Iatrogenic Injuries during Retrograde Delivery of Cardioplegia- Prevention, Diagnosis and Management: A Collective Review

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Abstract

The causative factors and morphologic spectrum of iatrogenic coronary sinus injuries during retrograde delivery of cardioplegia through the coronary sinus are many and varied. In this review, we give an account of all cases previously described as iatrogenic injuries of the coronary sinus, analyzing in detail those cases where an accurate anatomical description of the injuries was provided. We identified 27 investigations and reviewed the anatomic variations of the coronary sinus, causative mechanisms of injury to the coronary sinus, diagnostic features, intraoperative findings and management of the patients described. Transesophageal echocardiography, contrast injection into the coronary sinus and intraoperative identification of the catheter tip perforation of the inner wall of the coronary sinus, transmural migration and eventual perforation or laceration of the right ventricle and hemodynamic or pressure tracing of the coronary sinus identified these injuries involving the coronary sinus and its tributaries. We have grouped the injuries into categories that have a bearing on the appropriate surgical approach, discussing the appropriate repair for each group. We submit that an increased appreciation of various types of iatrogenic coronary sinus injuries may well contribute to its prevention and improved future surgical management.

Keywords: Coronary Sinus Injuries; Coronary Sinus Laceration; Myocardial Preservation; Retrograde Cardioplegia

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Introduction

The goal of cardiac surgeons must be an unhurried correction of cardiac abnormalities under direct vision. "...The heart suffering no damage during periods of arrest." So wrote Melrose and colleagues in The Lancet in 1955 in a classic treatise that initiated the concept of cardioplegia [1]. Although there have been major advances in the methods of myocardial protection since then, cardiac operations have nevertheless remained far from unhurried because of the anaerobic damage that can occur with all current methods of myocardial protection [2-7].

The objective of myocardial protection is to prolong the safe operating time, prevent operative death, perioperative infarction and functional impairment. This objective ultimately translates into optimizing the ratio of myocardial energy supply to energy demand, while the aorta is cross-clamped [2-5]. Despite numerous advances in methods of myocardial protection time remains a major adversary of the cardiac surgeon. Aortic occlusion renders the myocardium ischemic and dependent solely on the anaerobic metabolism. Hence, prolonged procedures are associated with higher morbidity and mortality [5-17]. Methods of myocardial protection in general use today provide excellent preservation for elective procedures in low-risk patients. They are associated with minimal attendant morbidity and mortality. The outcomes, however, are less optimal for urgent operations in high-risk subgroups with poor ventricular function and provide the impetus for investigating alternative methods of myocardial protection [12-20].

Regardless of its potential and proven advantages over the antegrade method, retrograde myocardial protection regime failed to gain wider acceptance for more than 20 years until the pioneering work of Menasche and colleagues in 1982 and Gundry and colleagues in 1990 [21,22]. Their work and the introduction of efficient closed delivery systems, incorporating DLP INC and Research Medical INC designed perfusion catheters have resulted in the resurgence of retrograde cardioplegia in high-risk and re-operative patients [23-27]. However, there is a sharp contrast between the number of experimental and clinical data available [23,28-34]. In the current practice, coronary sinus has been used as a route of delivery in several myocardial protection technique strategies including intermittent cold crystalloid cardioplegia, intermittent cold blood cardioplegia, continuous normothermic blood cardioplegia and continuous cold blood cardioplegia [24,25,35-41].

Despite widespread use of retrograde coronary sinus cardioplegia in recent years, little has been reported regarding the etiological mechanisms of coronary sinus injuries, their prevention, diagnosis and management [24,42-60]. With these deficiencies in mind, we have analyzed the published literature, using a MEDLINE search to identify the described instances of coronary sinus injury, the variations in the coronary venous anatomy, the methodology of diagnosis and the treatment modalities utilized for a successful outcome. We have synthesized all of these features with regard to their bearing on the strategies for surgical management of coronary sinus injuries. As far as we could establish, there have been 27 publications addressing specifically the etiological mechanisms and management of various types of coronary sinus injuries. For the purposes of this review we have selected these 27 publications which have an accurate description of the management strategy and perioperative mortality [24,42-60].

Advantages of Retrograde Cardioplegia

Retrograde coronary sinus cardioplegic perfusion offers several advantages.

1. It avoids the risk of injury to the coronary ostium associated with ostial cannulation [26,27].
2. In the presence of critically obstructive coronary artery disease, retrograde coronary sinus perfusion provides homogenous cooling [26,27,61,62].
3. It is a useful procedure in the presence of calcified aorta [45].
4. The surgery remains uninterrupted particularly during combined mitral and aortic valve replacement, Bentalls procedure, distal graft- aortic anastomosis and while closing the aortotomy [43-45].
5. It reduces the occurrence of supraventricular arrhythmias by retarding atrial rewarming during aortic cross-clamp [21]. Possibly, the egress of cold cardioplegic solution causes topical endocardial cooling of the right atrium [24-27].
6. Retrograde cardioplegia can provide uniform myocardial protection in the grossly hypertrophied myocardium due to the presence of numerous venous channels in the human heart which act as effective conduits for delivery of cardioplegic ingredients in a uniform manner [24-27,42-44,61-65].
7. Adequate, immediate delivery of the cardioplegic solution is achieved, especially in the setting of type-A

aortic dissection, thus minimising the ischemic time [66].

8. Coronary sinus cardioplegia is able to retrogradely flush air and atheromatous debris from the coronary arteries [43-45].

It is the author's routine practice to restart myocardial perfusion with warm blood via the pump after disconnecting the cardioplegia solution to decrease the myocardial ischemia in procedures requiring long aortic cross-clamp time, e.g., Bentalls procedure, concomitant valve replacement, coronary artery bypass grafting, and redo coronary artery bypass grafting [66,67].

Limitations of Retrograde Coronary Sinus Cardioplegia

As outlined by Menasche in his report on 500 patients and other investigators including us, retrograde coronary sinus cardioplegia does have some limitations [45]. These include:

1. Inadequate preservation of the right ventricle; this concern has been raised on the basis of canine studies [68]. However radionuclide angiocardiography studies, have demonstrated that the venous drainage patterns of the human right ventricle are more suitable for retrograde coronary perfusion, provided the balloon catheter does not impede cardioplegia flow into the distal branches of coronary sinus [26,27,69-71].

2. The cardioplegia distribution is non-homogenous since the venous system is located predominantly subepicardially [72].

3. Need for bicaval cannulation for proper positioning of the coronary sinus catheter.

4. Injury to the coronary sinus which may vary from atrioventricular hematoma to coronary sinus rupture.

5. It takes a longer time to arrest the heart with retrograde cardioplegia compared to the antegrade route. However, this delay can be circumvented by the first induction dose of cardioplegia through antegrade route [73-75].

Incidence of Iatrogenic Coronary Sinus Injury

Due to the rarity of coronary sinus rupture, distinct repair techniques are infrequently reported, and its actual incidence is unknown. The main risk factor indeed remains, i.e., the retrograde cardioplegia. However, a misplaced venous cannula causing coronary sinus rupture has been reported in case of an unfavorable anatomic configuration and during minimally invasive cardiac surgical procedures. Left ventricular and septal hypertrophy represent other risk factors for coronary

sinus injuries [46-48,55,58]. In the present day clinical practice, coronary sinus catheter misplacement or displacement has been reported in 2 to 2.6 percentages of patients and iatrogenic injuries in 0.06 to 0.6 percentages of patients. This is similar to the 1 to 5 percent incidence rate of coronary complications reported after the use of direct ostial cannulation [42-60].

Coronary sinus injuries also have been reported during retrograde pacemaker lead implantation for biventricular simulation. Injuries in about 10 percentage of the cases are clinically silent and do not require surgical treatment. It is essential to establish a clinically feasible routine to correct these injuries [73-82].

Retrograde Coronary Sinus Catheter: Techniques of Insertion, Determination of the Correct Placement

The retrograde cardioplegia catheter is inserted into the coronary sinus either by opening the right atrium or by puncturing the right atrial wall and blindly advancing the catheter. In the former, a successful insertion can be visually confirmed, but it requires isolation of superior and inferior caval veins. Meanwhile using the blind technique, it is difficult to insert and confirm successful placement by manual palpation especially in re-operations, smaller sized coronary sinus and in those with anomalies of the coronary venous drainage system. There is no way to recognize intracardiac events such as penetration of the coronary vein or coronary sinus perforation during cardiac manipulation.

The correct positioning of the catheter into the coronary sinus is vital to provide adequate administration of cardioplegia [81,83-86]. Methods to determine correct placement of the catheter are:

1. Blind insertion into the right atrium close to inferior caval vein - right atrial junction. This technique risks injury to the atrium, inferior caval vein or coronary sinus and/or its tributaries.

2. Palpate the right atrial-inferior caval vein junction on partial bypass to confirm the position of the catheter at the atrioventricular groove and the base of the left atrial appendage. This technique may be difficult in hemodynamically unstable patients [83-86].

3. Manasse has described an ingenious technique using a Y catheter inserted into the ascending aorta and another coronary sinus catheter inserted into the coronary sinus via right atrium and interconnecting the two. Thus, the arterial blood runs from the ascending aorta into the coronary sinus. If the retrograde sinus

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catheter is inserted correctly, the coronary sinus pressure increases immediately to 20-30 millimetre of mercury and does not change at all unless malpositioned [78,86].

4. Aldea and colleagues reported on the usefulness of transesophageal echocardiography for directing the coronary sinus catheter in the blind technique.[79] The coronary sinus is imaged in long axis by slightly advancing or retroflexing the probe from the mid-esophageal four-chamber view. It is seen in the short axis in the mid-esophageal two-chamber view just superior to the atrioventricular groove. The modified bicaval view with the probe in the mid esophagus at 110-120 degrees shows the orifice of the coronary sinus and is useful in placing percutaneous coronary sinus catheters during minimally invasive procedures [55,79,80].

5. Fluoroscopy and contrast injection: coronary sinus catheter placement via the right internal jugular vein is performed for retrograde cardioplegia administration in patients undergoing minimally invasive procedures. Fluoroscopy allows visual confirmation of coronary sinus cannulation and detects extravasation [87,88].

Causes for Unsuccessful Cannulation and Cardioplegia Delivery Failure

1. Smaller sized coronary sinus opening. The diameter of the coronary sinus orifice ranges from 4.7 mm to 10.7 mm (average 7.9 mm) [72,76].

2. As the catheter is inserted into the right atrium and advanced along the posterolateral right atrial wall towards the coronary sinus orifice, it may push the right atrium wall adjacent to coronary sinus orifice and gets misdirected towards the inferior caval vein or right ventricle. As described by Orihasi K and colleagues, anterior traction of the lateral right atrial wall helps in straightening the course of the catheter along the posterior right atrial wall towards the coronary sinus orifice [76]. This maneuver may not be possible in re-operative cases due to adhesions [79]. Transesophageal echocardiography is advantageous in guiding the catheter into the coronary sinus in such cases [76].

3. Another reason for unsuccessful cannulation was the common orifice of the coronary sinus and middle cardiac vein. If the operator forcefully advances the catheter in the branch vein against the resistance, the cardiac vein can be lacerated or penetrated. Higami and colleagues monitored the pressure at the catheter tip during retrograde infusion and obtained an unusually high pressure in 7.5 percentages of cases [86]. When

transesophageal echocardiography facility is not available, this anomaly of coronary sinus orifice can be identified by direct inspection or by preoperative coronary angiography [76].

The common reasons for retrograde cardioplegic delivery failure are smaller size coronary sinus opening, catheter displacement/misplacement, the direction of the catheter tip into one of the venous tributaries and extreme advancement of the catheter tip beyond the base of the left atrial appendage.

Diagnosis of Coronary Sinus Injuries

Diagnosis is difficult in most patients as can be seen in different publications. The diagnosis of coronary sinus injury is based on appropriate clinical context and echocardiography. The echocardiography will show an anechoic area with absence of flow suggestive of hematoma between the pulmonary veins and the inferior caval vein (the oblique sinus region) [42-60,87-89]. Catheter misplacement in the tributaries of the coronary sinus or the right ventricle is best identified by their radiologic appearance [56,57]. Intraoperatively misplacement of a catheter in the posterior cardiac vein is diagnosed by manual palpation, damp pressure tracings, and transesophageal echocardiography [80,87-89]. Catheter tip causing perforation of the inner wall of the coronary sinus is invariably associated with a transmural migration and eventual perforation or laceration of the right ventricle. This type of injury is usually extensive, but accessible and more easier to control than the posterior wall injuries [42-60].

Pitfalls in the use of Transesophageal Echocardiography

Transesophageal echocardiography is undoubtedly an essential tool for determination of correct placement of coronary sinus catheter to avoid coronary sinus injury. However, there are several pitfalls in the use of transesophageal echocardiography.

1. The images are tomographic, and the object out of the scanning plane is not visualized. With single plane transesophageal echocardiography, constant manipulation of the echocardiography probe is needed [76,87-89].

2. The catheter cannot be visualized when directed obliquely to the ultrasonic beam because the ultrasound beam is reflected elsewhere [76,87-89].

3. The right atrium and coronary sinus are not visualized distinctly when the blood is exsanguinated. Pooling a

certain amount of blood in the right atrium makes it easier to monitor the insertion procedures [76,87-89].

Pattern of Coronary Sinus Injuries And Surgical Procedures for Injured Coronary Sinus and its Tributaries

Published literature document retrograde catheter displacement, misplacement, smaller size coronary sinus opening, common opening of the coronary sinus and middle cardiac vein, direction of the catheter tip in to one of the venous tributaries, extreme advancement of the catheter tip beyond the base of the left atrial appendage are the main causative factors of the failures to deliver retrograde cardioplegia. Malpositioning of the designed perfusion catheters often predisposes to a subsequent dislodgement or iatrogenic injuries [42-60]. We used the descriptions of echocardiographic and surgical findings of the published cases with coronary sinus injury to stratify the various cases. We categorized the patients into several groups that have a bearing on the surgical mortality, morbidity, techniques and the outcome of surgical treatment (Figure 1). The patterns of iatrogenic injury during retrograde delivery of cardioplegia and their specific management as published in the literature are:
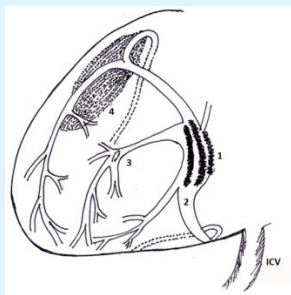

Figure 1: Diagrammatic representation demonstrating various types of iatrogenic injuries to the coronary sinus and its tributaries- (1) high pressure blow out rupture of the coronary sinus, (2) proximal injuries secondary to various causes, (3) distal rupture (perforation of the coronary sinus, and/or its radicals of the right ventricle), (4) hematoma without perforations in the atrioventricular groove.
(ICV- Inferior caval vein)

Proximal injuries: Proximal injuries are mainly due to direct perforation of the coronary sinus catheter tip with stylet in situ, catheter misplacement or displacement,

electrodes used during biventricular facing and misdirected venous cannula while performing minimally invasive procedures. Malpositioning of the specially designed catheters, often predisposes to a subsequent dislodgement or iatrogenic injuries (Figure 1).

Various repair techniques described in the literature for proximal injuries of the coronary sinus are direct suture repair, single onlay pericardial patch repair by Aharinejad and associates, and double pericardial patch technique by Aignor and associates [46,48,50,58]. The technique to treat coronary sinus ruptures are technically demanding to allow sufficient drainage through the coronary veins together with a complete hemostasis [83-85]. Direct suture repair frequently leads to stricture and distortion of the coronary sinus with increased risk for coronary sinus thrombosis [90-92].

The coronary sinus is repaired with an autologous pericardial patch that is secured with a continuous 5-0 polypropylene suture in the surrounding epicardium. A second patch is subsequently placed over the first one with an additional layer of fibrin glue in between the pericardial patches to achieve complete hemostasis. This technique avoids distortion and potential narrowing of the coronary sinus while providing adequate bleeding control [48].

Mid-portion injuries (Blow out rupture): A blowout rupture occurs in the middle portion of the coronary sinus due to balloon over-inflation or high infusion pressure [46-53,58-60]. In the case of blowout rupture, it is essential to stop the retrograde cardioplegia immediately, carry out the repair, and alter the strategy of myocardial protection [52].

When using a pericardial patch for repair, it is recommended to leave the catheter in situ to present the edges of the rupture. Weiss and associates have suggested placing a Gore-Tex conduit (WL Gore and Associates, Flag-staff, AZ), to create an alternative route between the patch and the right atrium [49]. A pericardial patch sutured directly to the edges of the rupture in most cases is technically not possible. Thus a patch anchored to the surrounding epicardium is an excellent solution to avoid this problem. A second patch may be placed over the first one to provide additional coverage with fibrin glue in between the patches for perfect hemostasis.[48]

Distal rupture (perforations of the coronary sinus, its radicals of the right ventricle): Rupture at the distal end of the coronary sinus, posterior cardiac vein or marginal

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cardiac veins are due to incorrect catheter placement, and/or hyperinflation of a catheter balloon which is advanced to the extreme end of the coronary sinus (Figure 1).

These injuries can occur during catheter manipulation with the stylet in situ. A clean and apparent injury is best repaired with 6-0 or 7-0 prolene. A small perforation of the veins may remain concealed underneath the sub-epicardial contusion [51,54,56,57]. These injuries have been treated conservatively, but a delayed rupture of cardiac contusion has been reported [40,54]. Therefore, a double layered on-lay pericardial patch is recommended to deal with this type of injury. To prevent delayed hemorrhage from a repair done on a decompressed right ventricle additional reinforcement is recommended on beating heart, before coming off cardiopulmonary bypass [84]. If overt bleeding is not present, treat conservatively [45-47]. Transesophageal echocardiography helps to detect the exact location of the injury [80].

Hematoma over the Atrio-ventricular groove: High infusion pressure can cause an atrioventricular groove hematoma and result in delayed coronary sinus rupture due to a retrocardiac chest tube. Non-expanding hematomas without hemodynamic compromise may be treated conservatively. Lacerations with expanding hematomas or hemodynamic alterations (e.g., pulmonary vein obstruction) necessitate repair with direct suture or pericardial patch [42-60].

Laceration of the coronary sinus (High pressure ruptures of the coronary sinus and its tributaries): An extensive laceration of the coronary sinus is usually secondary to balloon over-inflation or over-pressurization during retrograde cardioplegia infusion (Figure 1) [24,25]. This type of injury has been reported as a result of manual hyperinflation of a DLP Inc. catheter balloon, high flow rate through a research medical Inc. catheter with a self-inflatable balloon and due to high resistance encountered during delivery of cardioplegia through a malpositioned catheter [45-50].

Generally, rupture of a coronary sinus through its radicals is extensive; hemorrhage extends in the sub-epicardial plane and eventually ruptures at a remote point [52]. This type of injury is difficult to control, because of the difficult access, and ill-defined edges, which are unsuitable for primary repair. It is best to repair this type of injury on a fully decompressed heart, with double layered only pericardial patch sandwiched with fibrin glue, and suture to the epicardium beyond the

perimeters of the cardiac contusion, avoiding the branches of the coronary arteries [52]. Similar method may be used for the high-pressure ruptures of the coronary venous tributaries.

Prevention and Recommendations Of Management of Iatrogenic Coronary Sinus Injuries

From our experience and published literature, we recommend the following:

1. Insert the coronary sinus catheter on partial bypass while the right atrium is distended.
2. Check the position of the catheter at the atrioventricular groove and the base of the left atrial appendage using surgeon's middle finger.
3. If available, confirm the position by transesophageal echocardiography.
4. Use the cardioplegia pump and pressure transducer to confirm the position of the catheter.
5. In difficult cases, snug the superior and inferior caval veins, make a small atriotomy over the medial side of inferior caval vein - right atrial junction, 1 cm away from the atrioventricular groove. Then the catheter is placed within the coronary sinus under direct vision and secured with the atrial wall using a polypropylene suture.
6. Avoid over-distension of the balloon (saline should be used instead of air because it decompresses the balloon effectively between infusions) [58].
7. During balloon inflation, the delivery pressure needs to be monitored all the time, keeping it below 40 millimetre of mercury, rather than inflating the balloon to the manufacturer's labelled volume.
8. Avoid excessive retraction of the heart with the coronary sinus catheter in situ especially in the hypertrophied heart and during distal anastomoses of coronary artery bypass grafting.
9. The pressure transducer for measuring coronary sinus pressures should be zeroed and set on 0- to - 40 millimetre of mercury scale.
10. On instruction from the surgeon, activate the cardioplegia pump to the desired flow (125 millilitres per minute per metre square or approximately 200-250 millilitres per minute flow).
11. Monitor the coronary sinus waveform during the delivery of cardioplegia.
12. During delivery of the cardioplegia, the surgical team including the anesthesiologist, the perfusionist

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need to ensure that the coronary sinus pressure is below 40 millimetre of mercury at all times.

Conclusion

Iatrogenic injuries of the coronary sinus and/or its tributaries are rarely reported, thus may be underestimated. Unfavourable anatomic configuration, faulty catheter/electrode placement of the coronary sinus, left ventricular and septal hypertrophy and placement of electrodes for biventricular pacing remain the dominant causative factors for injury of the coronary sinus. The diagnostic accuracy is improving with the use of echocardiography and careful intraoperative examination. We have reviewed the various injury patterns, stratifying them into several categories. Management, however requires an individualized approach. Characterization of various injury patterns and their causative mechanisms will hopefully increase awareness of the existence and its management.

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Conflicts of Interest

None

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