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Laser Angioplasty, Principles of Lasers, Procedure, Benefits of Laser Angioplasty, Technique and Treatment

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Abstract:

Laser stands for light amplified stimulated emission of radiation. It involves generating high-energy or high-intensity beams of light that can be used for various purposes. They find application in a wide-range of industry processes. In medicine, laser beams can be used to ablate or destroy abnormal tissue in any part of the body. There are various ablation techniques used in various treatments today such as thermal (uses heat), RF (radio-frequency waves), electric (shocks given at site) and powerful drugs injected into the tissue. Laser is also one such ablation technique. It's widely preferred as it causes less of thermal damage from heat-based ablation techniques and less of trauma to surrounding tissue from the other techniques mentioned above. In fact, depending on the laser technology used, one can have 'cold lasers' which do not create any heat. There are various laser technologies and techniques used for angioplasty, the most common being Excimer Laser. Excimer lasers use high-pressure, pulsed-gas laser techniques. These create intense ultraviolet (UV) light that has a high peak-power at several useful wavelengths, which makes it highly efficient. The source of the laser emission (lasing technique) is a fast electrical discharge and the lasing medium is a high-pressure mixture of a rare gas like Argon and a halogen gas. The procedure is called Excimer Coronary Laser Atherectomy (ECLA).

Keywords: Laser Angioplasty, Principles of Lasers, Laser Angioplasty

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Introduction

Laser coronary angioplasty was introduced in the early 1980s, mainly to manage balloon-untreatable coronary artery lesions.[1] However, due to the huge cost of the laser system, disappointing results, and complications associated with the continuous waveform of argon and Nd: YAG lasers available at that time, it did not gain popularity.[2][3][4][5] Later in that decade, excimer lasers were developed. Excimer, an acronym for the excited dimer, produces ultraviolet laser energy pulsatile and short wavelength. The pulsatile nature ensured the precise ablation of plaque tissue with insignificant thermal injury to the vessel.[6] The short wavelength through less depth of penetration, compared to the infra-red range of argon and Nd: YAG lasers, also limited collateral damage. Both of these properties of excimer lasers, in addition to improvement in catheter design, proper selection of patients, and development of safety protocols, played a crucial role in the reintroduction of laser technology in routine practice.[7][8][9] [10] In 1988, the first successful excimer laser coronary angioplasty (ELCA) was performed on a human subject at the Cedar Sinai Medical Center, Los Angeles.[11] Angioplasty is a procedure that creates more space inside an artery that has plaque built up inside it. Your healthcare provider uses a tiny balloon to force plaque against the artery walls so blood can get through your artery. Often, they also place a stent or tube inside the newly opened space to keep it open.

What is angioplasty?

Angioplasty, also called balloon angioplasty, is a procedure that opens arteries to let blood go through more easily. Healthcare providers use this minimally invasive procedure in tight spots in arteries where plaque makes the space inside an artery too narrow or blocks it.

Who needs to have angioplasty?

People who have coronary artery disease or a heart attack may need to have coronary angioplasty. Angioplasty is also used in other parts of the body that have narrow or blocked arteries, such as your neck, arms and legs, kidneys and pelvis. Angioplasty allows more blood to get through an artery that's too narrow or blocked with plaque. This means the organ that artery reaches will get a better supply of blood after

How common is angioplasty?

Coronary angioplasty is one of America's most common procedures.

Overview about Angioplasty

Angioplasty with or without stenting is a nonsurgical procedure used to open clogged or narrow coronary arteries due to underlying atherosclerosis. The procedure involves introducing an inflatable balloon-tipped catheter through the skin in extremities and inflating the balloon once it traverses the stenosed arterial site. It presses the intraluminal plaque of atherosclerosis against the arterial wall and widens the luminal diameter.[12] Thereby it normalizes the blood flow to the myocardium and achieves the goal of angioplasty or percutaneous coronary intervention (PCI) by alleviating the chest pain. The PCI concept was introduced 40 years ago with the introduction of "plain old balloon angioplasty" (POBA) without stenting. In the mid-1980s, POBA use was limited because of an early complication of vascular recoil property and restenosis after balloon deflation which led to the invention of bare metal stents (BMS).[13] During the procedure, professionals use a tube-like metallic meshwork, and its scaffolding properties counteract vascular recoil property, thereby avoiding the early restenosis of POBA due to vascular recoil. However, long-term, in situ BMS, can induce wall stress, endothelial discontinuity, and permanent presence of the metallic foreign body in arteries leading to inflammation with fibrin deposition and promoting myofibroblast migration which gives rise to in-stent restenosis (IRS) due to a mechanism of neointimal hyperplasia.[14-19] This issue led to the development of drug-eluting stents (DES). DES technology uses a coating of an antiproliferative drug on top of the metallic structure of stents with the benefit of causing less neointimal hyperplasia and stent restenosis as compared with BMS. Late stent thrombosis is also associated with DES due to impaired arterial healing with a lack if re-endothelialization and fibrin deposition due to underlying chronic inflammation more commonly in first-generation DES. Second-generation DES has an extra coating of biocompatible polymer with better endothelial healing. Cobalt-chromium everolimus-eluting stents (second-generation DES) is safer than paclitaxel-eluting stent (first-generation DES) and BMS due to better vascular healing and re-endothelialization of stent struts as evidenced in an animal model. Recent studies show that second-generation DES with biodegradable polymer coating proved to have more efficacy in reducing target-vessel revascularization (TVR), target-lesion revascularization (TLR), in-stent late loss (ISLL), and late-stent thrombosis as compared to BMS. Studies also showed the higher efficacy of DES in complex lesion as compared to BMS.[20-24] The latest novel agent bioresorbable scaffolds system (BRS) maintains cyclic pulsatility with fewer chances of vascular remodeling and IRS due to the removal of metallic meshwork in stents platform which serves as triggering agent for late-onset complications such as IRS and stent thrombosis. However, BRS requires best implantation techniques and struts size. The limitation to BRS is struts thickness because in early post-procedural period restenosis is due to vascular recoil property which is counteracted by a metallic scaffold of BMS and DES. If struts size of BRS is reduced, vascular recoil cannot be antagonized adequately. Second-generation BRS has achieved this property somehow. After a time, BRS disappears entirely due to resorption which can be followed up with intravascular ultrasound (IVUS). IVUS and optical coherence tomography (OCT) can be used to install BRS appropriately. [25]There is not much data available on the safety of BRS, but the idea of the metal-free stent that helped develop BRS is criticized because scaffold thrombosis has been reported. Recently, Brown et al. suggested that during BRS implantation, both pre-dilatation and post-dilatation with pressure over 20 ATM is mandatory for preventing acute vascular recoil, and better scaffold expansion, and lower rates of scaffold thrombosis which is best predicted by minimal luminal area on IVUS.[28]

Anatomy and Physiology

Light amplification by stimulated emission of radiation, or LASER, in short, refers to the creation of high-energy, single-wavelength light beam from a gas mixture. For excimer lasers specifically, a mixture of xenon gas and diluted hydrogen chloride solution is used. After a high-voltage electrical discharge is passed through this gas mixture, excited dimers or excimers, xenon chloride (XeCl), are produced.[12] These dimer molecules subsequently release photons with an ultraviolet (UV) wavelength. Mirror systems are then utilized to amplify this process and deliver the resulting high-energy laser beam to target tissues. On contact with tissue, this laser beam then modifies it via three major mechanisms, as detailed below[29]:

1. Photochemical: Breakage of molecular bonds.

2. Photothermal: Vibration of molecular bonds generates heat and leads to the vaporization of intracellular water, causing bubble formation. This ultimately leads to cell rupture.

3. Photokinetic/photomechanical: The vapor bubbles generated secondary to the photothermal mechanism coalesce to form larger bubbles, further breaking down plaque tissue.

The breakdown products generated from these biochemical processes are small enough (usually < 10 µm) to be rapidly cleared by the reticuloendothelial system of the body, hence preventing distal embolization.[30]

Principles of lasers

The term “laser” is an acronym of “light amplification by stimulated emission of radiation”. Lasers consist of an excitation source (pump) and an optical resonator (a cavity or a chamber), with mirrors at each end. The optical resonator contains an active medium. The active medium defines the wavelength emitted by the laser, and gives the name to specific types of laser. This medium can be solid (e.g., neodymium yttrium aluminum garnet in Nd:YAG lasers, ruby crystal in ruby lasers), liquid (in dye lasers) or gas (argon ion in argon lasers, carbon dioxide in CO2 lasers, and dimer of a halogen and inert gas in excimer lasers). [31] The excitation source can be a flash lamp, electric current or another laser. When a certain quantum of energy is pumped from the source into the resonator, the atoms of the active medium become excited. After returning to their ground state, they release energy in the form of photons of light. This is called spontaneous emission of radiation, from which only a small amount of light energy is gained. Lasers work on the principle of stimulated emission of radiation, where photons within the optical resonator are reflected between mirrors and collide with atoms of the active medium, which causes them to reach an excited state. Much more light energy in the form of photons is gained from this method than by spontaneous emission.[32] One of the mirrors of the optical resonator is partially transparent, allowing the photons to exit the cavity. In contrast to nonlaser light, laser light has three unique characteristics: monochromacity, coherence, and collimation. Monochromacity is the emission of light of only one wavelength, or a narrow band of wavelengths. The coherence of laser light is based on stimulated emission, meaning that the light waves are parallel. Collimation can be defined as a narrow beam diameter with no divergence.[33] Hence, laser light does not lose energy, even after covering a large distance. Lasers can operate in either a continuous mode or in a pulsed mode, which generates short pulses (microsecond, nanosecond, or picosecond duration). Lasers emit light with very high intensity. In medicine, they can be used for various applications, including cutting, coagulation and ablation of tissues, among others.[34]

Procedure of Laser Angioplasty

The first step in the treatment process is to be examined by an interventional cardiologist or vascular specialist, who will determine the exact nature of the problem and plan a course of treatment based on the patient's health, including any other medical conditions that may affect the treatment outcome. Once the doctor determines that you are a good candidate for laser angioplasty, the procedure can be scheduled.[35]

1. You will have general anaesthesia.
2. The interventionist will cut a small incision in your groyne.
3. Using real-time X-ray pictures, a wire will be placed into the femoral artery and moved to the area where fatty deposits are preventing blood flow.
4. Once the blocked site has been determined, the wire will serve as a guide for a tube that will be implanted and moved to the blockage.
5. A laser will be placed into the tube and directed to the blockage location.
6. Once the laser is in place, it will be used to remove fatty deposits from the arterial walls. The X-ray images, combined with the application of contrast dyes, will allow the operator to observe the procedure as it occurs.
7. Once the plaque has been vaporised, the laser, tube, and wire will be removed, and the groyne incision will be closed.
8. You will then be taken to a rest area, and depending on your overall physical health and other considerations, you may be able to return home the following day.[36]

Benefits of Laser Angioplasty

1. Laser angioplasty removes the necessity for coronary artery bypass graft surgery, which means:
2. Less discomfort to the patient
3. The procedure is much faster
4. The hospital stays and overall recovery time is greatly reduced
5. You will be able to return to an active life in a short period[37]

Recovery of Laser Angioplasty

When the angioplasty is completed, the cardiologist removes the catheters & bandages. Soreness, bruising, and potentially bleeding are frequent at the site where catheters enter the body. Typically, a person will recover in the hospital for a few hours or overnight before returning home. They should not drive since they may still have sedatives in their system. [38] They will also be restricted from lifting for roughly a week later. People can usually return to work within a week, but their doctor will advise them on how active they should be and when. The follow-up visit following angioplasty is an important part of the treatment. The doctor will assess the patient's recovery, change medications as necessary, and create an ongoing treatment plan for their cardiovascular health.[39]

Preparation

Before the initiation and throughout the procedure's length, all staff present inside the room, and the patient is required to wear tinted eye goggles to protect against corneal or retinal damage by the UV laser. The procedure should be done in a room with tinted windows and locked doors, and unauthorized access prohibited.[40]

Once turned on, the excimer laser generator requires around 5 minutes of start-up time. An appropriate catheter is then selected, and its central guidewire lumen flushed. General concepts to consider when choosing a catheter are a) its size should not exceed two-thirds the diameter of the target vessel, and b) it should be able to deliver the intensity of energy needed to treat the target lesion based on the lesion's severity and consistency. Concentric catheters are most commonly utilized; however, eccentric catheters are recommended for in-stent restenosis, bifurcation lesions, and eccentric lesions since the laser beam can be rotated towards the target lesion using a torque knob.[41] The proximal catheter end is then attached to the laser unit and its distal end calibrated. Calibration is an automated process, which is achieved by pointing the catheter tip towards the energy detector on the main laser unit and activating the laser. Subsequently, the laser unit enters into a standby mode.[42]

Technique or Treatment

Astandard 0.014-inch PCI guidewire is typically advanced till it crosses the target lesion, after which the catheter is passed over it till its tip is in direct contact with the lesion. This is a major advantage of excimer laser coronary angioplasty (ELCA) over other atherectomy techniques, which usually require dedicated guidewires. The desired fluence, pulse rate, and pulse width settings are then selected. By default, the system calibrates at 45 mJ/mm^2 at 25 Hz, with a pulse width of 135 ns. If resistance is encountered with these default settings, they can be increased in a stepwise fashion. This should be undertaken slowly since higher energies and frequencies can be associated with a higher chance of dissection and perforation complications.[43] The manufacturer recommends that fluence be increased first rather than the frequency.

A saline flush protocol is then employed before initiation of lasing. The concept behind this step is that both blood and contrast media consist of macromolecules, including proteins, that can absorb the bulk of the laser energy and lead to the formation of insoluble gas bubbles. This also increases the risk of complications such as intimal dissection and perforation.[44] On the other hand, Saline provides a clear interface for the laser energy to be delivered directly to the target lesion. To perform the saline flush protocol, a 1 L bag of 0.9% normal saline is attached to one of the triple manifold ports via a three-way stopcock. The contrast syringe is replaced with a clean 20 cc syringe used for flushing contrast and blood from the entire system. Thereafter, the operator infuses a 5 to 10 cc bolus of normal saline through the guiding catheter, with the initiation of lasing immediately afterward. This is accompanied by a continuous infusion of normal saline at 1 to 3 mL/s throughout the duration of laser activation. The system is programmed to activate for 5 to 10 seconds, after which goes into a 5 to 10 second rest period. An audible alert will mark the end of this rest period, at which point the next lasing sequence can be commenced. This potentially helps avoid complications from prolonged laser energy exposure to the vessel.[45] It is also recommended that the catheter be advanced at a slow rate (<1 mm/s) within the vessel lumen to allow the plaque tissue sufficient time to adequately absorb the light energy and result in optimal vaporization and debulking.[46]

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