

Part 1: Balloon and principle of Balloon Angioplasty in Peripheral Arterial Disease (PAD)



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Abstract

Balloon angioplasty has been one of the modalities of choice in the treatment of peripheral artery disease, or PAD, for many decades. Balloon technology was developed not only in the form of designs and materials but also as a new application with the introduction of cutting, cryo, or drug eluted principles. Many clinical trials have been studied and have changed clinical guidelines in the treatment of peripheral arterial disease. This content of this article includes the principle of balloon angioplasty in atherosclerosis disease, types of balloon, materials, basic balloon selection with a focus on peripheral artery disease alone.

Keywords: angioplasty, peripheral artery disease, balloon

Charles T. Dotter was the first to describe balloon angioplasty and Melvin P. Judkins published the angioplasty technique using a Teflon dilating catheter in the magazine *Circulation* in 1964.¹ This technique was developed by Andreas Gruentzig to use in the clinic, especially in the coronary artery, and was published in *South Germany* in 1974. This marked an important change in the use of balloons in angioplasty and in organs which is still practiced today.

Anatomic layers in arterial wall

The innermost layer of the artery is called the Intima. It contains endothelial cells which have only one layer on the basement membrane and are inserted by a connective tissue around the subendothelial area that connects to the media layer. This seam is called the internal elastic lamina, or IEL. The media layer mostly contains smooth muscle cells along with some collagen fibers and elastic fibers. The adjoining media layer, before the outermost layer is called Adventitia, and is the joint called the external elastic lamina, or EEL. In the adventitia layer some connective tissues, especially elastic fibers, distribute loosely. In this layer, there are both vasa vasorum, nerve plexus and lymphatic vessels. Vasa vasorum provide nourishment to the media layer.

There are three types of arteries; arteriole, muscular arteries and elastic arteries. The aorta and the iliac are the largest elastic arteries in the body. These contain the most elastic fibers while muscular arteries such as the coronary artery, the arms, legs and abdominal arteries contain more smooth muscles than elastic fibers so they control the circulation and blood pressure. Arterioles, which are the smallest arteries, act as a controller of physiology and secrete substances to regulate the operation of coronary endothelial cells like endothelin-derived relaxing factor, prostacyclin, tissue plasminogen activator, heparin sulphate, and prostanoids.

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Pathology of the arterial wall

General lesions in arteries presenting with atherosclerotic symptoms will have fibro-fatty plaques in the intima layer. The media layer will also be thinner and will enter a decline leading to fibrosis.

There are 2 types of plaques; fibrous plaques and arteromatous plaques. Fibrous plaques are found in abundance in the intima layer. They are later replaced by smooth muscle cells and connective muscle cells. The bold area that extends into the blood vessels is called the fibrous cap of arteromatous plaques and mostly contain cholesterol. Both types of plaques can cause stenosis or obstruction in the blood vessels. If there is a lot of fat and high cholesterol, and plaques in the fibrous cap, it can split, break and become ulcerated which can then cause thrombus. When this occurs in small blood vessels, it causes an obstruction. If this happens to the larger blood vessels, the lesions might have fibrosis or might be calcified and that can lead to chronic artery stenosis (See Figure 1).

Mechanism and Pathology of Balloon Angioplasty²

Many theories try to explain the mechanism and pathology of balloon angioplasty by studying laboratory animals, and cadaveric and intravascular ultrasound (IVUS) studies.

In the early days, there was a belief that plaques compression or plaques displacement caused the remodeling of the endothelial. This theory was refuted when the pathological examination found that there was no change in the interior features of plaques. However, the result of the study using IVUS in measuring the size and the volume of plaques after balloon angioplasty found that plaques were squeezed out of the lesions to the top and the bottom of the lesions. This proved the existence of plaques compression and displacement but this is nonetheless not the main mechanism.

The most widely accepted theories nowadays are that plaques fracture and there is localized wall dissection. After balloon angioplasty, the plaques will split and break especially the thinnest area (in the case of eccentric plaques). Moreover, the tearing of the artery is also found in the intima layer and in some parts of the media layer around the IEL line, both circumferential and longitudinal. The tearing of the artery especially in the media layer causes a dissection flap which can be seen sometimes from the vascular imaging after balloon angioplasty. These are shown by the thin stripes in the longitudinal vessels or the stain of contrast media around the area that has the intimal flap (Figure 2,3,4).

Another mechanism that explains the result of balloon angioplasty is the arterial wall stretching of the media and

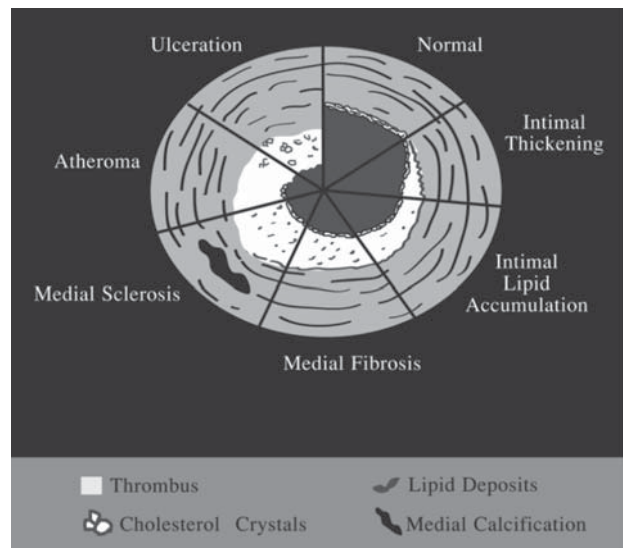


Figure 1: Diagram shows pathophysiology of artery plaques.

adventitia layers. From observation, it is found that there is a stretching of the smooth muscle cells and a necrosis of some smooth muscle cells. Studying the IVUS, it can be seen that arterial stretching happens to 25% of patients after having balloon angioplasty.³

Balloon

Rule of Laplace $T = P \times R$

T= Tension or pressure to the artery wall

P= Pressure inside the balloon

R= Radius of the balloon used

An increase in tension or pressure to the artery can be achieved by adding inflation pressure into the balloon or by increasing the diameter of the balloon.

The types of balloon are non-compliant, compliant and special.

A non-compliant type of balloon is used in balloon angioplasty. It means that, when the balloon is enlarged to its limit, it cannot be expanded no matter how much more pressure is added inside. Therefore, it is more suitable to be used in angioplasty than a compliant balloon. The size of a compliant balloon changes according to the pressure applied inside it. The pressure is higher in the area that has no obstruction while the stenosis area has lower pressure. This kind of balloon is mostly used with a balloon expandable stent or the balloon that is used in endovascular aortic repair (EVAR).

New types of balloon are made from different kinds of materials, such as polyvinyl chloride (PVC), polyethylene

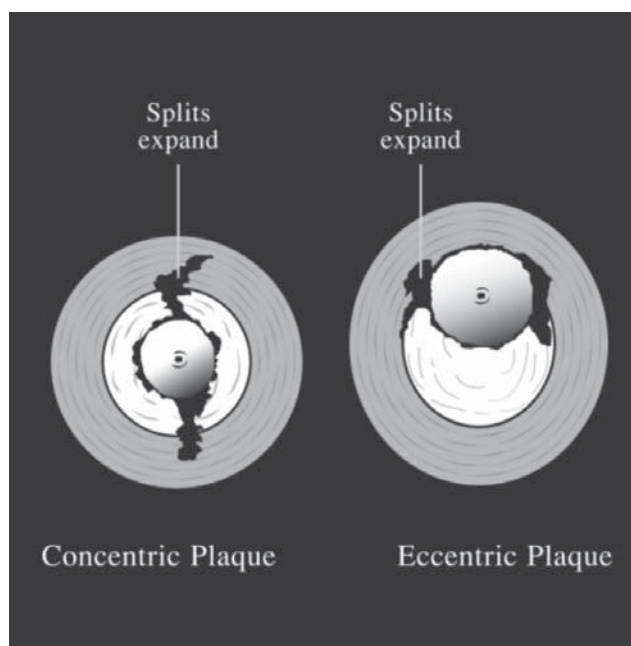


Figure 2: The demonstrated mechanism of balloon angioplasty on plaque.

(PE), polyethylene terephthalate (PET), polyolefin copolymers (POC), nylon derivatives (N), nylon-reinforced polyurethane (PU) (which is the most popular material used), and co-extruded copolymers (CP).

Non-compliant balloons are PET, PU and CP while PVC and POC are found in highly compliant balloons. The balloons that withstand High Burst Pressure (HBP) are PET, N, PU and CP. PU, CP and N can resist a puncture from sharp calcium or from the wire of a stent. Hydrophilic polymers or silicone are popularly used because of their coating effect, as this makes the balloon slippery and easier to put through the stenosis area.

The design of the balloon used nowadays is mostly true multiple-lumen (see Figure 5) which is the type of balloon that is used with guide wires sized 0.035 inch, 0.018 inch, and 0.014 inch. The same hole is used to inflate or deflate the balloon. Another type of balloon that is popularly used in expanding coronary arteries and small blood vessels is called the monorail balloon (see Figure 6). This type of balloon is special as its hole is located in the catheter that allows the guide wire to emerge from the side. With this balloon, a normal size guide wire can be used, and there is no need to change to the longer sized guide wire (such as in the case of the co-axial balloon). The disadvantage of using this kind of balloon is that it is impossible to inject the contrast media through the tip of the catheter and it might be more difficult to put the balloon through the stenosis areas.

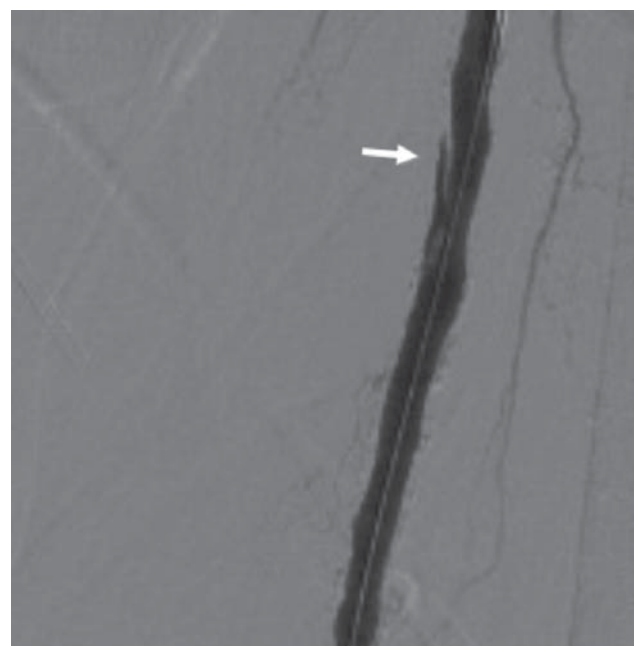


Figure 3: The right femoral artery shows an intimal flap after balloon angioplasty.

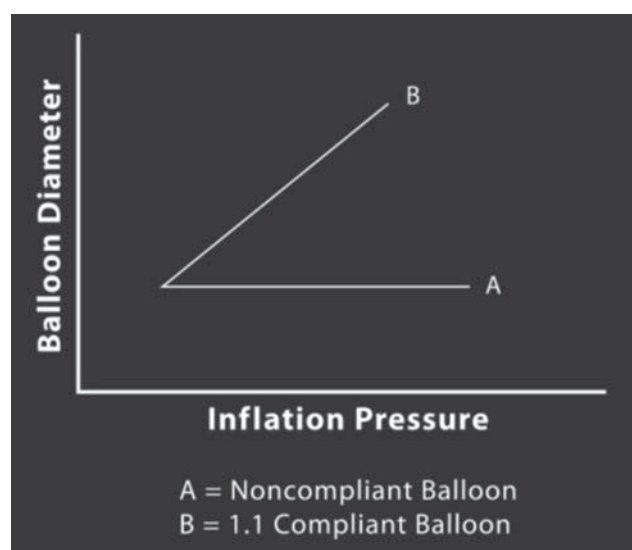


Figure 4: Diagram shows the rule of Laplace.

To select the appropriate balloon, the following factors need to be considered:

1. The size of the guide wire, 0.035, 0.018, or 0.014 inch.
2. The size of the introducing sheath that the balloon that it will be going through.
3. Type of balloon (co-axial or monorail).
4. When the co-axial balloon is used, the length of the catheter must be long enough. For instance, in the case of expanding the right side arteries, the length of the balloon catheter used is 135 cm, the catheter length must be 300 cm. when accessing the introducing sheath through the left groin.

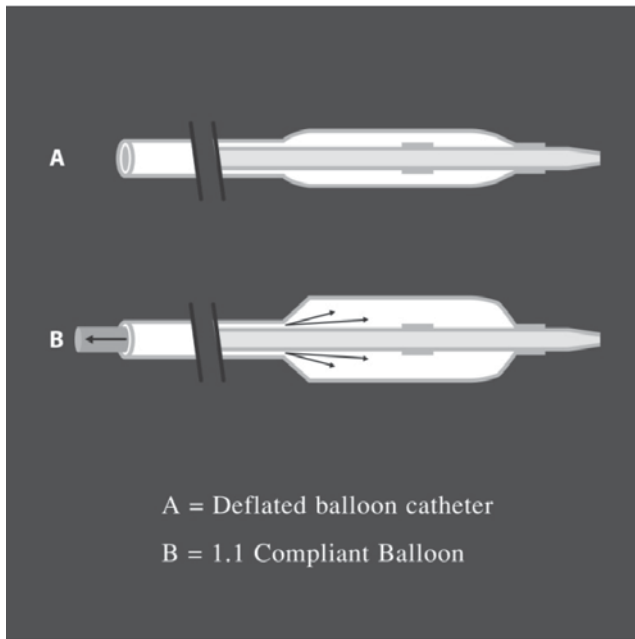


Figure 5: Diagram of true multiple-lumen balloons.

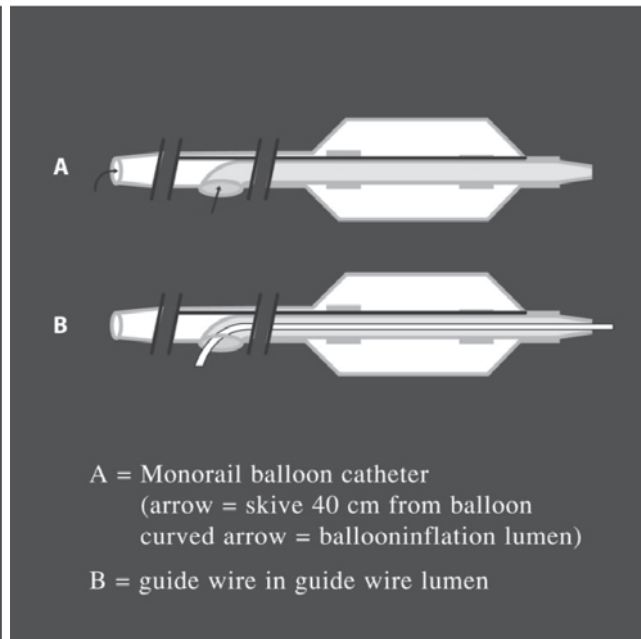


Figure 6: Diagram of monorail balloons.

5. The diameter and the length of the balloon are determined based on the size of the stenosis area.
6. Nominal pressure or suitable pressure in expanding the balloon must be known.
7. Burst pressure or the highest pressure in expanding the balloon must be known.
8. In the low profile balloon, the size of the diameter of the catheter in the balloon section is smaller than the diameter of the other catheters and that makes it easier to go through the stenosis areas.
9. The higher deflation rate, the faster it can flatten the balloon and that can make the procedure quicker to complete.
10. In general, the contrast media will be mixed in a proportion of 3 with the saline in the inflator used to expand the balloon. By doing so, the balloon can be seen in the fluoroscope screen. Moreover, it makes the balloon get flat easier and not too viscous for using the same balloon for the next angioplasties.

Special types of Balloons

1. Cutting balloons have long been used to expand the coronary artery with in-stent stenosis and have been applied more frequently to the peripheral arterial, especially in treating the stenosis area of an AV graft or AV fistula. This type of balloon is designed with 3-4 microsurgical blades or atherotomes designed to cut the lesions when the balloon is dilated. The blade will be placed only 0.127 mm. from the balloon. A cutting balloon makes a longitudinal incision to create a force on the vessel walls which is hard or high tension.

There are few effects on normal vessel walls and thus the flow-limiting dissection is reduced. This is one of the principles of the focal pressure balloon used more frequently nowadays.

2. Cryotherapy balloons are a blend of balloon mechanisms employed with the use of cold caused by nitrous oxide. A temperature of -10°C , has been found to reduce plaque inflammation post-angioplasty and as a result the elastic recoil and the growth of smooth muscle cells decreases. The likelihood of having neo-intimal hyperplasia is also reduced. However, the treatment results found that, compared with a normal type balloon, there are still some disadvantages for lesions that are very high in calcium. From the study of in-stent stenosis and in stenosis of an AV graft, it was found that the use of a cryotherapy balloon to expand the femoral arteries after using a nitinol stent (post-dilated balloon angioplasty) in patients with diabetes, can help reduce the chance of re-stenosis of the vessels more so than with a normal type balloon.⁴
3. Focal pressure balloons employ angioplasty by using the force exerted on each layer of the artery walls in a longitudinal position, to be able to enlarge the arteries to the same size as when using a normal type balloon. It decreases the unnecessary effects to the normal vessel wall, and reduces the chance of dissection and future stenosis caused by intimal hyperplasia. In designing the balloon, a nitinol coil will be cut in a stripe or spiral shape on a semi-compliant balloon. This kind of balloon is used more and more in many countries (but not to the same degree in Thailand).

4. The drug-eluting stent was in fact developed before the drug-eluting balloon but the problem of neo-intimal hyperplasia in the strut of the stent was still observed. The advantage of coating the drug on the surface of the balloon is that the drug can enter into direct contact with the blood vessel walls and there are more contact areas than with a stent. But the disadvantage is that the coating drug only stays on the blood vessel walls for a short period of time. Palitaxel is mostly used in coating as it has the effect of stopping the formation of microtubules in the smooth muscle cells of vessel walls. It can also stop some growth factors that contribute to the movement of smooth muscle cells to the intima layer. Palitaxel contains lipophilic that prevents the substance from getting into the blood vessel wall. Therefore, a mixture of hydrophilic substances, such as iopromide or urea, is needed to make the coating stay longer and more effectively on the blood vessel walls. In comparing the use of normal type balloon to cure stenosis of the femoropopliteal arteries, the study found that a drug-eluting balloon helps to reduce the chance of re-stenosis in both the short and long term when follow-up occurs over the period of 5 years.⁵
2. In the case of a tandem lesion, the selection of the lesion to be treated first is based on several reasons. If there is a lot of stenosis on proximal blood vessels, it is necessary to get expand this first before doing the distal blood vessel. But if there is only partial stenosis on the proximal area, the distal area should be performed first to avoid any disturbance from the proximal blood vessel. But be aware that, during the expansion of the distal blood vessel, the equipment including the balloon catheter will not produce any of the blood clots in the lesion of the proximal blood vessel. Heparin should be given in adequate quantities.
3. The length of the balloon should be as short as possible to cover the lesions. The length should not be longer than the balloon because that can cause unnecessary damage to the normal blood vessel wall which can happen by chance during dissection. However, if the balloon chosen is too short, especially in the stenosis lesions, the balloon may be affected by sliding skids. In the case of leg artery lesions, however, involving both the femoral artery and the infrapopliteal artery, the femoral artery will normally be treated first followed by the artery below knee level.

Principle and basic technique of balloon angioplasty

(Techniques in detail will be presented in Part 2)

1. Balloon angioplasty is prohibited or should be used with caution in the following cases:
 - 1.1. The stenosis of the arteries is attached to the aneurysm due to the risk of rupture of the vessels.
 - 1.2. Atherosclerotic plaque that is too big or is polypoid and located too far from the blood vessel wall has a significant chance of breaking and blocking the distal embolization.
 - 1.3. The stenosis of the arteries that happens all over the body or the stenosis that is very long.
 - 1.4. Blood vessels that are extended by balloon several times or has just extended recently. If possible, allow 3 months for the healing of pathology before the next angioplasty.
 - 1.5. Blood vessels that have been used to radiate arteries or veins of the patients who have had radiation around the iliac area or blood vessel that is badly infected in itself or its surrounding organs (similar to the case of a patient whose aorta was infected or in cases of an abdominal aortic of a patient with pancreatitis.)
4. In choosing the diameter of the balloon, the size of diameter should be larger than the diameter of the blood vessel by about 10-15% measuring the blood vessel from the vascular imaging using the available tools in the new DSA or by using the sizing catheter. The balloon with a small diameter will be applied first to give way to the larger diameter balloon catheter or stent's catheter to go through the stenosis. The techniques of balloon angioplasty are more varied at the present time.
5. The pressure used in an inflator balloon angioplasty of arteries is normally around 5-10atm and around 8-24atm in case of veins or artificial veins due to the high chance of recoil (refer above on how to choose the appropriate balloon for each procedure). If the balloon used is too big or if there is too much pressure inside the balloon, it may cause a rupture of the arteries. Should a balloon break, this can sometimes cause the tearing of blood vessels (although the tearing can also happen before the balloon breaks).⁶

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