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Multicenter experience with the antegrade fenestration and reentry technique for chronic total occlusion recanalization

Lorenzo Azzalini MD, PhD, MSc^{1,2}  | Khaldoon Alaswad MD³  |
Barry F. Uretsky MD⁴  | Pierfrancesco Agostoni MD, PhD⁵ |
Alfredo R. Galassi MD^{6,7} | Marcelo Harada Ribeiro MD^{8,9} |
Evandro Martins Filho MD¹⁰ | Neisser Morales-Victorino MD¹¹  |
Antonious Attallah MD¹² | Ankur Gupta MD, PhD³  | Carlo Zivelonghi MD⁵  |
Matteo Montorfano MD² | Barbara Bellini MD² | Mauro Carlino MD²

¹The Zena and Michael A. Wiener
Cardiovascular Institute, Icahn School of
Medicine at Mount Sinai, New York, New York

²Division of Interventional Cardiology, Cardio-
Thoracic-Vascular Department, San Raffaele
Scientific Institute, Milan, Italy

³Department of Cardiology, Henry Ford
Hospital, Detroit, Michigan

⁴Department of Cardiology, University of
Arkansas for Medical Sciences (UAMS) and
Central Arkansas Veterans Health System
(CAVHS), Little Rock, Arkansas

⁵Hartcentrum, Ziekenhuis Netwerk Antwerpen
(ZNA) Middelheim, Antwerp, Belgium

⁶Department of PROMISE, University of
Palermo, Palermo, Italy

⁷Department of Cardiology, Royal Brompton &
Harefield Hospital, London, UK

⁸SOS C  RDIO Hospital, Florian  polis, Santa
Catarina, Brazil

⁹Heart Institute, S  o Paulo University School
of Medicine, S  o Paulo, S  o Paulo, Brazil

¹⁰Interventional Cardiology, Santa Casa de
Miseric  rdia de Macei  , Macei  , Alagoas,
Brazil

¹¹Department of Cardiology, Adolfo Lopez
Mateos, ISSSTE, Mexico City, Mexico

¹²Ascension St. John Hospital, Detroit,
Michigan

Correspondence

Lorenzo Azzalini, Cardiac Catheterization
Laboratory, Klingenstein Clinical Center (KCC),
7th Floor North, The Mount Sinai Hospital,
1450 Madison Avenue, New York, NY, USA.
Email: lorenzo.azzalini@mountsinai.org

Abstract

Objectives: We aimed to evaluate the efficacy and safety of antegrade fenestration and reentry (AFR) for chronic total occlusion (CTO) recanalization in a multicenter registry.

Background: Adoption of antegrade dissection/reentry (ADR) for CTO recanalization has been limited, and novel ADR techniques are needed.

Methods: AFR involves the balloon-induced creation of multiple fenestrations between the false and true lumen. A targeted true lumen reentry is subsequently achieved with a low tip-load polymer-jacketed guidewire. Following the initial description and dissemination of AFR, patients undergoing AFR-based CTO recanalization at nine centers were included in the present registry. Study endpoints were AFR success, procedural success, and target-lesion failure (TLF) on follow-up.

Results: We included 41 patients. Mean J-CTO score was 2.5 ± 1.4 . In 80.5% of cases, AFR was performed after failed antegrade wire escalation. Another ADR technique was used before AFR in one-third of cases. AFR achieved distal true lumen reentry in $n = 27/41$ (65.9%) cases. In $n = 14/41$ (34.1%) cases with AFR failure, use of alternative techniques led to successful CTO recanalization in eight additional patients. The overall technical and procedural success rates were 85.4% and 82.9%, respectively. No AFR-related complications were observed. One-year TLF rate was 8.3% overall, with no differences between successful and failed AFR.

Conclusions: We report on AFR feasibility in a multicenter registry of patients undergoing CTO recanalization. We observed a moderate success rate, coupled with the absence of complications. Moreover, even a failed AFR attempt did not preclude the use of alternative techniques to achieve recanalization. Further studies should confirm and extend our findings.

KEYWORDS

chronic total occlusion, dissection, percutaneous coronary intervention, reentry, subintimal

1 | INTRODUCTION

The reported success rates of chronic total occlusions (CTO) percutaneous coronary intervention (PCI) have recently increased due in large part to the combination of advances in devices and a comprehensive and individualized treatment plan, including antegrade and retrograde approaches. These techniques have been incorporated into a treatment concept described as the “hybrid algorithm,”¹ in which multiple strategies may be utilized during a single case, switching early from a failing mode to optimize the likelihood of success. Occlusions longer than 20 mm, with a non-ambiguous proximal cap, and an adequate distal “landing zone”, are particularly suitable for antegrade dissection/reentry (ADR). Following the introduction of the CrossBoss/Stingray system (Boston Scientific, Marlborough, MA), the adoption and success rates of ADR-based CTO PCI have increased, as this method provides a teachable and predictable dissection/reentry approach with favorable long-term outcomes.²⁻⁵ However, the uptake of this technique is limited in many healthcare systems by several factors including costs, learning curve, and need for training. Moreover, the success rate of Stingray-based reentry in real-world clinical practice (i.e., among operators with variable degrees of experience) is only moderate.³ For these reasons, simpler, less costly, and more effective ADR-based approaches are being investigated.

In 2018, we described the “antegrade fenestration and reentry” (AFR) technique,⁶ which can potentially address all the aforementioned limitations of Stingray-based reentry. The initial AFR report was, however, based on a small single-center two-operator series, and whether AFR can be disseminated and effectively adopted by several operators is unknown.

The aim of the present study is to describe the feasibility and safety of AFR for CTO recanalization, using a multicenter registry of early adopters.

2 | METHODS

2.1 | Technique description

A detailed step-by-step description of AFR has been previously provided.⁶ Briefly, after (inadvertent or intentional) subintimal advancement of a guidewire beyond the distal cap, a second (low tip-load, polymer-jacketed) guidewire is advanced just proximal to the distal cap, in close proximity with the first one. At this point, a balloon (sized 1:1 with the artery) is advanced onto the first guidewire, and inflated across the distal cap. This will create transient fenestrations between the false and true lumen, and targeted reentry into the true lumen can be achieved engaging these fenestrations with the second guidewire.

2.2 | Study population

We included all patients undergoing CTO PCI using AFR-based recanalization at nine participating centers between August 2017

and September 2019. Individual annual operator CTO PCI volume, as well as proportion of overall ADR and Stingray-based ADR cases, are provided in the Online Table S1, which shows a pronounced diversity with regard to operator experience and practice within our registry. CTO PCIs were indicated according to the presence of angina, ischemia, or both, and performed electively.⁷ Baseline, procedural, hospitalization, and follow-up data were recorded. Due to the retrospective nature of our study, a waiver of informed consent was granted by the institutional review boards of the participating centers.

2.3 | Definitions

CTO was defined as a 100% stenosis with thrombolysis in myocardial infarction (TIMI) 0 flow for >3 months.⁸ AFR attempt was defined as antegrade balloon inflation across the distal cap followed by one or more reentry attempts with a guidewire. AFR success was defined as the passage of a subintimal antegrade guidewire from the false into the true lumen, following balloon dilatation at the distal cap (reentry must be achieved in the area where balloon dilatation has taken place). Technical success was defined as a final stenosis <30% with TIMI flow Grade 3 in the CTO vessel.⁸ Procedural success was defined as technical success plus the absence of in-hospital adverse events (all-cause death, Q-wave myocardial infarction, stroke, recurrent angina requiring target-vessel revascularization, and tamponade requiring pericardiocentesis or surgery).⁸ Follow-up was performed by means of phone interview, review of hospital records or outpatient visit. Target-lesion failure (TLF) was defined as a composite of cardiac death, target-vessel MI, and ischemia-driven target-lesion revascularization.

2.4 | Statistical analysis

Continuous variables are presented as mean $\pm$ SD and *t* test was used for comparisons. Categorical variables are presented as frequency (percentages) and compared using chi-square test. For all tests, a *p* < .05 was considered significant. Statistical analysis was performed using SPSS 24 (IBM Corp., Armonk, NY).

3 | RESULTS

3.1 | Baseline characteristics

A total of 41 patients were included: *n* = 27 with successful AFR and *n* = 14 with failed AFR. Baseline characteristics of the study population were similar between groups (Table 1). Mean age was 63.9 $\pm$ 10.5 years, 85% of patients were men, and 29% were diabetics. Prior myocardial infarction was present in 37% and prior coronary artery bypass graft in 10%. Most procedures were indicated for angina relief.

TABLE 1 Baseline clinical characteristics

Variable	Overall (n = 41)	AFR success (n = 27)	AFR failure (n = 14)	p-Value
Age (years)	63.9 ± 10.5	64.0 ± 10.4	63.8 ± 11.2	.94
Male gender	35 (85%)	23 (85%)	12 (86%)	.96
Body mass index (kg/m ²)	29.3 ± 4.7	29.5 ± 4.6	29.0 ± 5.3	.78
Diabetes	12 (29%)	7 (26%)	5 (36%)	.51
Dyslipidemia	31 (76%)	20 (74%)	11 (79%)	.75
Hypertension	35 (85%)	22 (82%)	13 (93%)	.33
Current smoker	11 (27%)	9 (33%)	2 (14%)	.19
Prior myocardial infarction	15 (37%)	10 (37%)	5 (36%)	.93
Prior CABG	4 (10%)	1 (4%)	3 (21%)	.07
Chronic kidney disease	1 (2%)	1 (4%)	0	.47
LVEF (%)	52.1 ± 9.7	51.8 ± 10.7	52.6 ± 7.7	.82
LVEF <50%	10 (25%)	8 (31%)	2 (14%)	.25
Indication of CTO PCI				
Symptoms	22 (54%)	14 (52%)	8 (57%)	.49
Silent ischemia	12 (29%)	9 (33%)	3 (21%)	
Low LVEF	6 (15%)	4 (15%)	2 (14%)	
Acute coronary syndrome	1 (2%)	0	1 (7%)	

Abbreviations: AFR, antegrade fenestration and reentry; CABG, coronary artery bypass graft; CTO, chronic total occlusion; LVEF, left ventricular ejection fraction; PCI, percutaneous coronary intervention.

3.2 | Angiographic characteristics and procedural data

Table 2 presents the angiographic characteristics and procedural data of the study population. No significant differences were noticed between cases with AFR success and failure. The most frequent target vessel was the right coronary artery. Technical difficulty was high, as reflected by an overall mean J-CTO score of 2.5 ± 1.4 , with 71% of patients having a J-CTO score ≥ 2 . Sixty-one percent of cases had a long landing zone for AFR, defined as a reentry area >20 mm long before any significant bifurcation. Intravascular imaging was used in one-third of cases. Procedural metrics reflected the complexity of these procedures.

3.3 | Technical details of AFR

In the vast majority of cases (80.5%), AFR was performed after failed antegrade wire escalation (AWE), while in the remainder it was used as first-line strategy, failed Stingray-/wire-based ADR, or failed retrograde approach (Figure 1). Technical details on the AFR technique are presented in Table 3. Again, there were no differences between successful and failed AFR cases. Another ADR technique was used before AFR in one-third of cases. While a variety of guidewires was used to reach the landing zone, reentry was performed mainly with guidewires belonging to the Fielder and Sion families. Several microcatheters were used for reentry (mainly Corsair and Turnpike families). A dual-

lumen microcatheter was used in 12% of cases to deliver the reentry guidewire at the landing zone. An average of 3.4 ± 2.3 AFR attempts was performed, indicating that AFR is often successful after multiple attempts. Mean balloon size for AFR was 2.7 ± 0.5 mm.

As shown in Figure 2, AFR achieved distal true lumen reentry in $n = 27/41$ (65.9%) of cases. Of these, technical success was obtained in all patients, while procedural success was observed in all but one case (96.3%; see below). In $n = 14/41$ (34.1%) cases with AFR failure, use of alternative techniques (the retrograde approach or other ADR techniques) led to successful CTO recanalization in eight additional patients. Importantly, Stingray-based reentry could successfully be performed distal to the AFR site in two of these cases. Technical/procedural success was 57.1% in the failed AFR group. The overall technical and procedural success rates in this study were 85.4% and 82.9%, respectively.

3.4 | Complications

No AFR-related complications (e.g., perforation or periprocedural myocardial infarction) were observed in this study.

One patient with successful AFR-based reentry and CTO recanalization suffered wire exit during initial AWE attempts (before AFR was performed). As the perforation was minor and the hemodynamics were maintained throughout the procedure, a conservative management was initially adopted and recanalization was completed. However, due to delayed-onset tamponade, pericardiocentesis was later

TABLE 2 Angiographic characteristics and procedural data

Variable	Overall (n = 41)	AFR success (n = 27)	AFR failure (n = 14)	p-Value
Target vessel				
Left anterior descending	8 (20%)	7 (26%)	1 (7%)	.15
Circumflex	6 (15%)	5 (19%)	1 (7%)	
Right coronary artery	27 (66%)	15 (56%)	12 (86%)	
In-stent CTO	0	0	0	—
Blunt stump	30 (73%)	20 (74%)	10 (71%)	.86
Moderate or severe calcifications	17 (42%)	10 (37%)	7 (50%)	.42
>45° bending	13 (32%)	6 (22%)	7 (50%)	.07
CTO length > 20 mm	32 (78%)	20 (74%)	12 (86%)	.39
Retry	12 (29%)	7 (26%)	5 (36%)	.51
J-CTO score	2.5 ± 1.4	2.3 ± 1.5	2.9 ± 1.2	.26
J-CTO score ≥ 2	29 (71%)	17 (63%)	12 (86%)	.13
Proximal cap ambiguity	30 (73%)	20 (74%)	10 (71%)	.86
Absence of interventional collaterals	14 (34%)	11 (41%)	3 (21%)	.22
Moderate or severe tortuosity	6 (15%)	2 (7%)	4 (29%)	.07
Circumflex CTO	6 (15%)	5 (19%)	1 (7%)	.33
PROGRESS-CTO score	1.4 ± 0.8	1.4 ± 0.7	1.3 ± 1.0	.66
PROGRESS-CTO score ≥ 2	14 (34%)	9 (33%)	5 (36%)	.88
Length of landing zone (mm)				
<5	3 (7%)	0	3 (21%)	.15
5–10	5 (12%)	4 (15%)	1 (7%)	
10–15	3 (7%)	2 (7%)	1 (7%)	
15–20	5 (12%)	4 (15%)	1 (7%)	
>20	25 (61%)	17 (63%)	8 (57%)	
Intravascular imaging	13 (32%)	10 (37%)	3 (21%)	.31
Total stent length (mm)	78 ± 30	77 ± 29	82 ± 35	.68
Contrast volume (ml)	386 ± 156	403 ± 157	354 ± 156	.35
Kerma area product (Gy·m ²)	295 ± 215	305 ± 249	273 ± 109	.70
Fluoroscopy time (min)	65 ± 29	64 ± 33	69 ± 21	.57
Total procedure time (min)	154 ± 63	142 ± 60	175 ± 66	.13

Abbreviations: AFR, antegrade fenestration and reentry; CTO, chronic total occlusion.

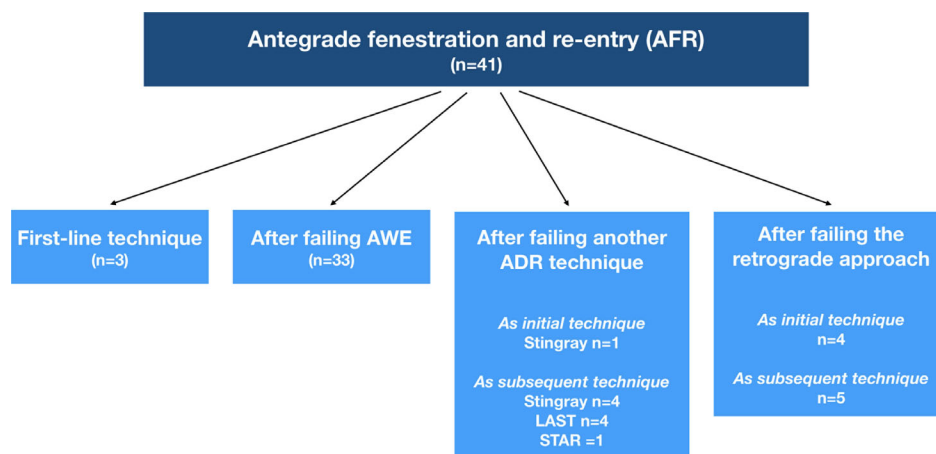


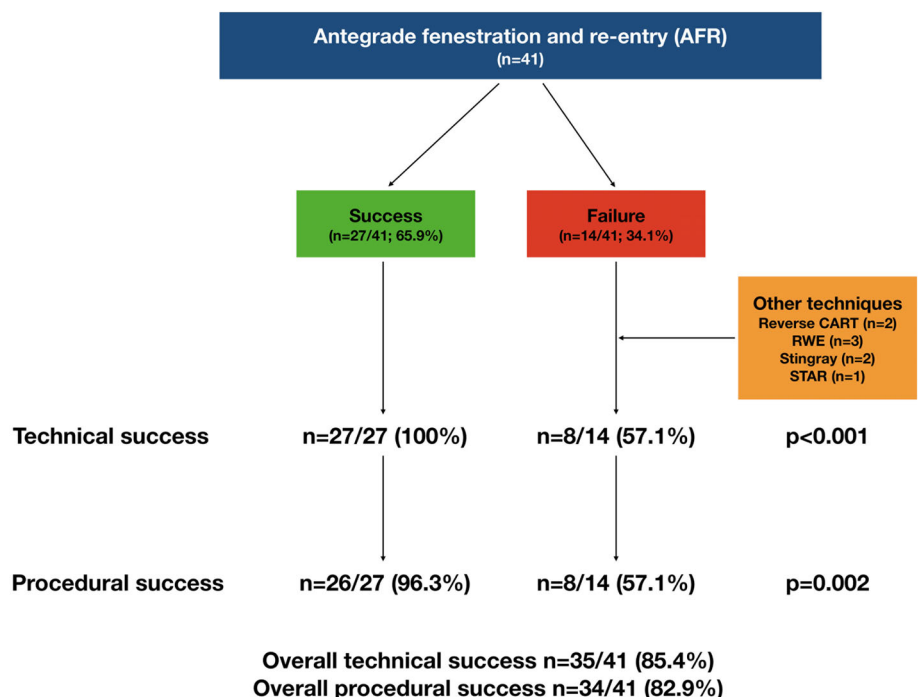
FIGURE 1 Role of antegrade fenestration and reentry (AFR) in the procedural workflow of this cohort. Note: as multiple techniques were often employed in a given patient, the sum of techniques attempted is greater than the overall sample size. ADR, antegrade dissection and reentry; AWE, antegrade wire escalation; LAST, limited antegrade subintimal tracking; STAR, subintimal tracking and reentry [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Technical details on AFR-based recanalization

Variable	Overall (n = 41)	AFR success (n = 27)	AFR failure (n = 14)	p-Value
Other ADR technique used before AFR	14 (34%)	8 (30%)	6 (43%)	.40
Subintimal guidewire				
Pilot family	11 (27%)	7 (26%)	4 (29%)	.64
Gaia family	8 (20%)	5 (19%)	3 (21%)	
Fielder family	6 (15%)	5 (19%)	1 (7%)	
Miracle family	5 (12%)	4 (15%)	1 (7%)	
Confianza family	1 (2%)	0	1 (7%)	
Others	10 (24%)	6 (22%)	4 (29%)	
Guidewire used for reentry				
Fielder family	20 (49%)	10 (37%)	10 (71%)	.046
Sion family	13 (32%)	12 (44%)	1 (7%)	
Pilot family	2 (5%)	2 (7%)	0	
Others	6 (15%)	3 (11%)	3 (21%)	
Microcatheter used for reentry				
Corsair (pro)	14 (34%)	9 (33%)	5 (36%)	.37
Turnpike family	10 (24%)	5 (19%)	5 (36%)	
Finecross	6 (15%)	5 (19%)	1 (7%)	
Others	7 (17%)	4 (15%)	3 (21%)	
None	4 (10%)	4 (15%)	0	
Dual-lumen microcatheter to deliver reentry guidewire	5 (12%)	4 (15%)	1 (7%)	.48
Number of AFR attempts	3.4 ± 2.3	3.2 ± 2.3	3.8 ± 2.3	.46
Balloon size for AFR (mm)	2.7 ± 0.5	2.8 ± 0.5	2.7 ± 0.5	.79

Abbreviations: ADR, antegrade dissection and reentry; AFR, antegrade fenestration and reentry.

FIGURE 2 Antegrade fenestration and reentry (AFR) success/failure rates, as well as technical/procedural success rates in the study population. CART, controlled antegrade and retrograde subintimal tracking; RWE, retrograde wire escalation; STAR, subintimal tracking and reentry [Color figure can be viewed at wileyonlinelibrary.com]



performed. This was successful, and the patient was discharged uneventfully. Another patient presented an AWE-related perforation, which was managed conservatively. Two patients presented collateral

channel perforations during the retrograde approach (one was treated with fat embolization). No deaths or other major complications were observed in this cohort.

3.5 | Clinical outcomes on follow-up

Follow-up was available for $n = 36/41$ patients (87.8%). One-year clinical follow-up data are presented in Table 4. The incidence of TLF was 8.3% overall, with no differences between groups. No cases of myocardial infarction were observed. The rate of cardiac death was 5.6% and that of target-lesion revascularization was 2.8%.

4 | DISCUSSION

We report an initial multicenter experience with the AFR technique for CTO recanalization. Our study findings were: (a) AFR success rate was moderate (65.9%); (b) when AFR-based reentry was successful, the procedure could be completed with optimal result in the vast majority of patients (96.3%); (c) AFR was safe, with no complications

TABLE 4 Clinical outcomes at 12-month follow-up

	Overall ($n = 36$)	AFR success ($n = 24$)	AFR failure ($n = 12$)	<i>p</i> -Value
TLF	3 (8.3%)	2 (8.3%)	1 (8.3%)	1
Cardiac death	2 (5.6%)	2 (8.3%)	0	.30
Target-vessel myocardial infarction	0	0	0	—
Target-lesion revascularization	1 (2.8%)	0	1 (8.3%)	.15

Abbreviations: AFR, antegrade fenestration and reentry; TLF, target-lesion failure.

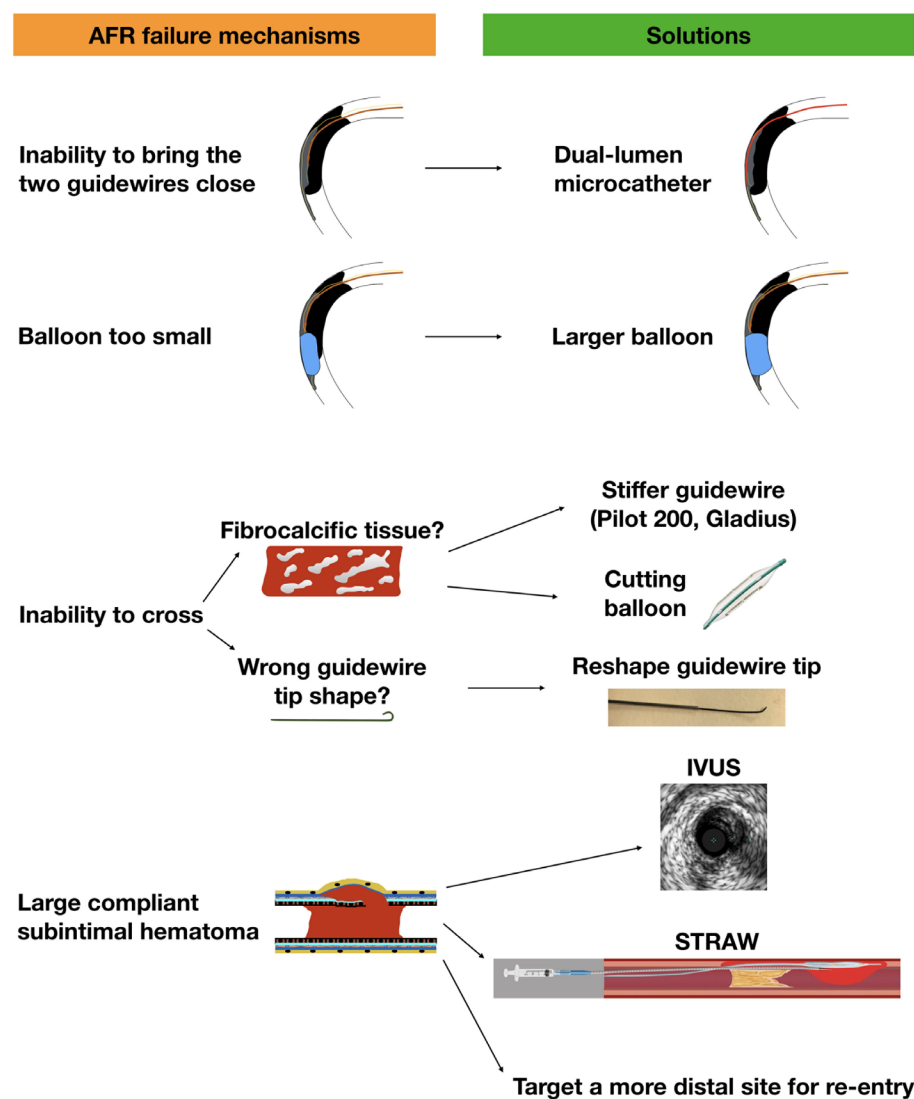


FIGURE 3 Antegrade fenestration and reentry (AFR) failure mechanisms and proposed solutions. IVUS, intravascular ultrasound; STRAW, subintimal transcatheter withdrawal [Color figure can be viewed at wileyonlinelibrary.com]

ascribed to such technique in our cohort; (d) 1-year follow-up showed encouragingly low rates of adverse events.

The field of ADR for CTO recanalization has witnessed a remarkable advancement over the past decade. The development of subintimal tracking and reentry (STAR) allowed for the first time the antegrade recanalization of complex occlusions, where traditional AWE was unsuccessful.⁹ However, unpredictable reentry, with

subsequent long subintimal tracks, loss of side branches, and sub-optimal distal runoff led to high rates of restenosis on follow-up,^{4,10} which is why STAR is currently recommended only as a bailout technique, as a bridge to further staged recanalization attempts.¹¹ Improvements of such wire-based reentry approach (mini-STAR, contrast-guided STAR, and limited antegrade subintimal tracking) were equally associated with challenges in controlling the exact

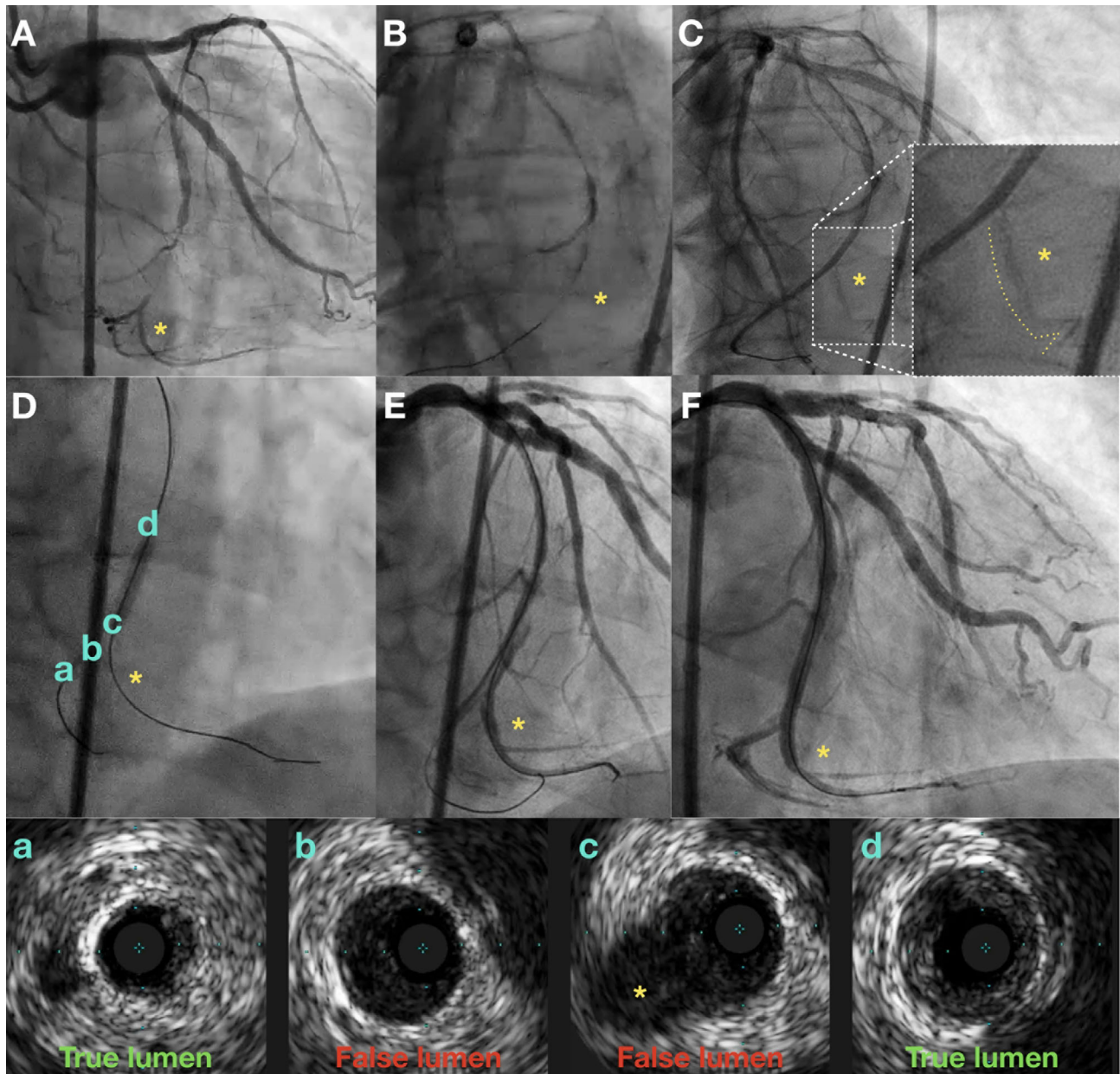


FIGURE 4 Example of intravascular ultrasound (IVUS)-based antegrade fenestration and reentry (AFR) troubleshooting. (A) Distal circumflex chronic total occlusion (CTO). The asterisk highlights, throughout the figure, a large second obtuse marginal (OM2) branch. (B) After antegrade wire escalation-based crossing and (C) predilatation, the OM2 branch is lost (dotted line in the insert). (a-d) IVUS interrogation shows (a) true lumen situation distally; (b,c) a long subintimal track compromising the ostium of the OM2 branch (asterisk in c); and again (d) true lumen situation more proximally. IVUS indicated that the reference vessel diameter at the OM2 takeoff was approximately 3 mm. (D) Accordingly, a 3.0 mm balloon was used to fenestrate at the OM2 ostium level, and reentry into the OM2 branch was easily achieved with a Fielder XT wire. (E) Result after predilatation at the circumflex/OM2 bifurcation. (F) Final result after implantation of a 2.5 × 28 mm stent from the distal circumflex into the OM2 branch and a 3.0 × 33 mm stent on the proximal circumflex [Color figure can be viewed at wileyonlinelibrary.com]

reentry site, lack of reproducibility, difficulty in teaching, and sub-optimal patency rates.^{4,10}

A major improvement in the field was the development and implementation of the CrossBoss/Stingray system. By creating a “dry” dissection plane with the blunt-tip CrossBoss, subintimal hematoma is reduced, which increases the possibility of reentry by means of the Stingray system by reducing the size of the subintimal space. This method utilizes a low-profile over-the-wire balloon that has a flat shape with two exit side ports (oriented at 180° to one another). With low-pressure inflation in the subintimal space, the Stingray balloon self-ori-ents one exit port toward the true lumen. An angiographic projection parallel to the device is sought. Subsequently, a stiff wire is used to “poke” through the layer of tissue separating the subintimal space from the true lumen, to re-enter the latter. Implementation of the CrossBoss/Stingray system into the hybrid algorithm has led to an

increase of the procedural efficiency and success of CTO PCI, with favorable acute and long-term outcomes.²⁻⁵

However, Stingray-based ADR has several drawbacks, including costs, a steep learning curve with need for dedicated proctored training, and a non-negligible rate of failure, most frequently due to compressive subintimal hematoma and inability to “poke” through calcified tissue. In fact, success rates of Stingray-based recanalization are not ideal (81%) among operators with different degrees of experience.³ As a consequence of all these considerations, the uptake of Stingray-based ADR ranges from 32% (RECHARGE Registry)³ to 55% (PROGRESS-CTO Registry)² in communities that embrace the hybrid algorithm, and is negligible in others.^{12,13}

Our study reports encouraging findings in an intermediate-sized multicenter cohort of patients undergoing AFR-based recanalization. Importantly, no complications were ascribed to this technique, as all

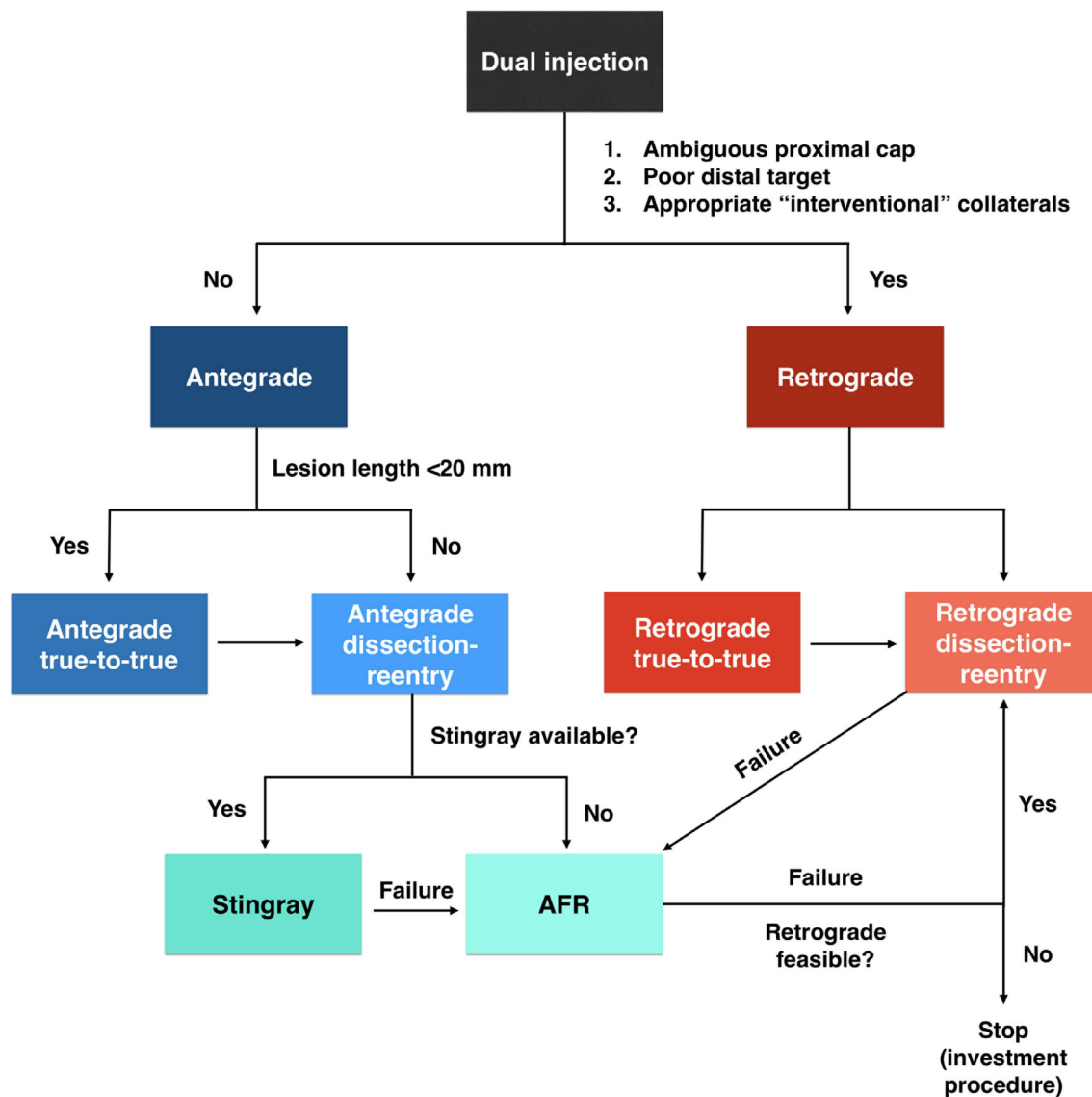


FIGURE 5 The proposed role of antegrade fenestration and reentry (AFR) in the hybrid algorithm [Color figure can be viewed at wileyonlinelibrary.com]

four perforations diagnosed in our study were observed during either AWE attempts before AFR or the retrograde approach. Moreover, AFR did not preclude alternative bailout approaches in case of failure (either during the same procedure or as a staged intervention). In fact, in two patients, subintimal balloon dilatation as part of AFR actually served as investment procedure for subsequent staged recanalization attempts. In our experience, AFR success rate was moderate (65.9%), which can be explained by a variety of reasons including: (a) several operators involved; (b) early experience with the technique (all operators except LA and MC included their very first AFR cases); (c) AFR is a “young” technique and can still be improved upon (either in its technical execution or in the identification of the lesions with highest likelihood of successful recanalization).

In fact, our experience with AFR allowed us to identify several mechanisms for failure, which are summarized in Figure 3, together

with corresponding proposed troubleshooting maneuvers. A dual-lumen microcatheter can be advanced (following predilatation of the subintimal track with a small balloon, if needed) to quickly deliver the reentry guidewire at the distal cap, should conventional wiring with a microcatheter prove difficult. Indeed, it is currently standard practice among some of the operators of this study to use a dual-lumen microcatheter to quickly and efficiently deliver the reentry guidewire at the AFR site. Inadequate fenestration can result from balloon undersizing, which underlines how important it is to use a balloon sized 1:1 with the artery. Inability to cross through fenestrations can result from two mechanisms: (a) presence of fibrocalcific tissue at the reentry site, which can in principle be overcome using a higher tip-load polymer-jacketed guidewire (such as Pilot 200 or Gladius) or cutting balloon dilatation; or (b) wrong guidewire tip shape, which should be corrected creating a 2-mm, 45° bend. Finally, the presence of a



FIGURE 6 Role of antegrade fenestration and reentry (AFR) and other available techniques in case of subintimal crossing during antegrade wire escalation. LAST, limited antegrade subintimal tracking; STAR, subintimal tracking and reentry [Color figure can be viewed at wileyonlinelibrary.com]

large, compliant subintimal hematoma (possibly arising from multiple previous failed AFR attempts) will hinder further fenestration attempts, since the subintimal space is capable of stretching to a great extent,^{10,14} thus accommodating further balloon dilatations. In such cases, intravascular ultrasound interrogation can provide invaluable information on the optimal site for reentry (where the hematoma is smaller and the true lumen is not surrounded by thick fibrocalcific tissue). An example of intravascular ultrasound-assisted AFR is shown in Figure 4. Alternatively, the subintimal transcatheter withdrawal technique¹⁵ can reduce the size of the hematoma, thus facilitating subsequent fenestration attempts. Finally, moving the "base of operations" more distally is another possible solution to such problem, provided that no major branch exists proximal to the targeted site for reentry. In our experience, the initial cause of failure in a considerable proportion of cases was felt to be incorrect balloon sizing with regard to actual vessel size (underestimation). At that point, subintimal hematoma would hamper subsequent reentry attempts. Performing intravascular ultrasound in either scenario (before AFR, to choose a balloon with an actual balloon-to-artery ratio of approximately 1; and after subintimal hematoma formation, to identify the most favorable reentry zone as the one where the hematoma is smallest and the lumen least compressed) would provide additional value and likely increase AFR success rates. Whether these speculations might find confirmation in clinical practice should be evaluated by further studies.

Although AFR has been successfully utilized in a variety of angiographic/procedural scenarios, it is important to remember that AFR, like any other ADR technique, should not be attempted in the following settings: (a) landing zone too close to a major bifurcation; (b) small vessel (poor runoff); (c) excessive vessel tortuosity at the landing zone (landing zone in a curve); and (d) excessive landing zone calcification.

Figure 5 presents a proposal of the role of AFR in the contemporary hybrid algorithm, which is based on our personal experience with this technique together with the findings contained in the present report. When ADR is indicated and the distal landing zone has been reached (e.g., with a straight-tip or knuckled wire or the CrossBoss), the Stingray-capable operator can attempt Stingray-based reentry, which is currently the ADR approach for which most literature and experience exist.²⁻⁵ When this fails, or at institutions where Stingray is not available, AFR can be attempted. In case of persistent AFR failure following the troubleshooting maneuvers outlined in Figure 3, the operator can switch to a retrograde approach. If this is deemed not feasible (lack of experience, absence of interventional collaterals, operator/patient fatigue, exclusive presence of epicardial collaterals, etc.), the procedure can be stopped. At this point, multiple balloon dilatations throughout the occlusion (as part of AFR) have created the basis for an "investment procedure" (also known as "subintimal plaque modification"), which has the potential to greatly facilitate a staged CTO PCI reattempt.^{11,16} Figure 6 indicates the role of AFR and alternative techniques in the CTO operator's toolkit, in case of subintimal crossing during AWE attempts.

Our study has some limitations. First, the small sample size of our cohort precludes drawing definitive conclusions on the widespread

applicability of AFR. Second, the lack of angiographic follow-up and short duration of clinical follow-up prevent a rigorous assessment of the durability of AFR-based recanalization. Third, although we did not observe any AFR-related complications, we cannot rule out that these might manifest in a larger cohort. Fourth, angiographic/procedural data and event adjudication were self-reported by the operators at each participating site. Fifth, the moderate success rate of AFR in our report reflects an early multicenter experience with the technique, which should be improved upon with the tips and tricks outlined in Figure 3, as well as novel maneuvers and possibly the development of a dedicated AFR device.

In light of all these considerations, until the promising data contained in the present report are confirmed by larger series (e.g., within a large international multicenter registry), Stingray-capable centers and operators might consider AFR after failed Stingray-based reentry.

5 | CONCLUSIONS

We report on the feasibility of AFR in a multicenter registry of patients undergoing CTO PCI. We observed a moderate success rate, coupled with the absence of complications. Further larger-sized studies should confirm and extend our findings. Modification of the original AFR technique, as well as the development of a dedicated device, might lead to further improvement in success rates and favor a wider adoption of AFR.

CONFLICT OF INTERESTS

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ORCID

Lorenzo Azzalini  <https://orcid.org/0000-0001-9758-0360>

Khaldoon Alaswad  <https://orcid.org/0000-0003-1368-5320>

Barry F. Uretsky  <https://orcid.org/0000-0001-9423-4702>

Neisser Morales-Victorino  <https://orcid.org/0000-0003-0299-6502>

Ankur Gupta  <https://orcid.org/0000-0002-0610-5028>

Carlo Zivelonghi  <https://orcid.org/0000-0001-9825-6589>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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