Review Article

Right coronary artery anatomy: Chronic total occlusion interventionist's perspective

ABSTRACT

Chronic total occlusion (CTO) intervention success has been improving with the evolution of newer devices and increasing operator expertise. In the recanalization of CTO, apart from CTO anatomy, occluded artery anatomy on either side of the CTO and collateral anatomy play a significant role in planning interventional strategy. Occluded artery anatomy affects the support provided by the guide for antegrade wiring, retrograde gear reach to the distal cap, selection of the site, and the type of reverse controlled antegrade and retrograde tracking and externalization. The right coronary artery (RCA) is the most common host for CTOs and shows many more variations in the course than other coronaries, posing specific challenges to interventionists while planning wiring strategies. The collateral entry pattern into RCA affects the retrograde gear reachability to the distal cap, steerability of wire, and support provided to retrograde wire escalation. Overall, some unique challenges interventionists face while treating RCA CTOs are linked to frequent anatomical variations in the origin from the aorta, tortuosity in the atrioventricular groove course, site of patent ductus arteriosus origin, and collateralization pattern both ipsilateral and contralateral. This manuscript describes anatomical variations of RCA and its collaterals, which interventionists should be mindful of while planning the wiring strategy and other procedural steps.

Keywords: Antegrade, chronic total occlusion, patent ductus arteriosus, retrograde, right coronary artery, tortuosity

INTRODUCTION

The last two decades have witnessed considerable progress in techniques and technologies that have increased the success rate of chronic total occlusion (CTO) interventions. In the recanalization of CTO, apart from CTO anatomy, occluded artery anatomy and collateral anatomy play significant roles in planning the interventional strategy.[1] Occluded artery anatomy affects the support given for antegrade wiring, retrograde gear reach to the distal cap, site, and the type of reverse controlled antegrade and retrograde tracking (CART) and externalization. Anatomically, the right coronary artery (RCA) is not only the common host for CTOs[2,3] but also shows much more course variations than other coronaries, posing challenges to interventionists while planning wiring strategies.[2] Collateral entry into RCA affects the retrograde gear reachability to the distal cap, steerability of the wire, and support provided for retrograde wire escalation. The unique challenges interventionists face while opening RCA CTOs are due to the frequent anatomical variations in the origin from the aorta, course in the atrioventricular (AV) groove, site of patent ductus arteriosus (PDA) origin, and collateralization pattern both ipsilateral and contralateral. This manuscript

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describes anatomical variations of RCA and its collaterals, which interventionists should be mindful of while planning wiring strategy and other procedural steps.

RIGHT CORONARY ARTERY ORIGIN AND PROXIMAL COURSE VARIATIONS

The anomalous origin of RCA is the most common among all coronary anomalies.[4] The origin of RCA affects the choice of the guide catheter and the support given for antegrade wiring.[4] Common RCA origin anomalies are anterior origin from the right sinus [Figure 1a], high anterior origin, and shepherd crook origin.[5]

RIGHT CORONARY ARTERY ORIGIN IMPACT ON STUMPLESS OSTIAL RIGHT CORONARY ARTERY CHRONIC TOTAL OCCLUSION ASSESSMENT AND PROCEDURAL PLANNING

Anatomical variations of origin make understanding of stumpless aorto-ostial RCA CTO more complex and mandate computed tomography (CT) coronary angiogram for interventional planning [Figure 2a and b]. Antegrade options are not available in this scenario. In retrograde, after placement of the microcatheter at the distal cap, the RCA origin and course of the proximal segment should guide the wire of choice for escalation. In the regular origin with perpendicular course from sinus, the wire can be escalated to intermediate penetration force wires like Gaia 2, 3 [Figure 2c and d] or high penetration force Conquest (Asahi Intecc, Japan) or Hornet (Boston Scientific, USA) wires if required. However, in other origins with vessels coursing along the aortic wall either upward or downward, the possibility of intermediate or high penetration force wires entering the aorta through the subintima or extra-arterial course is high. Hence, escalation to low or medium penetration force polymer jacket wires (Pilot series [Abbott Vascular, USA]) is the preferred option when channel tracking wires do not make any progress. Entry into the aorta through subintima can pose the risk of aortic dissection or aortic intramural hematoma.[6,7] In addition to these, externalization in this scenario needs snaring [Figure 6i] of retrograde wire, preferably in the brachiocephalic artery or descending thoracic aorta if feasible.

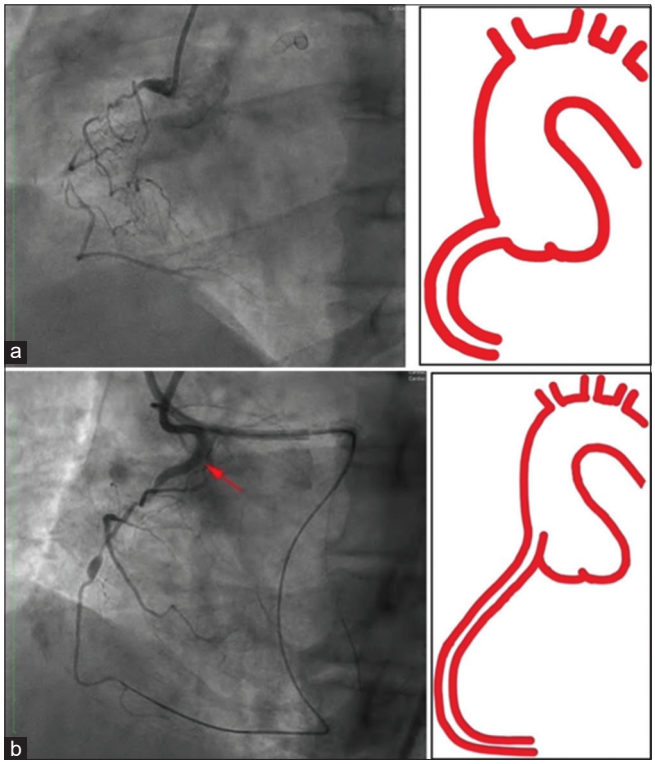

Figure 1: (a) RCA originating from anterior part of right sinus and traversing horizontally. (b) RCA originating from anterior and cranial part of right sinus and traversing downwards

RIGHT CORONARY ARTERY ORIGIN ANOMALIES AND ITS IMPACT ON NONOSTIAL RIGHT CORONARY ARTERY CHRONIC TOTAL OCCLUSION INTERVENTION PLANNING

Guide support is crucial for crossing the CTO segment with wire escalation that depends on the type of guide and its coaxial alignment with ostio-proximal RCA. The type of guide and guide coaxiality is determined by the origin of RCA and its subsequent course after its origin.[8] The aforementioned RCA origin variations do not allow deep seating of guide catheter, leading to noncoaxiality and poor support for antegrade wire escalation and gear advancement. Anchor balloon [Figures 1b and 3a-c] or preemptive usage of guide extension catheter, preferably TrapLiner (Teleflex, USA) [Figure 3c], enhances guide support facilitating wire escalation and also assists in reverse CART and externalization. Antegrade dissection with knuckle wire in this scenario can only be done by balloon anchoring of microcatheter [Figure 3d and e] or by guide-extension balloon anchoring using a ping-pong guide if adequate vessel size is available proximal to CTO [Figure 3b].

MID-RIGHT CORONARY ARTERY COURSE VARIATIONS

Mid-RCA course in left anterior oblique (LAO) projection is generally perceived as "C" shape and that guides the operator in wiring CTOs in this location. This general assumption does not work every time as variations in the course of RCA as "Z" or "S" bends are common in this segment [Figures 4a-c and 6a, b]. If there is a long CTO encompassing the entire mid-RCA, a complete understanding of the course of RCA is important for wiring either antegrade or retrograde. Certain anatomical clues like the origin of acute marginal arteries [Figure 5a and b] help in ascertaining the course of the vessel in angiography.

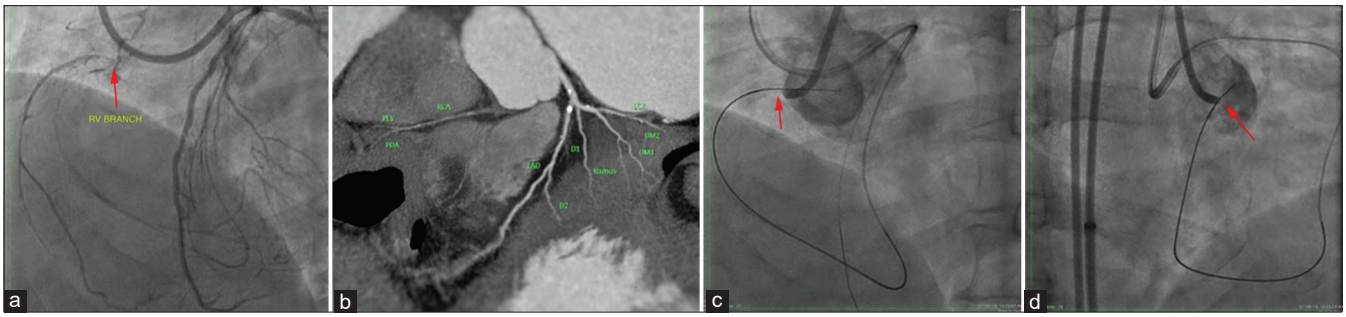

Figure 2: Stumpless ostial RCA CTO. (a and b) Angio and CT image showing short segment ostial RCA CTO and normal origin with perpendicular course of proximal RCA. (c) LAO View: Retrograde Gaia 2 Coursing horizontally towards aorta. (d) RAO view: Retrograde Gaia 2 entering aorta at mid right coronary sinus. RCA: Right coronary artery, CTO: Chronic total occlusion

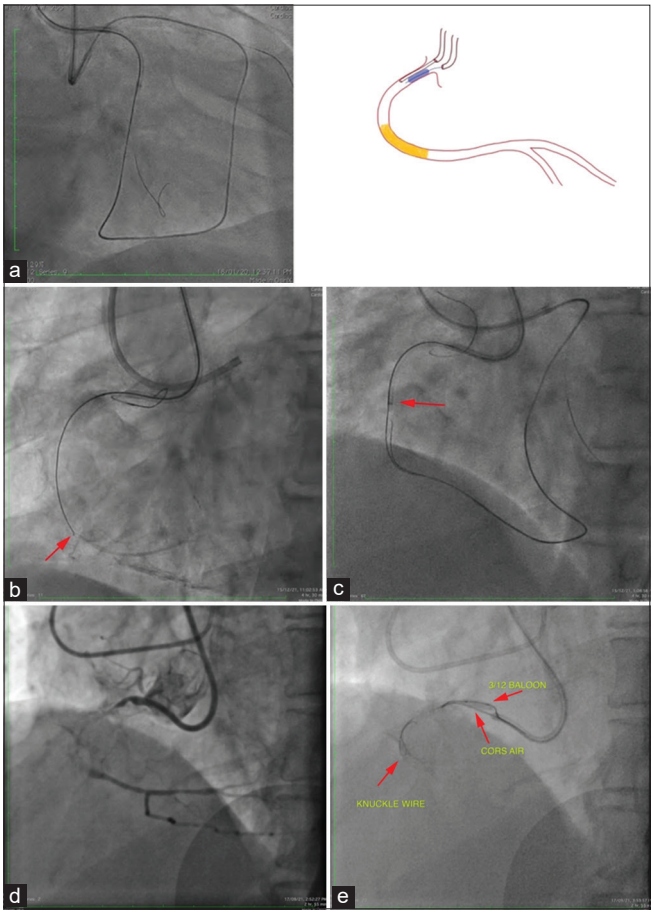

Figure 3: (a)Proximal RCA loop. (b) 1.5 mm anchor balloon in SA node branch to enhance guide support for AWE. (c) Antegrade wiring supported by guide extension and anchor balloon support. (d) Proximal to mid RCA instent CTO. (e) Knuckled wire through Corsair entrapped in proximal RCA with 3 mm balloon

However, when the course is unclear in angiography, CT coronary angiography is needed for better understanding to prepare an appropriate wiring strategy.

IMPACT OF THE BENDS ON PROCEDURAL PLANNING FOR MID-RIGHT CORONARY ARTERY CHRONIC TOTAL OCCLUSION

"Z" or "S" bends in mid-RCA result in difficulty in navigating medium-to-high penetration force wires due to unclear paths. These bends increase the possibility of antegrade wire going subintimal or even out of vessel architecture if high HPF wires are used (Hornet 10, 14/Conquest 12,20). CT fusion into a fluoroscopy screen would guide the operator to navigate wire across the CTO body, but it is not unremarkably accurate. When the course is unclear, medium penetration force polymer-jacketed wire is a better choice for wire escalation, and parallel wire or antegrade dissection and reentry (ADR) would help in bailing out when the first wire goes subintimal. However, the threshold to go retrograde is much less in

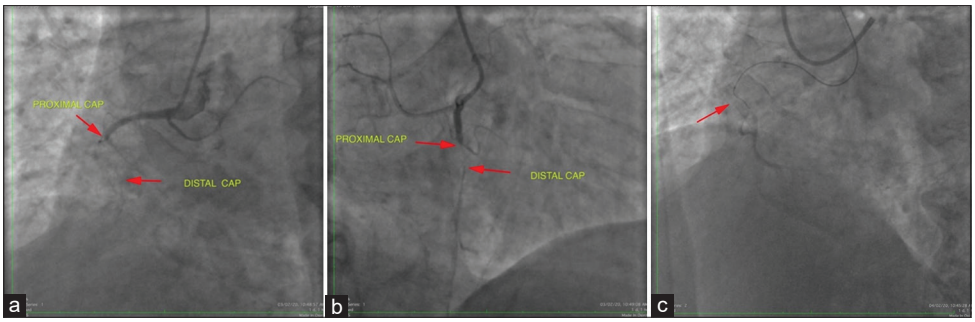

Figure 4: (a and b) Mid RCA CTO - CTO segment appeared straight in RAO view but non-linear location of caps of CTO in LAO view. (c) Fielder XTR (Asahi Intecc, Japan) wire forming a loop in the CTO segment in LAO view.

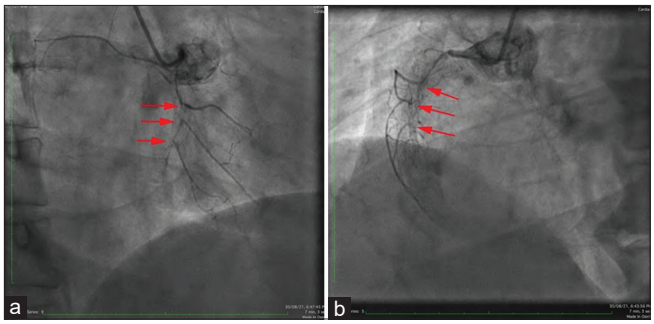

Figure 5: (a and b) Mid RCA CTO acute marginals origin delineating the course of the vessel

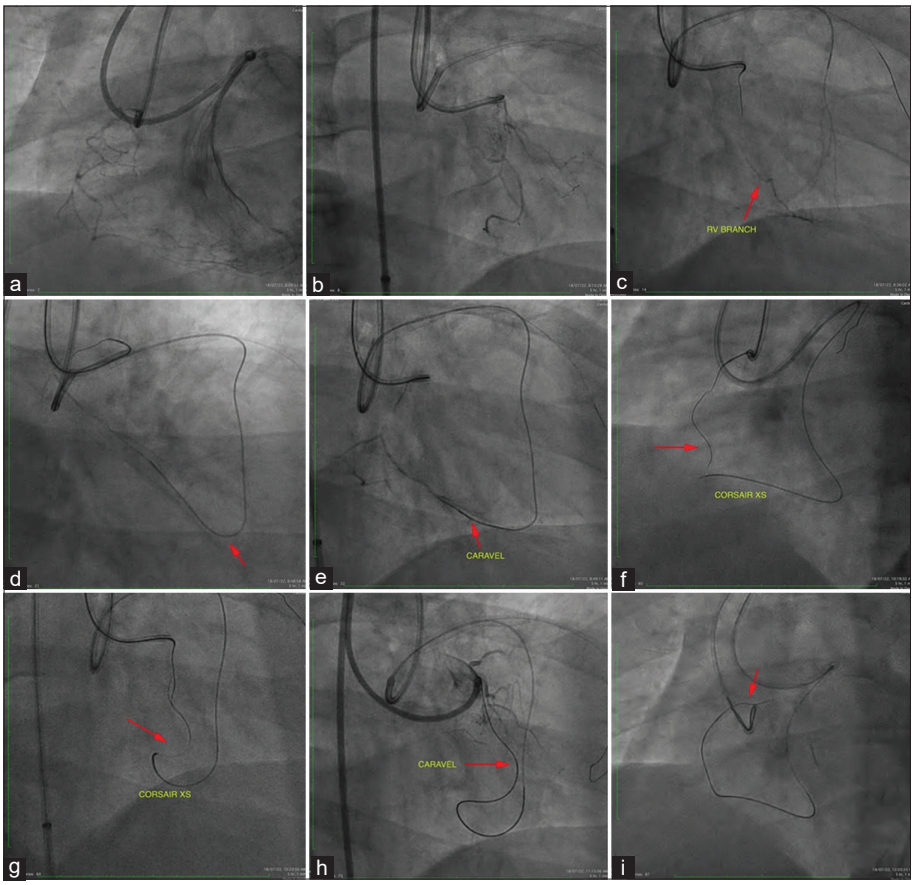

Figure 6: (a and b) S or Z bend in mid RCA with a short CTO. (c and d) Septal collateral connecting to RV branch with an acute bend at transition delineated by Caravel microcatheter (Asahi Intecc, Japan). (e) Caravel through septal into RV branch - angiogram showing short collateral entry to distal cap distance. (f and g) Loop in mid RCA transition to distal RCA in LAO and RAO view. Retrograde Corsair stuck at the loop. (h) Caravel traversed the loop. (i) Retrograde wires snaring with goose neck snare through the antegrade guide

such tortuous anatomies as two wires on either side of CTO would help in the advancement of either wire using the other as a marker. In retrograde, while choosing collateral, if the septal collateral is connected to the right ventricular (RV) branch [Figure 6c], the site of RV branch origin in relation to the distal cap [Figure 6d and e] is important as short RV branch entry to distal cap distance coupled with its increased mobility in fluoroscopy reduces maneuverability and steerability of retrograde wire. For retrograde wiring in mid-RCA bends, the microcatheter should be advanced close to the distal cap for better wire control and escalation to medium penetration force wires. If Corsair does not advance [Figure 6f and g], switch to a more flexible microcatheter like Caravel or Fine Cross (Terumo, Japan) [Figure 6h] to traverse the loops to reach the distal cap.

Furthermore, tortuosity would result in divergence of antegrade and retrograde wires, resulting in difficulty in connecting spaces [Figure 7a and b]. In case of persistent difficulty in approximating antegrade and retrograde wires, knuckle wire can be used, preferably, retrograde knuckling to overcome the course ambiguity. Conventional reverse CART with 1:1 balloon and high tip load retrograde wire (Hornet or Conquest series) with long curve or IVUS-guided reverse CART in feasible cases would increase the success of bringing retrograde wire into antegrade space. Operators need to be mindful of all the branches of mid-RCA when ADR is considered to prevent CrossBoss (Boston Scientific, USA) or knuckle wire entry into these branches and consequent perforations. A larger knuckle can be used to cross past the side branches if CrossBoss is entering side branches. In Z or S bends, knuckle wire is the safer strategy for dissection than CrossBoss. Mid-RCA is not a good zone for reentry due to poor visibility and hypermobility.

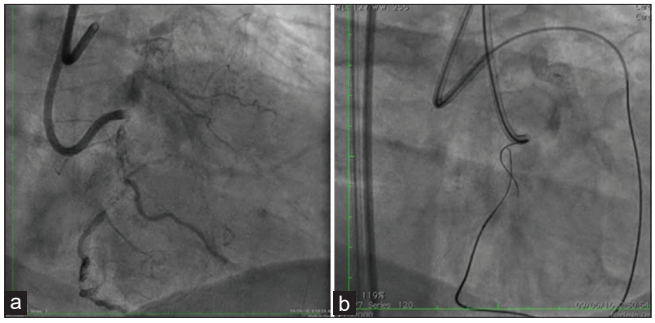

Figure 7: (a) Tortuous CTO segment in mid RCA. (b) Antegrade retrograde wires in different planes due to tortuosity

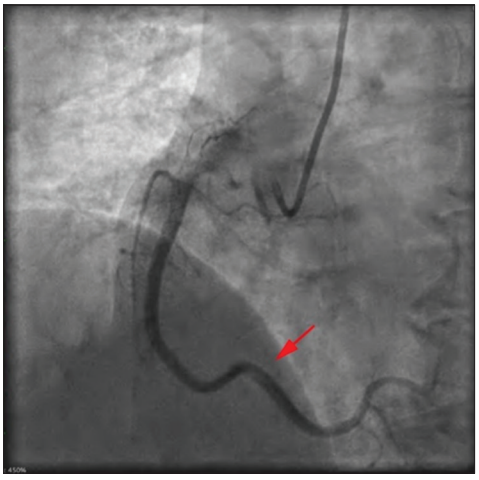

Figure 8: Sinusoidal bend in normal distal RCA in LAO projection

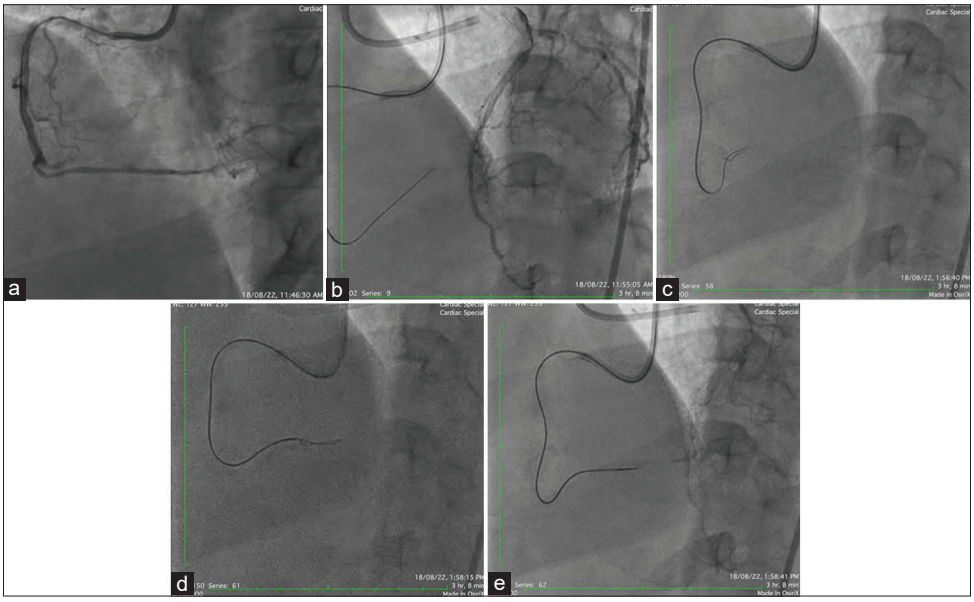

Figure 9: (a) Dual injections showing CTO of distal RCA with early origin of PDA. (b) Gaia 2 exited vessel architecture due to bend. (c) Knuckled wire with Fielder XTR beyond the proximal cap. (d) Knuckled wire across the bend till the segment of RCA which is in line with distal vessel. (e) Switch to directable wire (Gaia 2) after crossing loop with a knuckle and advancement of microcatheter

IMPACT OF THE BENDS ON PROCEDURAL PLANNING FOR DISTAL RIGHT CORONARY ARTERY CHRONIC TOTAL OCCLUSION

In this scenario, antegrade wire maneuverability is reduced, so preemptive guide extension catheter (preferably TrapLiner) placement across the loops of RCA would facilitate antegrade wire escalation (AWE). Furthermore, guide extension would simplify externalization when moved to retrograde as maneuvering high penetration force wires across these bends till the antegrade guide catheter is time-consuming and, at times, the wire may go subintimal before reaching the antegrade guide catheter. Guide extension also facilitates seamless subsequent antegrade device movement across the loops.

DISTAL RIGHT CORONARY ARTERY VARIATIONS

Distal RCA course can show similar loops [Figure 8] as mid-RCA but less frequently. Nonetheless, the site of PDA origin and its alignment with distal RCA plays a significant role in planning CTO intervention.

IMPACT OF THE BENDS ON PROCEDURAL PLANNING FOR DISTAL RIGHT CORONARY ARTERY CHRONIC TOTAL OCCLUSION

Figure 9a-c shows distal RCA CTO with the early origin of PDA. AWE to intermediate or high penetration force wires can lead to wire exiting out of vessel architecture [Figure 9b]. Even retrograde wire can exit in a similar way. Hence, the knuckle wire [Figure 9d and e] in this situation helps in clearing the

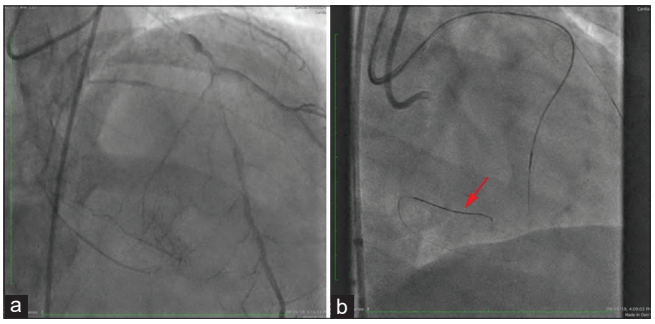

Figure 10: (a and b) Distal RCA to PDA angulation unfavourable for retrograde wire entry to distal RCA

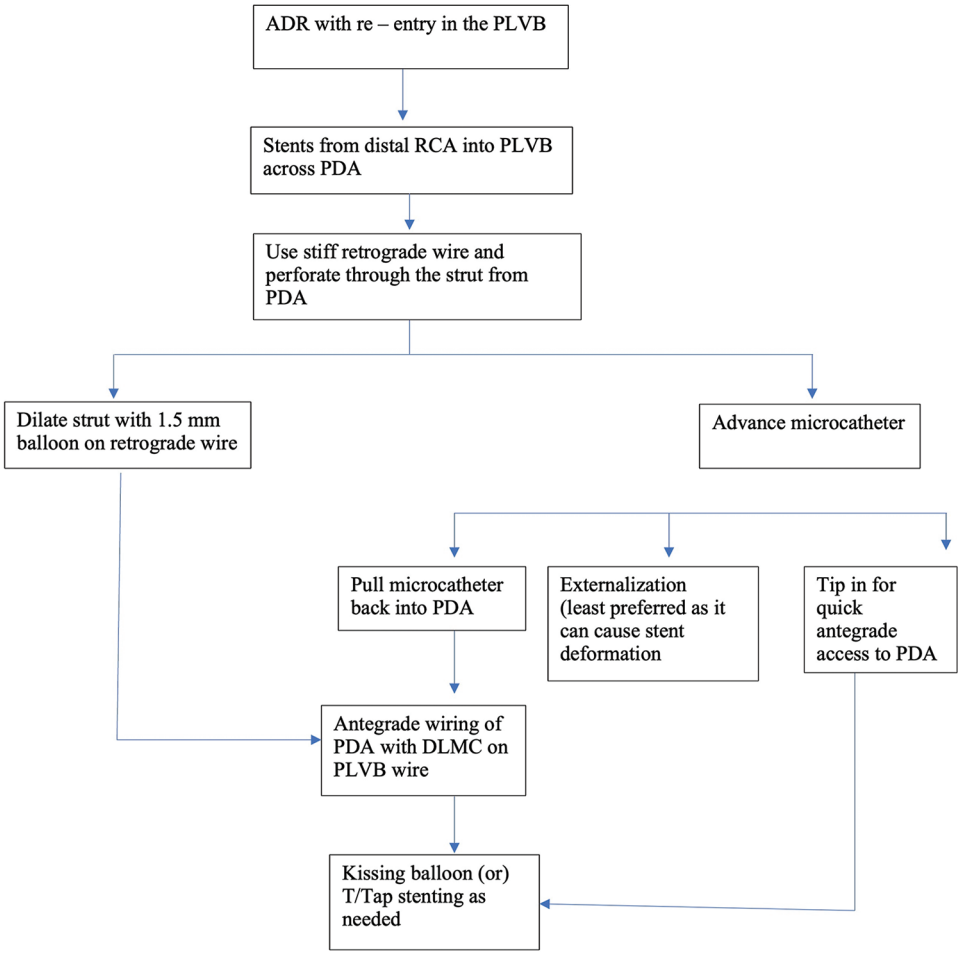

Figure 11: PDA recanalization in ADR with re-entry in PLVB

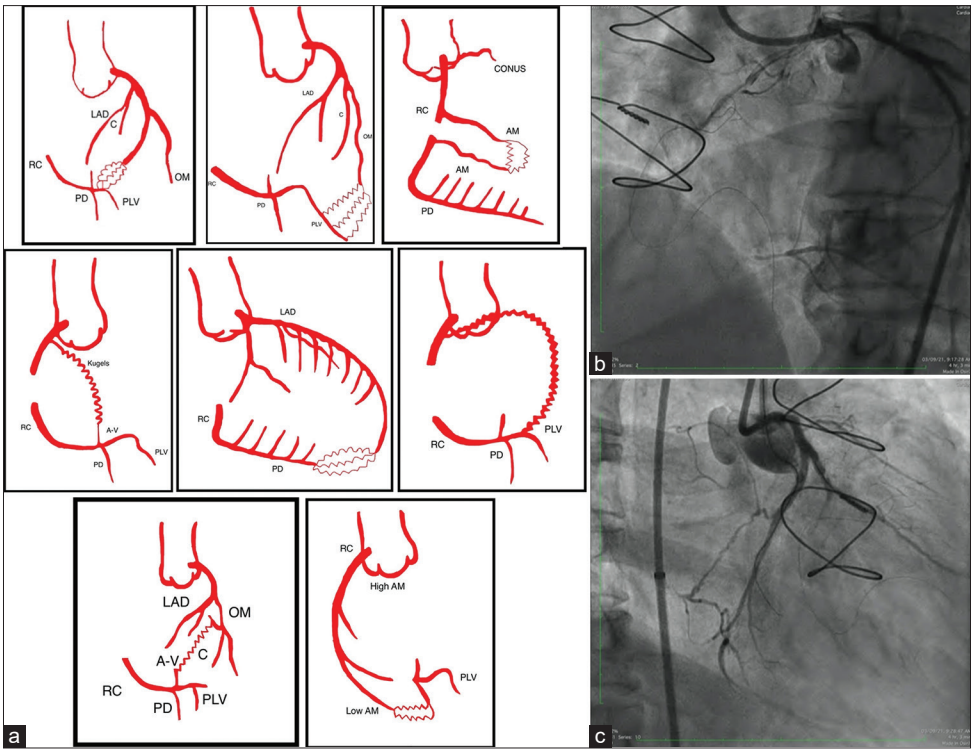

Figure 12: (a-c) Posterior AV groove epicardial collateral from LCX to PLVB

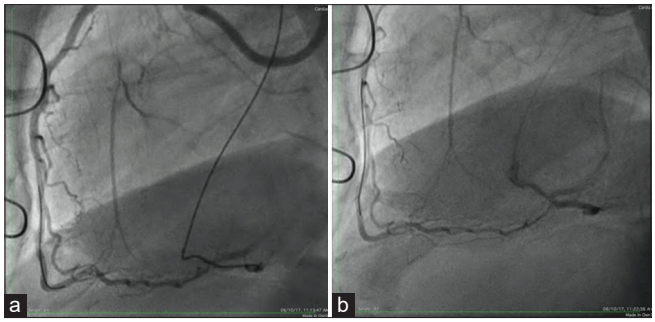

Figure 13: (a and b) SVG to distal RCA anastomose before crux. SVG is coaxially aligned to distal RCA and wire went into distal RCA

path but necessitates having a reentry strategy if the knuckle goes subintimal.

IMPACT OF THE BENDS ON PROCEDURAL PLANNING FOR PROXIMAL TO MID-RIGHT CORONARY ARTERY CHRONIC TOTAL OCCLUSION

After crossing CTO, the antegrade wire must be navigated carefully under visualization to prevent entry to subintima. However, advancing the microcatheter beyond CTO, if possible, and swapping it to workhorse wire shall simplify crossing distal tortuous RCA. Similarly, when retrograde wiring is used, the microcatheter should be placed close to the distal cap traversing the loop before escalating to intermediate or high penetration force wires [Figure 6f-h].

SEPTAL COLLATERALS AND THEIR VARIABLE COURSE AND DRAINAGE

Septal collaterals are generally safe retrograde channels but are next only to venous graft conduits.[9,10] Crossing of septal collaterals from the left anterior descending artery (LAD) to RCA is easier than vice versa due to the favorable take-off angle. Nevertheless, septal collaterals for retrograde RCA percutaneous coronary intervention (PCI) can pose many challenges due to its variations of entry into RCA, coaxiality of the recipient branch with the distal RCA, and collateral entry to distal cap distance. In general, septal collaterals enter PDA, but infrequently, entry into RV branches is shown in Figure 6c. Unlike septals entering the PDA, those entering the RV branch would pose challenges to advance retrograde microcatheter due to the acute angle of entry and reduce wire maneuverability due to hypermobility [Figure 6d and e]. Sufficient collateral entry to distal cap distance is crucial to maneuver retrograde gear[11] into the distal RCA. In cases of distal cap at the crux, steering retrograde gear into distal RCA becomes difficult. Further, steering wire into distal RCA is difficult if proximal PDA is not coaxial with distal RCA but aligned to posterior left ventricular branches (PLVB), as shown in Figure 10a and b. In such situations, retrograde double-lumen catheter (Sasuke, Asahi Intecc) would offer some support for wire navigation; However, ADR or marker wire technique can be used to navigate antegrade wire into PLVB. If reentry is in PLVB, PDA can be rescued using techniques described in Figure 11.

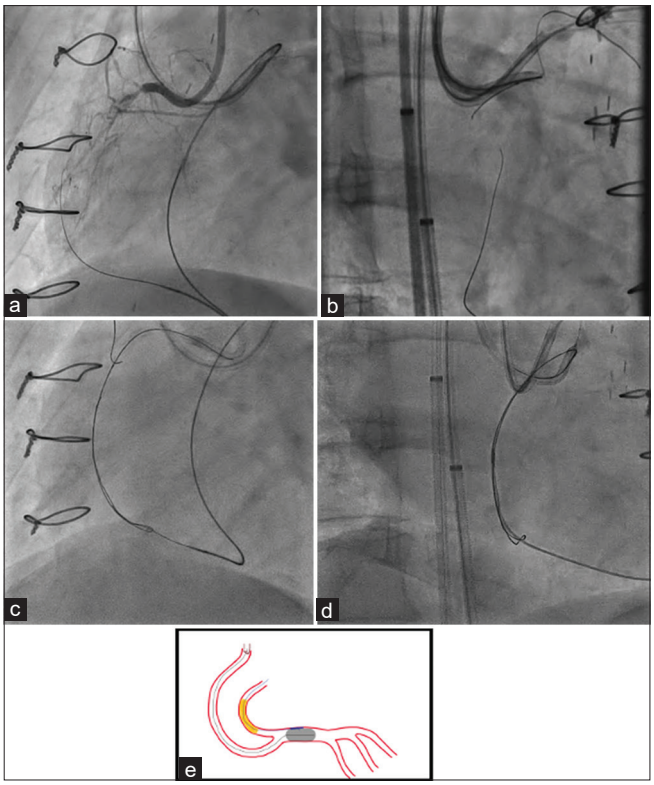

Figure 14: (a and b) Retrograde wire appearing as if in RCA in LAO view but in RAO view wire positioned was anterior to RCA suggestive of SVG. (c and d) Retrograde wire in RCA in LAO and RAO views. (e) Facilitated ADR

EPICARDIAL COLLATERALS OF RIGHT CORONARY ARTERY

RCA is supplied with a variety of epicardial collaterals, both ipsilateral and contralateral, based on the location of CTO, as depicted in Figure 12a-c. Among them, posterior AV groove and distal LAD to PDA collaterals are often used for retrograde interventions as the size is conducive. Determine the better view for visualization of the channel before embarking on wiring it. Certain nuances must be kept in mind when distal LAD to PDA epicardial collateral is chosen, use short guides to get the more usable length of microcatheter and use antegrade guide extension catheter for externalization. AV groove collaterals are preferred over septal when angulation of PDA at the crux is noncoaxial with distal RCA and distal cap to PDA origin distance is too short for wire maneuvering. When AV groove collaterals are used in postcoronary artery bypass graft patients, the threshold for embolization is much lower if perforated, as it might lead to a loculated tamponade of LA.[10,11]

RIGHT CORONARY ARTERY GRAFTS AS CONDUITS

RCA is grafted with either venous or arterial grafts based on the availability of conduit, age of patient, and choice of surgeon. In general, venous grafts are the safest retrograde conduits.[12] Crossing occluded venous grafts becomes difficult with a longer duration of occlusion. Graft characteristics that affect technical decisions while using it as retrograde conduit are aortic anastomosis site, lie of the graft, distal anastomosis site, and angulation of the distal part of saphenous vein graft (SVG) with the recipient vessel proximal to anastomosis.

Proximal anastomosis of SVG is generally done on the right anterior aspect of the aorta. Guide selection is the key, as retrograde catheter advancement needs good support. Judkins right, multipurpose, Amplatzer left, or right venous bypass cannulates SVG based on the site of anastomosis on the aorta and the angulation of proximal graft with the aortic wall. The course of the venous graft depends on the site of distal anastomosis and the length of the graft. Distal anastomosis is generally done in distal RCA territory to [Figure 13a and b] proximal PDA, proximal PLVB or rarely on to RV branches of good size. Usually, surgeons prefer the graft to be coaxial with the distal recipient for favorable flow dynamics, which makes graft angulation with the proximal vessel more acute. This kind of angulation would make retrograde wire navigation into proximal RCA a bit challenging, especially when graft length is short, as it makes the angle more acute.[13-15]

In retrograde RCA PCI through septal collateral with occluded venous graft anastomosed to distal RCA, the operator should navigate through pre-crux RCA in both LAO and right anterior

oblique (RAO) views as plain LAO does not differentiate wire course in RCA from that in SVG [Figure 14a-d].[16]

The availability of SVG conduit in native RCA CTO PCI increases the success of reentry by facilitated ADR[17] [Figure 14e]. In this, a balloon of 1:1 size is inflated at the reentry site, followed by reentry through Stingray (Boston Scientific, USA) using stick and drive technique with Gaia 2/3, Conquest, or Hornet wires.

CONCLUSION

RCA is the common host for CTO and also for anatomical variations, which complicates CTO interventional planning. The anatomy of the CTO segment plays a major role in preparing the wiring strategy, but the vessel proximal and distal to the CTO also determines the success by influencing the navigability of antegrade or retrograde gear. Hence, a comprehensive idea of the anatomy of the entire RCA from its origin to bifurcation at the crux would help in suitable collateral selection and preparing an appropriate bailout strategy for anticipated problems. Understanding RCA tortuosity in CTO or non-CTO segments and the site of origin of branches within respective segments helps in tailoring ADR and choosing the site and the type of reverse CART.

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Conflicts of interest

There are no conflicts of interest.

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