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Management of coronary artery perforation

Ahmed Abdalwahab [a,b], Mohamed Farag [a,c], Emmanouil S. Brilakis [d], Alfredo R. Galassi [e], Mohaned Egred [a,f,*]

[a] Department of Cardiology, Freeman Hospital, Newcastle upon Tyne, UK
[b] Cardiovascular Medicine Department, Faculty of Medicine, Tanta University, Egypt
[c] School of Life and Medical Sciences, University of Hertfordshire, Hertfordshire, UK
[d] Minneapolis Heart Institute Foundation, Minneapolis, MN, USA
[e] University of Palermo, Palermo, Sicily, Italy
[f] Translational and Clinical Research Institute, Newcastle University, Newcastle upon Tyne, UK

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ABSTRACT

Coronary artery perforation (CAP) is a rare but potentially life-threatening complication of percutaneous coronary intervention (PCI), however if recognized and managed promptly, its adverse consequences can be minimized. Risk factors for CAP include the use of advanced PCI technique (such as atherectomy and chronic total occlusion interventions) and treatment of severely calcified lesions. There are 3 major types of CAP depending on location: (a) large vessel perforation, (b) distal vessel perforation, and (c) collateral perforation.
Large vessel perforation is usually treated with implantation of a covered stent, whereas distal and collateral vessel perforations are usually treated with coil or fat embolization. In this article we provide a state-of-the-art overview of the contemporary management of CAP.

Contents

1. Introduction

Coronary artery perforation (CAP) is a rare complication of percutaneous coronary intervention (PCI) with an incidence of about 0.2–0.5% [1,2]. It is more common in complex PCI, such as chronic total occlusion

* Corresponding author at: Cardiology Department, Freeman Hospital, Newcastle University, Newcastle-upon-Tyne, Tyne and Wear NE7 7DN, UK.
E-mail address: m.egred@nhs.net (M. Egred).

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(CTO) PCI (4%) [3], especially with retrograde approach (15%) [4], unprotected left main PCI (0.9%) [5], bypass graft PCI (0.32–0.68%) [6], and PCI in women and the elderly [7]. CAP is associated with high risk in-hospital and late major adverse cardiac events, as it can lead to cardiac tamponade, hemodynamic compromise and death [7].

CAP is best classified according to its location into 3 categories: large vessel, distal vessel, or septal or epicardial collateral perforation. Each type has different risk factors and treatment [8]. Common causes of large vessel perforation include use of oversized balloons and stents, use of high inflation pressures, particularly in tight, highly calcified lesions that are not properly remodeled by rotational atherectomy upfront. Furthermore, the aggressive plaque modification devices, such as cutting balloons, excimer laser, rotational, or orbital atherectomy devices might increase the risk. In addition, rupture of inflated balloon or "grenadoplasty" may cause coronary perforation [9,10]. Despite the fact that coronary intravascular lithotripsy shows a great success in remodeling calcified lesions, it might also increase the risk of large vessel CAP.

Distal vessel perforation is usually caused by distal wire migration, especially when polymer-jacketed guide wires are used. In one registry approximately 90% of distal wire induced CAP was due to the polymer-jacketed wire family [11,12].

Epicardial vessel collaterals perforation is not uncommon in retrograde approach for CTO PCI. Indeed, coronary perforation exists in 15% of total retrograde cases in one study [4].

CAP can also be classified according to its severity using the Ellis classification [13]; type I, extra luminal carter without significant extravasation and without linear staining; type II, pericardial or myocardial extravasation with less than 1 mm hole; and type III, hole larger than 1 mm with frank extravasation or bleeding into another cardiovascular cavity. Type III CAP is highly associated with cardiac tamponade, hemodynamic collapse and death. Occasionally, even low-risk type I or II CAP can have a poor clinical outcome [13].

Interventional cardiologists should be able to recognize CAP and become familiar with available general and specific treatment options, as if recognized quickly and managed adequately, its adverse impact can be minimized. In general, proximal large vessel CAPs usually require covered stents and distal or collateral vessel CAPs can be safely treated with embolization therapy. In this article, we review available treatment strategies and provide a simplified universal and type-specific approach to manage CAP.

2. Universal management for CAP

2.1. Immediate blocking balloon

The first step after diagnosis of CAP is to stop extravasation with inflation of a balloon (1:1 balloon:vessel size) proximal to or at the site of perforation for about 5–10 min at a low pressure (maximum 8 atm). The maximum tolerated time to occlude a coronary artery without causing significant myocardial damage is about 20 min and therefore repeated 5–10 min inflations can be done until either successful sealing of the perforation or evidence of significant ischaemia. If this intermittent occlusion is not efficient, persistent partial occlusion with allowed TIMI II flow may be attempted for a longer period, although a definite treatment, such as coiling, covered stents, should be the aim [14]. A passive auto-perfusion balloon may also be useful to maintain blood flow to the distal vessel with sealing of the perforation site, although these have not been available commercially for a while [15].

2.2. General circulatory support

In case of compromised hemodynamic parameters suggestive of cardiac tamponade physiology (tachycardia, pulsus paradoxus, low cardiac output and right ventricular failure), intravenous fluids, vasopressor and circulatory support devices are recommended (examples are intra-aortic balloon bump, impella or even extracorporeal membrane oxygenation [ECMO]), as adequate blood pressure support is paramount [9]. In case of continued hypotension, angiography of the affected coronary segment can help determine whether blood extravasation has stopped. A central venous access via the femoral vein can be useful, especially in large perforations.

2.3. Pericardiocentesis and autologous reinfusion

CAP can lead to cardiac tamponade. In fact and importantly, as small as 100 ml of blood accumulating in pericardium may cause tamponade if occurs rapidly. Urgent pericardiocenesis is usually attempted using anatomical landmarks under fluoroscopic or echocardiographic guidance. Reinfusion of the aspirated pericardial blood into a central vein may improve the outcome of CAP and decrease the need for blood transfusion. The reinfusion can be performed through a closed circuit; the pig tail catheter, which is positioned into the pericardial sac to be connected to a central venous access, then the drainage and reinfusion, can be done manually by 20 ml lock syringe in order to re-inject the whole aspirated blood back to the systemic circulation. Following successful sealing, it is recommended that the catheter is left in place for 24 h to be taken out if <50 ml accumulates in less than 12 h [16]. It is very important to regularly check the activated clotting time (ACT) and keep it above 300 s while reinfusing the aspirated pericardial fluid to prevent clotting.

2.4. Call for help (echocardiographer, surgeon and anesthetist)

Call for help early is of paramount importance, especially in case of type III CAP. Urgent echocardiogram is crucial to rule in/out cardiac tamponade and/or guide pericardiocentesis. If bleeding into a cardiovascular cavity is suspected, echocardiographic contrast imaging, CT scan or cardiac MRI (at a later stage) may be needed to help identify the cavity. Follow up echocardiogram in 3–8 h post management is also crucial, particularly in cases of distal vessel CAP, as delayed pericardial effusion and tamponade may ensue a few hours afterwards [17]. A cardiac surgeon and an anesthetist may need to be involved if pericardiocenesis is not feasible or effective. Emergency surgical repair in these settings carries high mortality.

2.5. Management of large vessel CAP

The previous mentioned universal measures should be applied for all types of CAP. If these measures fail to stop bleeding into the pericardium, additional treatment strategies should be used (Fig. 1).

In case of large vessel CAP, prolonged balloon inflations and/or conventional stenting may be enough to seal the perforation, especially in type I or II CAP, although stenting may sometimes worsen the perforation. Deployment of a covered stent at the site of perforation can provide definitive treatment of large vessel perforations, especially in vessels with a diameter > 2.5 mm without sizable side branches [17]. Placement of a covered stent should ideally be performed while minimizing the balloon deflation time.

Reducing the time of blocking balloon deflation is crucial in order to reduce bleeding into the pericardium and potential development of tamponade. If large guides (8 French) are used, delivery of the covered stent can be performed through the same guide catheter along with the blocking balloon with the least time of balloon deflation (block and deliver technique) [18]. Alternatively, the "ping pong", also called "dual guide catheter" or "dueling guide catheter" technique can be used. In this technique, a second guide catheter is inserted via a second vascular access. The first catheter is retracted slightly to enable the engagement of the second catheter while the balloon is still inflated. Through the second catheter, a second coronary guidewire is advanced to the blocking balloon, followed by a brief deflation of the blocking balloon to allow the second guidewire to pass to the distal segment of the perforated vessel. A covered stent is then advanced over the second wire

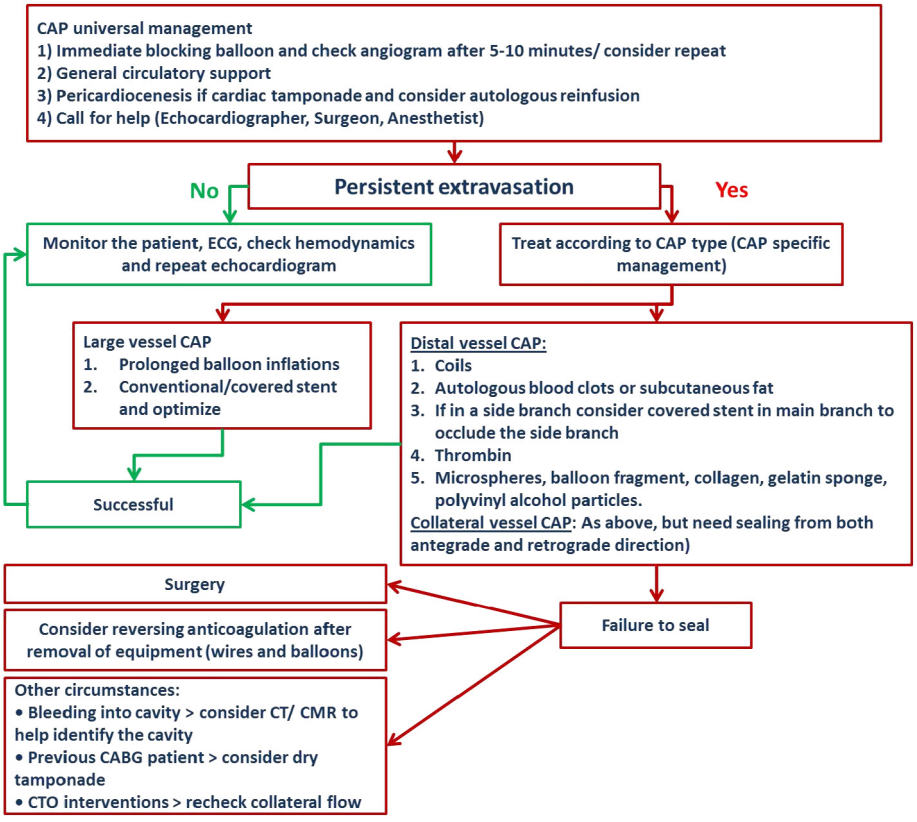

Fig. 1. Universal and type-specific coronary artery perforation management algorithm.

and when it reaches the blocking balloon, the balloon is deflated and withdrawn to allow for covered stent delivery and deployment [19].

Using covered stents in large bifurcation vessels, such as the left main, can be challenging because the covered stent will probably occlude the side branch potentially causing significant myocardial ischaemia. However, it has been reported that the side branch can be successfully re-opened by piercing the polytetrafluroethylene layer with a high tip load wire (Cofianza Pro 12 ASAHI Intecc, Santa Clara, CA, USA) through a dual lumen micro catheter [20]. Jailed balloon technique may also be used to secure the side branch after deployment of a covered stent in the main vessel [21]. In addition, and if the coronary anatomy allows, kissing stents technique with a covered stent and conventional drug eluting stent can be adopted as a method to preserve the flow to the side branch [22].

The main objective of a covered stent is to seal the perforation with a layer impermeable to blood. Although survival after CAP has improved and the need for emergent surgical intervention has decreased since the introduction of covered stents, there remain a few important intrinsic limitations. The long-term outcome of these stents is doubtful mainly due to concerns on increased thrombogenicity [23]. Also, covered stents are bulky; hence, delivery and deployment can be difficult and may fail in tortuous or calcified vessels. In addition, theses stents frequently require post-dilatation to further seal the perforation and/or optimize the treated segment and their design may render this step challenging.

Until 2019, the Graftmaster covered stent (Abbott Vascular, Santa Clara, CA) was the only commercially available covered stent. It consists of a polytetrafluroethylene layer in between two stainless steel stents; therefore, it can be particularly challenging to deliver or even expand.

In a study conducted on 57 CAP patients treated with Graftmaster covered stents, 38% had major adverse cardiac events, 26% had repeat revascularization procedures, and 3.5% had stent thrombosis for up to 3 years after the index procedure [24]. Another study reported the incidence of stent thrombosis to be as high as a quarter of all patients with Graftmaster covered stents [25].

The PK Papyrus covered stent (Biotronik, Lake Oswego, OR) is a newly developed covered stent consists of a single layer of polytetrafluroethylene covering a cobalt chromium stent and therefore is easier to deliver with better crossing profile than the Graftmaster stent. In a study comparing PK Papyrus and Graftmaster stents in CAP patients, the PK Papyrus stent was associated with shorter delivery time (8 vs. 15 min) along with significant reduction in pericardial effusion and cardiac arrest (41% vs. 72% and 5% vs. 26%, respectively) [26].

The BeGraft stent (Bentley InnoMed GmbH, Hechingen, Germany) is another newly developed covered stent consists of a single layer of polytetrafluroethylene covering a cobalt chromium stent yet with further improvements in delivery dynamics. However, in a series of CAP patients treated with this stent, the incidence of death, periprocedural myocardial infarction and target vessel revascularization was remarkable at 8.2%, 31.1%, and 18%, respectively, but with no stent thrombosis reported [27].

3. Specific management for distal vessel CAP

In case of distal vessel CAP, deployment of a covered stent in the main vessel at the ostium of the perforated branch to occlude it from the origin, or material embolization to distal vessel can be attempted [18,28].

The embolization technique involves selection of the embolization material and the method of delivery. The commonly used methods to deliver the material are deeply engaged guide catheters, thrombus aspiration catheters, over the wire balloons or microcatheters. The latter two are frequently used for distal and more precise placement.

Several materials can be used for distal embolization, such as autologous blood clots or subcutaneous fat, micro-coils, thrombin containing substances, microspheres, collagen, gelatin sponge, polyvinyl alcohol

particles, autologous skin, balloon fragments (personal experience), or the cut tip of angioplasty wires (personal experience) [8,29,30].

Additionally, any sterile stable micro-foreign body particles may be used. To obtain radiopacity, the embolic particles should either be dipped into or delivered using contrast media. The mechanism by which the embolic material stops the bleeding is by formation of a clot that eventually occludes the vessel. Subsequently, the embolic material causes a foreign body granuloma formation different in nature from the embolized material [31].

Some new described techniques have been developed to minimize the time of balloon deflation during material embolization. The most commonly used is to deflate the blocking balloon for few seconds to allow passing a micro-catheter over a second guide wire then the balloon is re-inflated to jail the micro-catheter (block and deliver technique). Consequently, the embolization of any occluding materials can be done with the balloon inflated at the same time. However, this technique is only feasible in case of using a large guide catheter, such as 7 or 8 French [32,33].

3.1. Autologous blood clots or subcutaneous fat

Using blood clots or subcutaneous fat particles has the advantage of biocompatibility in every patient and is universally available. The successful sealing of CAPs with autologous blood clots soaked in saline and contrast media has been described [34,35]. Injection of autologous subcutaneous fat particles through a microcatheter or equivalent can successfully occlude distal perforations. The fat is usually harvested from around the access sheath (next to the puncture site) or via a small incision in the upper thigh or anterior abdominal wall, then it is divided with scalpel into very small segments and pushed by a wire in a microcatheter or with saline and contrast media [36,37].

3.2. Microcoils

Micro-coils are permanent metallic devices with a wired structure of synthetic wool or Dacron fibers and thrombogenic properties. Microcoils need practice and expertise in their use, but not difficult to perform and are usually delivered through microcatheters. There are 0.014 and 0.018 inch coils. The 0.014 inch coils are preferred as they can be delivered through any microcatheter. The 0.018 inch coils can be delivered through a Finecross or through a larger microcatheter such as Progreat or Renegade. Moreover, coils can be pushable or detachable. Detachable coils are preferable as optimal positioning can be confirmed prior to releasing them. Some types of the coils, such as the Hilal and Tornado coils (Cook Medical, Bloomington, IN, USA) can be advanced in a wide lumen microcatheter, such as the 2.6 French Stride micro-catheters. Ideally, the coil size should be slightly larger than the target vessel size to ensure complete vessel adherence. The coil is introduced in the microcatheter then the guide wire is advanced to push the coil to the distal vessel. In 66 cases of distal wire and collateral perforations, Tornado coils were successfully used by pushing a 0.014 inch guide wire through a Finecross microcatheter [38]. Other Ultra Coils (such as Stryker, MI, USA) can be delivered through any 0.014 inch microcatheters however released by an electrolytic current application [37].

3.3. Thrombin

Thrombin is the key mediator of dense fibrin thrombi formation. Embolization of solutions or commercial glue containing thrombin, administered through microcatheters or over the wire balloons after mixing with saline and contrast media, have been shown to successfully seal distal CAPs [39,40].

3.4. Other micro substances

Micro substances embolization is a growing area for innovative techniques and research. Microspheres are spherical, hydrophilic, non-absorbable, varying size (from 1 to 1500 μm) particles that are delivered through a microcatheter and cause sealing of distal perforations in a similar fashion to coils. The evidence supporting the safety and efficacy of microspheres in the management of CAP is still scarce [41].

A new innovative technique was described to seal distal wire CAPs via embolization of angioplasty balloon fragment (balloon cut at middle part). This can be done by pushing the balloon fragment by another intact monorail balloon over the same wire distally to the perforated artery. Then the guide wire is pulled back slightly to allow embolization of the balloon fragment making it freely released into the distal perforated site. After that, the driving balloon is safely pulled back over the wire. This is considered a readily available, cost effective method of distal wire CAP management (personal experience) [42].

Embolization of collagen, which is available commercially in femoral occlusion angioseal devices could be another cheap option of distal embolization material. This can be done by extracting the collagen from an angioseal device and cutting it into small particles using a scalpel. The collagen material is then put into the hub of a deeply engaged guide catheter and flushed rapidly with 10 ml of saline [43]. Gelatin sponge can also be used to stop leakage from distal vessel perforations. It can be prepared by cutting the sponge into small particles and mixing it with saline and contrast media. After that, it can be injected manually with a syringe through a deeply engaged guide catheter [44]. Injection of polyvinyl alcohol particles through the lumen of an inflated over the wire balloon or via a microcatheter can also be used to occlude distal vessel CAPs [45]. Embolization of autologous skin particles can also be used to seal the distal CAPs. This may be done by advancement of the skin part to the distal artery over the guidewire and then released with the help of balloon [46].

4. Specific management for septal or epicardial collateral perforation

Septal or epicardial collateral perforations are not uncommon during CTO interventions and are usually managed conservatively. Management of significant septal or pericardial collateral bleeding can be challenging because of the dual source of blood supply, and therefore, may require embolization simultaneously from both antegrade and retrograde feeding vessels in order to block both ends of the collateral in a fashion similar to distal vessel management approach [47,48].

Extra caution should be exercised for post coronary artery bypass grafting surgery patients, as small bleeding not detected by echocardiography may compress various cardiac chambers leading to dry tamponade (intramyocardial, myocardial wall haematomas) or pocket tamponade (compressing haematomas) with significant haemodynamic compromise, which may require CT guided drainage or surgical intervention [49,50].

5. Anticoagulation reversal

This is a crucial and most important aspect on managing CAP. Anticoagulation reversal may be considered in the management of CAP however if done prematurely may precipitate life-threatening thrombotic complications and/or clotting of the pericardial fluid potentially making it difficult to drain.

It is recommended to be done as a last resort and only if other CAP treatment options are exhausted with persistent extravasation. After confirming CAP and undertaking initial management, measuring ACT as a baseline reference may be useful. For heparin anticoagulation, the safe target of ACT of less than 150 s can be reached by intravenous administration of 1 mg of protamine sulphate for each 100 unit of heparin given (maximum 50 units of protamine). On some occasions, a half dose

protamine sulphate may be all is needed to stop any persistent extravasation if other measures fail. In the case of bivalirudin, fresh frozen plasma is usually required to reverse its action [29]. Other intravenous antiplatelet therapy such as Cangrelor needs to be discontinued. Anticoagulation reversal is only recommended after removal of all intracoronary equipment, including wire and balloons, in order to avoid acute intracoronary thrombosis [8,37].

6. Conclusions

CAP is an infrequent complication but continues to be associated with high morbidity and mortality in patients undergoing PCI. It is critical for interventional cardiologists to take precautions to avoid this complication and more importantly to recognize it early if occurs and to be familiar with the universal and specific management algorithms. Invasive coronary imaging may guide a safe PCI strategy in terms of device selection including rotational atherectomy and/or balloon selection, and this may theoretically reduce the incidence of CAP. Covered stents can help seal large vessel CAP albeit with concerns on late thrombogenicity that might be overcome with prolonged dual antiplatelet therapy. In distal vessel and collateral vessel CAP, embolization of autologous material or coils often achieve hemostasis. The patient's baseline function, coronary anatomy, CAP location, hemodynamic stability and the amount of myocardium at risk often determine the treatment strategy and overall prognosis.

Declaration of competing interest

All authors of the manuscript “Management of coronary artery perforation” have no conflict of interest to declare.

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