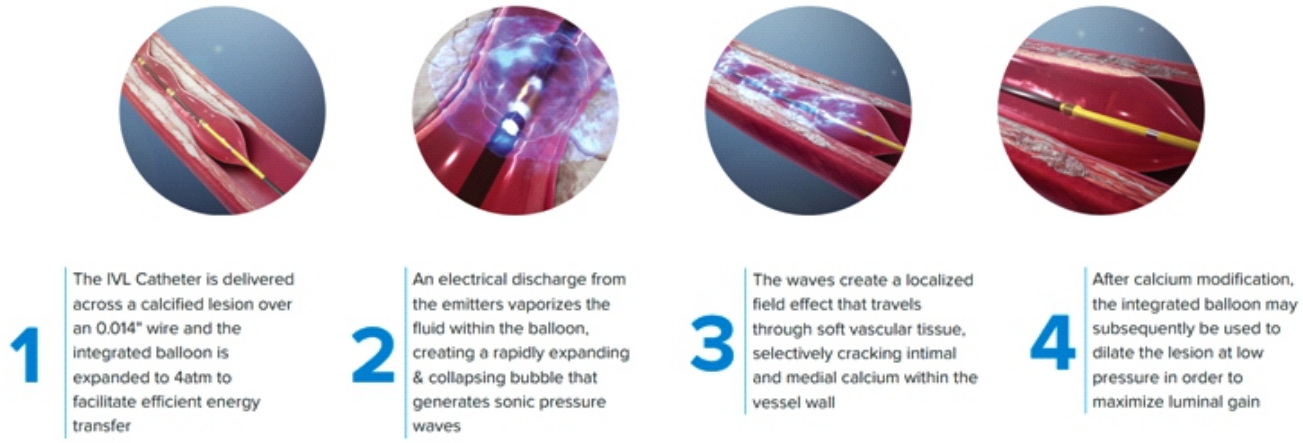


Intravascular Lithotripsy:

Intravascular lithotripsy (IVL) is a new vessel preparation technique for calcified coronary artery lesions that creates multiplane micro/macro fractures in the calcified plaque before stenting or allowing for an improved stent expansion. The Shockwave Medical Coronary IVL system (Shockwave Medical) consists of three components: a generator; a connector cable and a sterile catheter incorporating the lithotripsy emitters enclosed in a semi-compliant balloon . IVL emitters produce electric sparks that create vapour bubbles in the surrounding fluid medium in the integrated balloon. IVL produces low levels of electric energy, leading to the formation and rapid expansion of vapour bubbles, resulting in acoustic pressure waves that radiate circumferentially and transmurally in an unfocused manner. These acoustic pressure waves interact with high-density tissues such as calcium without affecting soft tissue. This interaction disrupts the calcium by creating micro-macro fractures, and increases vessel compliance.

The catheter, available in 2.5–4.0 mm diameters, is programmed to deliver 10 pulses in sequence at a frequency of 1 pulse/second for a maximum of 80 pulses per catheter. The low pressure inflation avoids the barotraumatic vessel wall injuries related to high pressure inflation.The role of the fluid-filled integrated balloon is to facilitate efficient transmission of shockwave energy to vascular tissue by several

Figure 7: Procedural steps to perform Shockwave IVL



mechanisms: creation of the spark which requires ions, adequate interface with similar acoustic impedances, avoiding thermal injury, and shielding the emitters from direct contact with the arterial wall. Compared with atherectomy, the IVL acoustic burst penetrates deeper into the arterial wall to generate multiplane longitudinal fractures without affecting healthy tissue.

Intravascular Lithotripsy Therapy Application:

The catheter diameter should be selected at a 1:1 ratio relative to the target-vessel diameter and inflated at a sub-nominal pressure (4 atm). Proper apposition of the catheter to the arterial wall is necessary for an adequate fluid/tissue interface to optimise acoustic energy transfer. As noted above, there are several mechanisms responsible for the disruption; in addition to spallation squeezing, cavitation and plaque fatigue that all play a role, as detailed in a recent review. The estimated peak pressure of the wave is 50 atm. Notably, the wave and not the balloon generates the disruptive force. This has several advantages .It allows low-pressure balloon inflation which reduces the risk of barotrauma, vascular dissection and perforation. One catheter can deliver a maximum of 80 pulses.

Robotic systems for PCI:

CorPath GRX Robotic System (Corindus, a Siemens HealthineersCompany , USA) included two primary components: a shielded interventional cockpit and a bedside unit. The interventional console contained high-definition monitors, from which the operator could view angiographic images and hemodynamic information, the control console, which included touch screens and two joysticks to provide commands to coronary devices, and an X-ray foot pedal. The bedside unit consisted of an articulating arm, the robotic drive, and disposable cassette; guidewires and other devices were loaded into the latter. After an introducer sheath was manually inserted into the access artery and guide catheters , rapid-exchange devices have been loaded into the robotic cassette, the operating physician could control guide catheters , guidewires, balloon/stent delivery systems, and other devices with a joystick and rotate devices using touch-screen controls to perform robotic PCI (r-PCI). The operator could robotically advance devices in millimetre increments. The system also permitted sub-millimetre measurement of lesions.

Remote robotic PCI:

Remote robotic PCI had been conducted from a 32.2 kilometres distance in India. The CorPath GRX interventional console was located at Akshardham, Gandhinagar, from where PCI was performed on five patients who were at the Apex Heart Institute, using internet through which cath lab & CorPath GRX interventional console were connected. Cameras in the cath lab permitted to view the patient bedside from the interventional console.

Advantages of robotic PCI:

By placing the operator away from the patient and the radiation source, it has been shown to reduce the radiation exposure for both the cardiologists and the catheterization laboratory staff with an expected decrease in orthopaedic problems, premature cataract and malignancy. Patient has also benefit of less radiation & less contrast .Precise measurements of lesion length, precise movement of PTCA wires and more stable deployment of angioplasty balloons and stents. Looming on the horizon is the possibility to perform remote r-PCI, which could open this life-saving treatment to patients in underprivileged areas.

Further Reading:

1. Grossman and Baims Cardiac Catheterization Angiography and Intervention Textbook.
2. Textbook of Interventional Cardiology by Eric J. Topol MD Paul S. Teirstein MD
3. Braunwald's Heart Disease – Textbook
4. Patel T M, Shah S C, Pancholy SB. Long Distance Tele-Robotic-Assisted Percutaneous Coronary Intervention: A Report of First-in-Human Experience. E Clinical Medicine. 2019 Sep 3;14:53-58. doi: 10.1016/j.eclinm.2019.07.017. eCollection 2019 Sep. PMID: 3170940
5. Patel T M, Shah S C, Soni Y Y, Radadiya R C, Patel G A, Tiwari PO, Pancholy S B. Comparison of Robotic Percutaneous Coronary Intervention With Traditional Percutaneous Coronary Intervention: A Propensity Score-Matched Analysis of a Large Cohort. Circ Cardiovasc Interv. 2020 May; 13(5):e008888. doi: 10.1161/CIRCINTERVENTIONS.119.008888. Epub 2020 May 14.PMID: 32406263
6. Hill JM, et al. Intravascular Lithotripsy for Treatment of Severely Calcified Coronary Artery Disease. J Am Coll Cardiol. 2020. PMID: 33069849
7. Gupta T, et al. Rotational Atherectomy: A Contemporary Appraisal. Interv Cardiol. 2019. PMID: 31867066