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Review

Coronary computed tomography angiography following robotic coronary artery bypass grafting surgery: Systematic approach to image analysis and practical considerations

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ABSTRACT

Standard open chest Coronary Artery Bypass Grafting (CABG) has evolved over last couple of decades. With advancement in minimally invasive procedures, Robotic CABG (RCABG) is still in its evolution phase. There is dearth of experienced surgeons in this complicated field and lack of data to verify it clinical safety. in this review, we intend to describe the utility of Cardiac Computed Tomography Angiography (CCTA) in assessment of graft anatomy and quality, grafting strategy, distal graft anastomosis site evaluation and detection of complications associated with RCABG. CCTA appears to provide valuable information regarding the visualization of grafts, target coronary arteries and other cardiac and non-cardiac structures.

1. Background

Coronary artery disease (CAD) is the leading cause of death in United States with 80% of the deaths occurring in elderly population [1]. In the last few decades, coronary artery bypass grafting (CABG) has evolved since the first CABG performed by Sabiston in 1962 [2]. CABG provides symptomatic and prognostic benefits in patients with CAD [3]. Early and late complications of the conventional CABG surgery requiring sternotomy may lead to significant delay in the recovery and healing processes in these patients. In the past two decades, there have been significant improvements in development of minimally invasive procedures in multiple surgical fields, including cardiothoracic surgery. While minimally invasive surgery has become almost the universal approach for mitral valve repair, robotic and/or less invasive coronary artery bypass (RCABG) grafting is still in evolution. This slow adoption is due in part to a paucity of data to establish its clinical utility and the lack of surgeons trained in this complicated domain [4]. Assessment of the graft anatomy, quality and other diagnostic and prognostic data post RCABG are not well defined. This review article focuses on the utility of Cardiac Computed Tomography angiography (CCTA) imaging in post RCABG follow up and systematic approach to image analysis and practical considerations. Surgical details of the RCABG procedure are out of the scope of this review.

2. Overview of robotic CABG

The first successful single vessel RCABG was performed by Loulmet and colleagues in 1991 [5]. Now, multivessel RCABG is being more frequently performed due to more familiarity with the technique. Absence of midline sternotomy and less traumatic access to the heart are important clinical benefits of this procedure (Fig. 1). RCABG can be performed on beating heart (off pump) or arrested heart with utilization of cardiopulmonary bypass (CPB). Beating heart surgery avoids the complications associated with the CPB. Patients with severe systemic atherosclerosis who are high risk patients are good candidates for off pump surgery [6]. A variety of studies have documented the added value of robotics used during CABG by showing improved clinical outcomes (i. e. shorter recovery, less complications) along with close analysis of the financial data (i.e. only modest increase in hospital costs that represent a favorable return on investment) when compared with conventional CABG [6,7]. Surgical morbidity and mortality are improved due to small incisions and preserved integrity of the sternum. RCABG also offers less risk of postoperative stroke when compared to a standard CABG protocol [8,9].

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3. Importance of Cardiac Computed Tomography Angiography for a follow up post robotic CABG

Compared to open CABG, robotic CABG is an emerging technology, and has not yet been widely adopted. Broader adoption has been hindered in large part by a concern that the graft outcomes (i.e. long term patency) of this technically demanding procedure may be compromised compared to the relatively easier and more reproducible conventional CABG.

Given this apprehension, CCTA plays an important role as a great anatomic imaging tool and a quality assurance tool that can be deployed to detect postoperative problems and to improve outcomes in their RCABG programs. The main uses/aims for CCTA following RCABG include: (1) assessment of conduit anatomy and quality, (2) evaluation of issues related to grafting strategy, (3) evaluation of site of distal graft anastomosis, and (4) detection of early and late complications associated with RCABG. To cover the above aims, CCTA readers must widely utilize 3D postprocessing, 3D volume rendered images maximal intensity projection (MIP) and multiplanar reformat (MPR) views. We demonstrate a few clinical examples of this approach further in Figs. 1–7.

4. Assessment of conduit anatomy and quality

The most common conduits used in robotic CABG are the left (LIMA) and right (RIMA) internal mammary arteries. These conduits have been shown to have better long-term patency than saphenous veins but are harder to harvest. The lack of tactile feedback for the surgeon operating the robotic instruments creates a risk that the delicate IMA tissue can be torn, dissected or otherwise injured during harvest. Postoperative CCTA allows the IMA conduits to be inspected for any evidence of injury (Fig. 2). A few studies have shown high sensitivity and specificity in detecting patency of the grafts after CABG [10,11]. This is often illustrated by areas of focal luminal narrowing of the conduit, typically in the region of where surgical clips were placed. Evidence of injury can prompt a review of the intraoperative video of the harvest of the particular portion of conduit that was injured. This provides excellent feedback to the surgeon about where his/her technique may have gone wrong so that performance can be improved. CCTA images of patent grafts provide very important feedback to the surgeon attempting to safely incorporate novel techniques for their RCABG practices. Long-term outcome is the ultimate metric of success for both robotic and conventional CABG. The aim of the new robotic program is to provide a less morbid surgical experience without compromising the long-term results. The long-term results that are of interest are graft patency and full resolution of any early postop complications that are increased in robotic vs. conventional CABG. The CCTA is very helpful feedback in that regard and this gives the surgical team confidence that their new program is viable.

5. Evaluation of issues related to grafting strategy

While bilateral IMA conduits improve long term survival after CABG, 95% of open CABG cases use only a single IMA and other targets are addressed using saphenous veins. Surgeons do not harvest bilateral IMA out of concern for causing sternal healing difficulties. Robotics circumvents the need for a sternotomy, thus eliminating the risk for bilateral IMA harvest. However, this introduces the choice of "grafting strategy" as a new variable that can influence outcomes after CABG. This term refers to the following: if the right IMA is left intact proximally (called an "in situ graft") and the distal end is grafted onto the left anterior descending artery (LAD), it requires adequate length of the right IMA conduit in order to reach the target without creating undue tension on the distal anastomosis (Fig. 3). The anatomical location of the LAD is important – sometimes it is laterally displaced and out of reach of a typical right IMA. If that appears to be the case, the right IMA can be taken as a "free graft" (disconnected proximally) and sewn onto the side of the left IMA, which makes a composite "y-graft" that can be grafted onto 2 or 3 different left sided targets (Fig. 4). Postoperative CCTA is able to assess the quality of this difficult end-to-side IMA-IMA anastomosis. In addition, tension on the distal coronary anastomosis is not usually a major concern when a y-graft configuration is used, but rather the main problem is that grafts are at risk for an improper course due to twisting, kinking or other abnormal angulation. When any of these issues occur, it is unusual for the affected patient to have clinical symptoms or signs during the postoperative hospitalization – instead there is a delayed presentation at a time when the surgeon has forgotten the technical details of the surgery. Thus, CCTA is a necessary way to reliably demonstrate these problems and provide useable feedback to the surgeon. Graft differences between RCABG and conventional CABG are listed in Table 1.

6. Evaluation of site of distal graft anastomosis

Choosing to graft onto the most optimal portion of the coronary artery is one of the most important part of the surgical planning. During conventional CABG, the entire coronary artery is inspected so that the distal graft anastomoses are performed on the portion of the coronary where the target is the largest and also free of atherosclerotic disease. RCABG provides a far more limited field of view due to use of a smaller surgical incision. During their novice phase (i.e. first 50–100 cases), many RCABG surgeons place their grafts on whatever portion of the coronary, behind the stenotic part, they have access to via the mini-thoracotomy and they often find it difficult to determine precisely where on the coronary artery this is. With experience, it is possible for the surgeon to gain access to the entire coronary artery in order to graft the optimal portion of the coronary artery as in conventional CABG. The learning curve for optimal target selection is greatly accelerated by routine feedback on where past grafts have been placed. The site of the

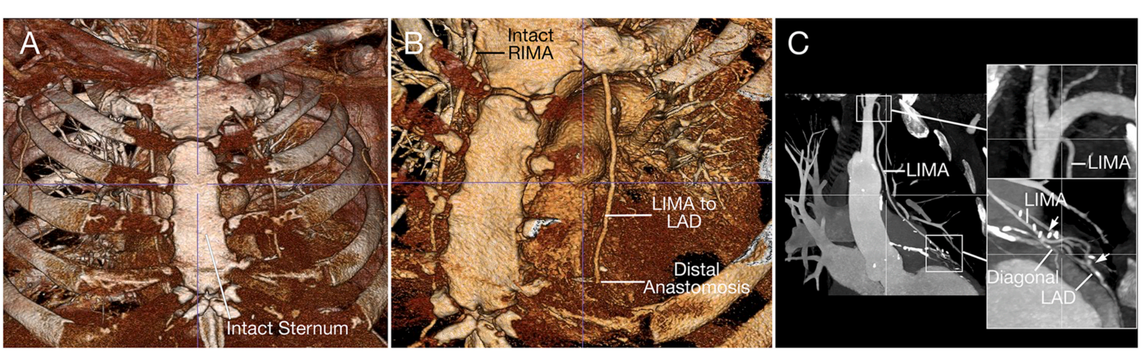

Fig. 1. Cardiac Computed Tomography Angiography (CCTA) reveals intact sternum (1A) with intact right internal mammary artery (RIMA) and left internal mammary artery (LIMA) graft to the distal left anterior descending artery (LAD) with patent anastomosis (1B). Origin and distal anastomosis of LIMAare shown in zoomed views (1C). LIMA demonstrates a normal side-to-side anastomosis with the first diagonal artery and an end-to-side anastomosis to the distal LAD (1C).

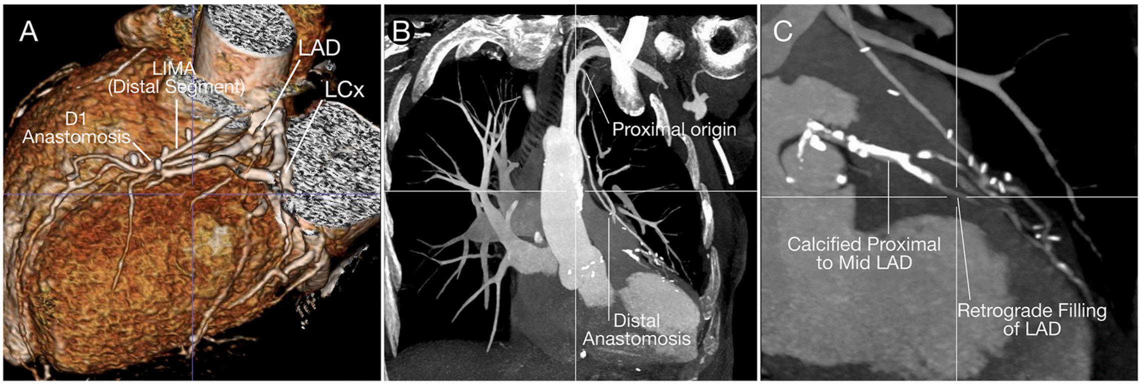

Fig. 2. An 81-year-old man presented with non-ST elevation myocardial infarction and had high grade stenosis of the mid LAD and the first diagonal artery (D1). Patient had severe chronic obstructive pulmonary disease (COPD) hence he underwent successful RCABG (LIMA to D1 and to LAD) to reduce the risk associated with wound healing secondary to hypoxia and cough. CCTA performed 3 days after the surgery shows calcified proximal to mid LAD (2A-2C) along with retrograde filling to the LAD (2C). Origin, body and distal anastomosis of LMA graft well visualized (1B) on thick slice MIP images (2B).

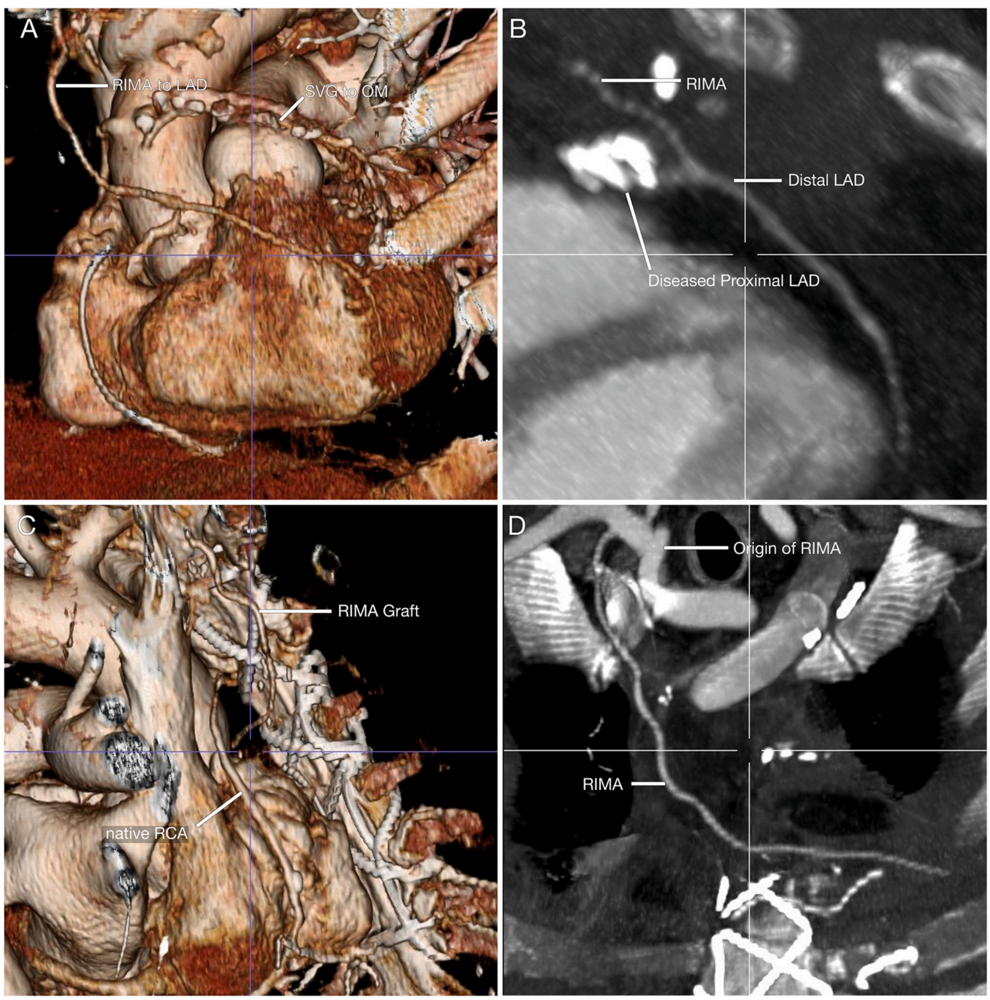

Fig. 3. 69-year-old patient had a history of prior conventional CABG. LIMA used in prior CABG as a graft to LAD, was occluded. During RCABG, RIMA was utilized as a free graft to distal LAD (3A-3C). RIMA to distal LAD can be seen along with saphenous vein graft (SVG) to obtuse marginal (OM) (3A-3B). Origin, body and distal anastomosis of the RIMA graft to LAD are shown on maximal intensity projection (MIP) and multiplanar reconstruction (MPR) views (3B, 3D).

distal graft anastomosis is information easily provided by CCTA (Fig. 5 and Fig. 6). In this regard, preoperative CCTA may be a valuable "road-map" modality for the surgeon, especially in potentially complex cases.

7. Detection of complications associated with robotic CABG

The risk of pulmonary complications with RCABG are similar to open CABG. However, the rate of left sided effusions are slightly higher with robotic CABG because the port sites tend to provoke an effusion [12].

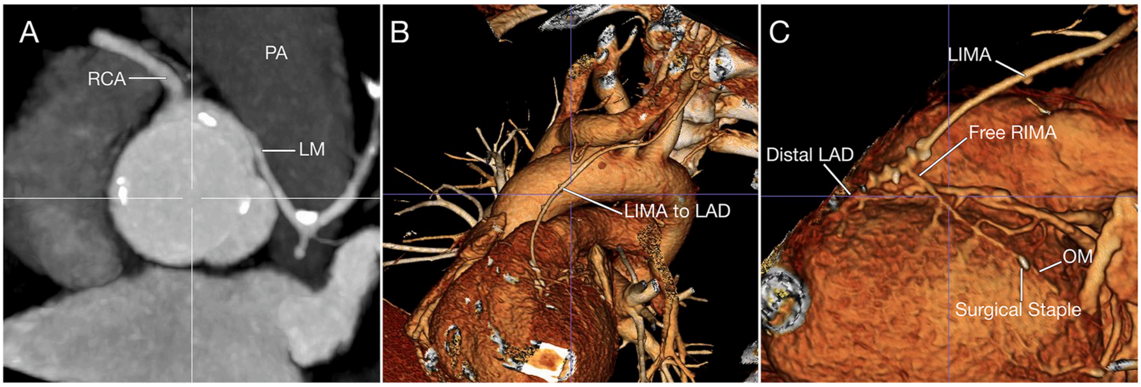

Fig. 4. CCTA shows Left Main (LM) coronary anomaly. LM originates from the right cusp, with malignant interarterial/intramural course (4A). Distal connection of LIMA to LAD (4B) and free RIMA graft originating from distal LIMA to distal obtuse marginal (OM) branch of the Left Circumflex Artery (LCx) can be seen (4C).

Table 1
Grafting differences between robotic CABG and open CABG assessed on CCTA.

	Robotic CABG	Conventional CABG
Most common conduit for grafting the LAD	Left internal mammary artery	Left internal mammary artery
Proximal anastomotic site of a saphenous vein graft	Left axillary artery	Ascending aorta
Frequency of using the right internal mammary artery	Most common conduit used after the LIMA	Less than 5% of cases use RIMA[13]
Location on the coronary artery chosen for a distal anastomosis	Tendency to graft the distal third of the coronary artery	Usually the mid-portion of the coronary artery
Risk of distortions in the graft (kinking, tension, poor angle)	Higher than open CABG because the positioning of the graft cannot be easily seen intraoperatively	Low because the complete course of the graft can be visualized during the entire case
Grafting strategy	Variable: Multiple arterial grafts, use of a free RIMA, use sequenced anastomoses (e.g. LIMA to diagonal and LAD)	Less variable than robotic: 95% of cases involve LIMA and 1 or more SVG from the aorta to the distal coronary targets

Serous or serosanguinous effusions that are small and not associated with compressive atelectasis are likely to remain asymptomatic. Most eventually resorb fully in 1–2 weeks with the ongoing daily diuresis that is standard for most patients. However, if there is a large volume of blood clots retained in the thorax, this is not likely to resorb on its own and the patient is likely to require some type of invasive intervention. If there is compressive atelectasis associated with the clot, this puts the patient at risk for a trapped lung. There are also occasionally small mediastinal effusions which also resolve with time.

A small degree of pneumothorax and subcutaneous emphysema immediately after surgery are also more common due to incomplete evacuation of the CO2 insufflation used during the case (Fig. 7). This typically resorbs over the first 1–2 days after surgery and has no clinical importance. A pneumothorax that is associated with any signs of mediastinal shift is worrisome for tension pneumothorax and is too large for non-invasive management strategies. RCABG may involve bilateral IMA harvesting, which means that both pleura are opened during the procedure. In cases of bilateral IMA harvesting, a left sided pneumothorax may have access to the right thorax, which can result in bilateral pneumothorax and a much greater risk of pulmonary compromise. Fortunately, early postoperative CCTA can easily identify these potential life-threatening complications (especially in cases with unclear or mixed clinical picture) and provide an important information for establishing the most effective treatment plan tailored to the specific patients' needs.

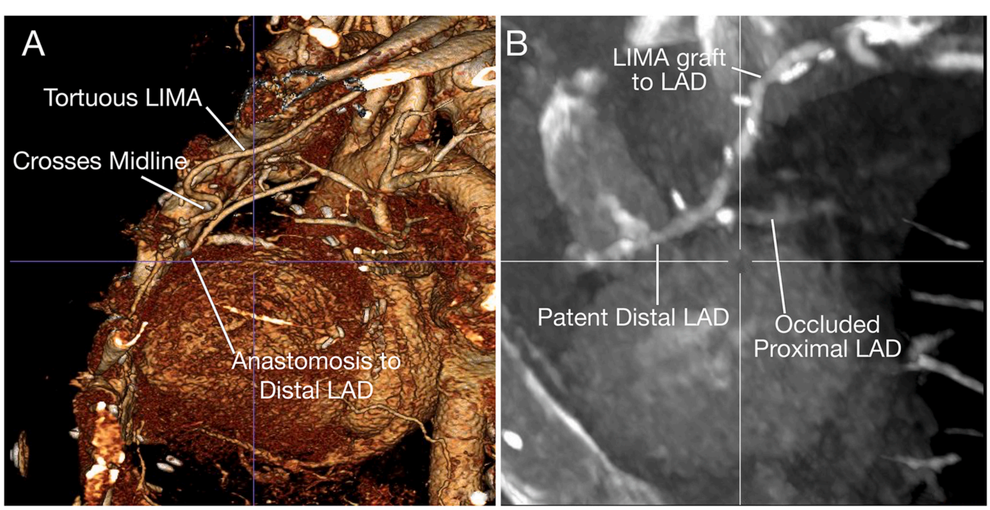

Fig. 5. CCTA reveals tortuous LIMA that crosses the midline, with anastomosis to the distal LAD (5A-B). The LAD is seen to be occluded proximally and patent distally (5B).

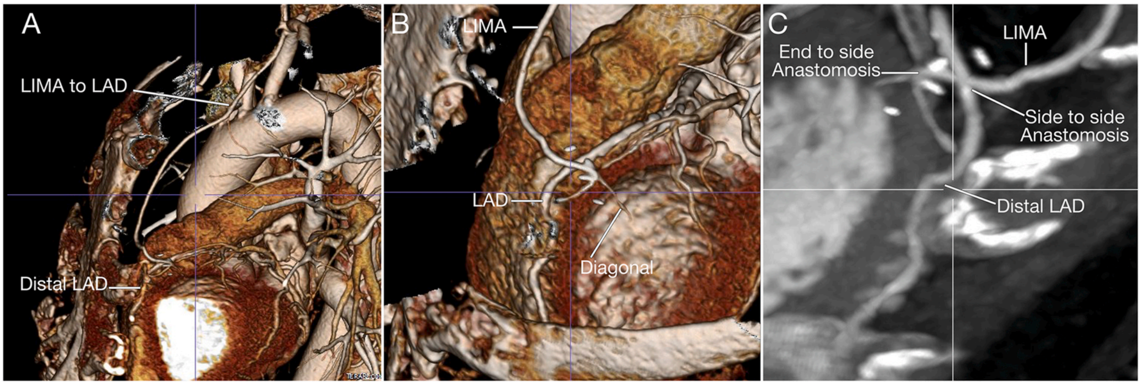

Fig. 6. 3D volume rendered (3VR) illustrates LIMA to LAD anastomosis (6A), LIMA to LAD as well as diagonal anastomosis can be seen (6B). Sequential LIMA graft with distal side-to-side anastomosis to LAD and end-to-side anastomosis to diagonal artery is evident (6C).

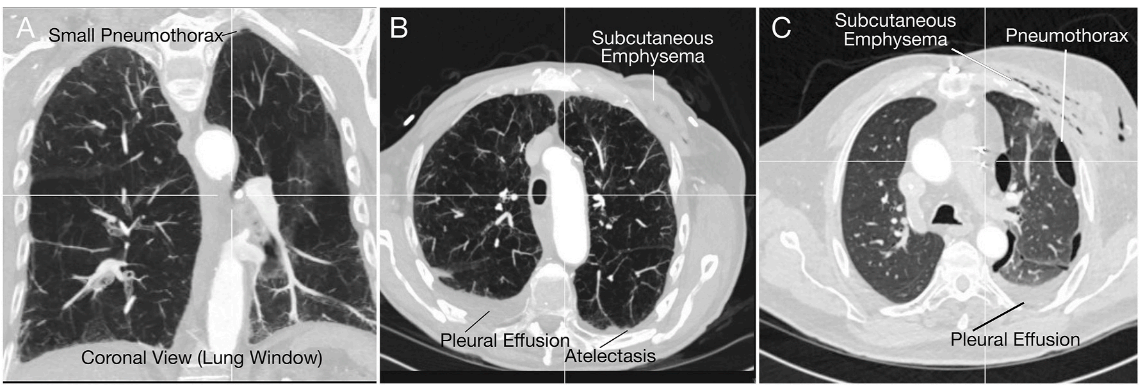

Fig. 7. CCTA shows postoperative changes of a small pneumothorax, subcutaneous emphysema, pleural effusion and atelectasis (7A-C).

8. Conclusion

Based on published evidence and review of available imaging cases series from our database, CCTA imaging appears to be a reliable tool allowing visualization of the grafts, target coronary arteries, other cardiac and non-cardiac structures in patients undergoing a RCABG procedure, with a high spatial and temporal resolution. It helps in evaluating baseline coronary and graft anatomy, early and late complications and also, provides an important follow up information in assessing the graft patency. The valuable information, which can be obtained from CCTA, provides feedback to the surgeon which is quite helpful in improving the technique and also lays a roadmap for further interventions if required. There are no guidelines or recommendations available as to when CCTA should be performed after RCABG, however, our experience and experience of other RCABG centers supports utilization of the comprehensive CCTA imaging following this novel surgical methodology.

Disclosures

None.

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None.

Ethical approval

This is a review article; hence, ethics committee approval is not needed.

Consent

This is a review article containing de-identified radiological images of important aspects of robotic CABG, no consent is needed.

Author contributions

Study concept or design: AA, AKP.
Data collection and analysis: AKP, JZL, AA.
Writing the paper: AKP, JZL, RSP and AA.
Final approval: AKP, JZL, RSP and AA.

Registration of research studies

1. Name of the registry:
2. Unique Identifying number or registration ID:
3. Hyperlink to your specific registration (must be publicly accessible and will be checked):

Guarantor

Ahmed K. Pasha and Aiden Abidov.

Declaration of competing interest

None for all authors.

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