Received: 27 June 2024 | Revised: 23 August 2024 | Accepted: 14 September 2024

DOI: 10.1002/ccd.31243

ORIGINAL ARTICLE - CLINICAL SCIENCE

WILEY

HydroDynamic contrast Recanalization (HDR): Description of a new crossing technique for coronary chronic total occlusions

Mauro Carlino MD[1] | Angelo Nascimbene MD[2] | Emmanouil S. Brilakis MD, PhD[3] | Akshitha Yarrabothula MD[2] | Antonio Colombo MD[4] | Sunao Nakamura MD[5] | Lorenzo Azzalini MD, PhD, MSc[6] | Bashir Hanif MD[7] | Bilal Iqbal MD, PhD[8] | Salman A. Arain MD[2]

[1]IRCCS San Raffaele Scientific Institute, Milan, Italy

[2]McGovern School of Medicine, Department of Cardiology, University of Texas, Houston, Texas, USA

[3]Minneapolis Heart Institute, Minneapolis, USA

[4]IRCCS Humanitas Research Hospital, Rozzano, Milan, Italy

[5]New Tokyo Hospital, Chiba, Japan

[6]Heart Institute, University of Washington Medical Center, Seattle, Washington, USA

[7]Tabba Heart Institute, Karachi, Pakistan

[8]Victoria Heart Institute Foundation, Victoria, Canada

Correspondence
Mauro Carlino, MD, IRCCS San Raffaele Scientific Institute, Via Olgettina 60, 20132 Milan, Italy.
Email: carlino.mauro@hsr.it

Abstract

Background: Intraplaque delivery of contrast has been utilized during percutaneous coronary interventions (PCI) of chronic total occlusions (CTO) to delineate anatomy and to facilitate wire crossing. Its utility as a tool to accomplish primary crossing of CTOs has not been described or validated.

Aims: We describe a new technique leveraging the diagnostic and therapeutic roles of intraplaque contrast injection to accomplish primary crossing of CTOs: Hydro-Dynamic contrast Recanalization (HDR).

Methods: HDR is an antegrade crossing method for coronary CTOs based on the synergistic use of contrast microinjections and polymer jacketed wires. We present a retrospective, first-in-man, case series utilizing HDR for CTO PCI in patients with favorable CTO anatomy (visible proximal segment and identifiable distal target). The primary outcome was procedural success. The secondary outcome was any procedural complications.

Results: A total of 43 patients with 45 CTOs underwent CTO PCI with HDR. Mean patient age was 64.3 ± 11 years. The mean Japanese CTO and PROGRESS CTO scores were 2.3 ± 0.7 and 1.8 ± 0.7, respectively. CTO complexity was high, with an ambiguous or blunt cap in 34 occlusions (76%); lesion length ≥ 20 mm in 27 occlusions (60%); and moderate/heavy calcification in 36 occlusions (80%). Procedural success using HDR was 100%. There were no complications.

Conclusions: This study shows the utility of HDR in CTO PCI. HDR appears to be a safe and promising new contrast-based primary crossing technique in selected patients. This strategy warrants further evaluation in larger prospective studies.

KEYWORDS

chronic total occlusion, contrast-mediated recanalization, percutaneous coronary intervention

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1 | INTRODUCTION

Antegrade wiring is the most common crossing strategy during chronic total occlusion percutaneous coronary intervention (CTO PCI).[1] CTO operators favor antegrade wiring because of its relative ease of use, familiarity with the approach (similar to non-CTO PCI), and safety compared with antegrade dissection and re-entry (ADR) and the retrograde techniques.[1] Development of specialized microcatheters and composite core wires and widespread adoption of standardized crossing algorithms have further improved technical success rates of CTO PCI.[2] Intraplaque contrast injection through a microcatheter (the Carlino technique)[3] is an adjunctive maneuver that is typically utilized by hybrid operators to allow negotiation of difficult-to-cross occlusions in both the antegrade and the retrograde direction[4] with high success and low complications rates.[5]

Despite several publications confirming the safety of the Carlino technique,[5,6] contrast modulation of plaque has largely been relegated to a "bail-out" maneuver in challenging anatomic subsets. There are many potential explanations: uncertainty about the mechanism of action; concerns about the safety of intraplaque contrast delivery; lack of standardization; fear of vessel disruption limiting further crossing strategies; and, perhaps most significantly, incomplete understanding of the different angiographic staining patterns seen following intraplaque contrast injection. Nevertheless, contrast injection has become an important (although underutilized) tool in the CTO operators' armamentarium, typically used for resolving hostile or ambiguous anatomies during CTO PCI.[5]

We describe a new technique for CTO crossing called **Hydro-Dynamic contrast Recanalization** (HDR), which is based on the synergistic use of contrast microinjections and polymer jacketed wires. HDR represents further evolution of the principle of contrast modulation in CTO PCI. It is founded on our observation that intraplaque delivery of small (≤0.5 mL) contrast volumes can facilitate crossing of polymer jacketed wires by recruiting lipid-rich soft regions of the plaque. HDR can be applied to a variety of CTO anatomic subsets as exemplified by our series.

2 | METHODS

2.1 | Study design

This was a retrospective analysis of patients who underwent CTO PCI utilizing HDR between October 2022 and April 2024 at 3 centers: (a) IRCCS San Raffaele Scientific Institute, Milan, Italy; (b) University of Texas, Houston, Texas, USA; and (c) Tabba Heart Institute, Karachi, Pakistan. All patients had at least one coronary CTO and symptoms refractory to optimal medical therapy, or symptoms associated with a large (>15%) ischemic region on cardiac positron emission tomography. The selection criteria for HDR were: (a) presence of a proximal patent segment; and (b) identifiable distal target within the occluded artery. All demographic, clinical and technical data were retrieved to complete the analysis.

2.2 | Outcomes

The primary outcome was technical success, defined as achievement of TIMI grade 2 or greater antegrade flow in all ≥2.5-mm distal branches with <30% residual stenosis of the target CTO lesion at procedure end. The secondary outcome was procedural related complications (coronary perforation, myocardial infarction and death). Procedural and technical data were used to determine the CTO crossing times (defined as time from guidewire insertion to removal of microcatheter after confirmation of distal true lumen re-entry), and number of wires used to accomplish CTO crossing and the CTO PCI in its entirety.

2.3 | Ethics

All patients gave written consent for the procedure. The study protocol was reviewed and approved by the institutional research board of the University of Texas, Houston, Texas.

2.4 | Statistical analysis

Categorical data are presented in proportions and continuous data are expressed as mean ± standard deviation or median (interquartile range), as appropriate. Statistical analysis was performed with STATA v17 (College Station).

2.5 | The HDR technique

A step-by step description of the HDR technique is detailed below. Please also see Figure 1 and Videos S1–S5.

1. Dual injection angiography is performed in multiple projections to establish the appropriateness of the vessel anatomy for HDR and to determine the length of the CTO.
2. After the proximal cap of the CTO has been identified, a microcatheter is advanced over a workhorse wire until its tip is adjacent to the cap. We prefer to use torquable microcatheters such as the Turnpike LP (Teleflex) or Corsair Pro (Asahi Intecc) to facilitate subsequent cap penetration (Video S1).
3. The proximal cap is punctured using a wire with medium or high penetration force according to the operator's preference (Video S2). We prefer to start with a Gaia or Gaia Next 2 wire (Asahi Intecc) followed by a Confianza Pro 12 (Asahi Intecc) or Hornet 14 wire (Boston Scientific), if necessary.
4. The wire should only be advanced 2 to 4 mm into the body of the CTO to minimize the possibility of entering the extraplaque space.
5. The microcatheter is advanced over the wire until the tip is visibly positioned beyond the boundary of the proximal cap. Angiography is performed to confirm the location of the microcatheter tip (Video S3).

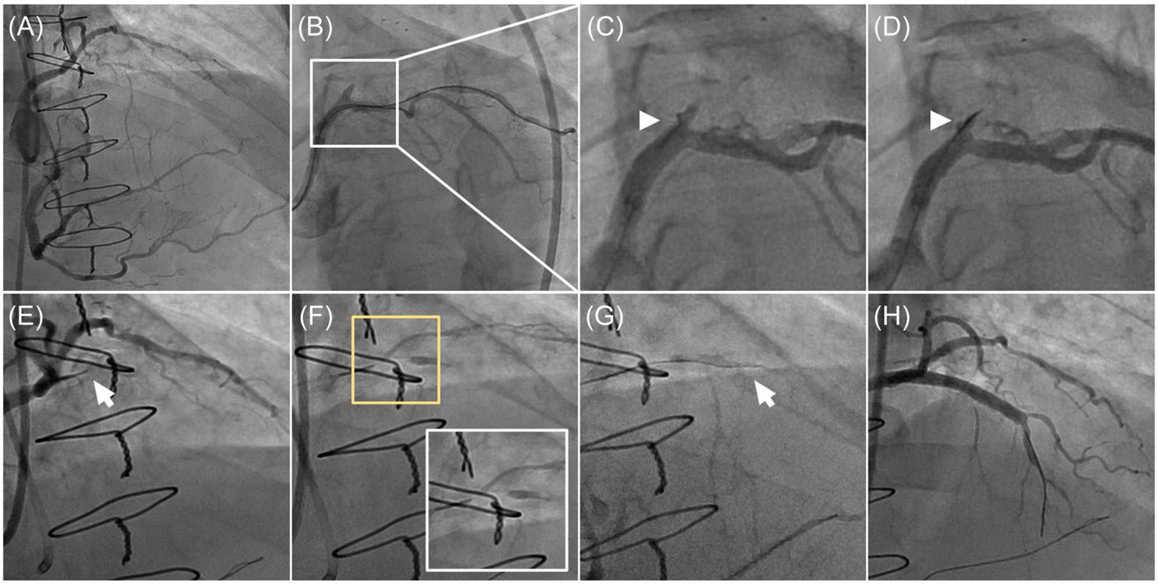


FIGURE 1 Hydrodynamic contrast recanalization step-by-step technique. Dual injection angiography is used to define the CTO length and locate the proximal cap (panels A and B, Video S1). A microcatheter is advanced to the proximal cap (arrowhead, panel C). A medium tip load wire (e.g., Gaia 2) is used to puncture the cap (arrowhead, panel D, Video S2) and the microcatheter is advanced 2–3 mm into the occlusion (arrow, panel E, Video S3). A small volume of contrast (0.5 mL) is slowly injected into the occlusion, and the contrast stain is analyzed (inset, panel F, Video S4). A polymer jacketed wire (e.g., Fielder XT-R shown here) (arrow, panel G, Video S5) is advanced into the distal true lumen under fluoroscopic guidance. Final angiogram after successful PCI of the proximal and mid left anterior descending artery (LAD) (panel H, Video S6). [Color figure can be viewed at wileyonlinelibrary.com]

6. The microcatheter hub is filled with saline or contrast using a wire introducer as the wire is removed to ensure that air does not enter the microcatheter.
7. A small (3 mL) Luer lock syringe filled with pure contrast is attached to the microcatheter hub. Aspiration is performed to confirm that the microcatheter lumen is free of air.
8. A small volume of contrast (≤0.5mL) is injected slowly under cine angiography until contrast appears within the body of the CTO distal to the microcatheter tip (Video S4).
9. A contralateral injection may be performed to evaluate the true length of the CTO based on the distance of the contrast stain from the distal cap of the CTO.
10. The angiogram is reviewed to determine the characteristics of the intraplaque contrast deposit and identify the pattern type: patchy and localized (type 1), or linear with visualization of the distal true lumen (type 2a) or a side branch (type 2b), or patchy at the origin with a linear track leading to the distal true lumen (type 3).
11. The contrast syringe is removed, and a polymer jacketed wire is inserted into the microcatheter. The wire is advanced along the trajectory marked by the contrast. We prefer to use a wire from the Fielder family (Asahi Intecc) with a short tip bend (<2 mm, ~30-° angle) or a Gladius Mongo wire (Asahi Intecc) for this purpose (Video S5).
12. If the wire cannot be advanced further within the plaque, we recommend advancing the microcatheter by a few mm and performing another intraplaque injection at the new location. This step may be repeated until the microcatheter crosses the point of obstruction or further progress is not possible.
13. If the wire fails to enter the distal true lumen, crosses into the extraplaque space, or forms a knuckle, then the operator has the option of (a) repuncturing the proximal cap at a different location and repeating the HDR sequence, or (b) switching to an alternate crossing strategy such as wire escalation or ADR.

3 | RESULTS

During the study period a total of 43 patients with 45 CTOs underwent CTO PCI using a primary HDR strategy. Patient characteristics are shown in Table 1, angiographic and procedural characteristics are listed in Table 2, and technical data are listed in Table 3. Representative cases are shown in Figure 1 and 2.

3.1 | Baseline patient characteristics

The mean patient age was 64.3 ± 11 years. A total of 34 patients (79%) were male and 17 patients (39%) were diabetic. Baseline left ventricular ejection fraction was 51 ± 9%. The mean estimated glomerular filtration rate was 72 ± 23 mL/min/1.73 m^2. All patients presented with angina (mean Canadian Cardiovascular Society class 2.1 ± 0.9). At the time of the procedure, 30 patients (70%) were

TABLE 1 Patient demographics and medications.

Patients (total number)	43
Age (years)	64.3 ± 11
Sex (male)	34 (79%)
Diabetes	17 (39%)
Hypertension	43 (100%)
Angina (CCS)	2.1 ± 0.9
Medications	
– Aspirin	41 (95%)
– Clopidogrel or ticagrelor	34 (79%)
– Beta-blockers	38 (88%)
– Calcium channel blockers	5 (12%)
– Nitrates	11 (26%)
– Ranolazine	8 (19%)
– ACE-I, ARB, or ARNI	29 (67%)
– Statin	42 (98%)
– Oral DM medication	12 (28%)
LVEF (%, mean ± SD)	51 ± 9
eGFR (mL/min/1.73 m^2, mean ± SD)	72 ± 23
Medical history	
– Previous MI	15 (35%)
– Previous PCI	18 (42%)
– Previous CABG	11 (26%)
– Previous stroke or TIA	2 (5%)
– Previous PAD	2 (5%)
– Previous lung disease	2 (5%)
– History of smoking	
Current	3 (7%)
Former	10 (23%)
Never	17 (40%)
Not available	13 (30%)

Abbreviations: ACEI, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor blocker; ARNI, angiotensin receptor/neprilysin inhibitor; ASA, aspirin; CCS, Canadian Cardiovascular Society angina class; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; PAD, peripheral arterial disease; TIA, transient ischemic attack.

TABLE 2 Procedural data and lesion characteristics.

Occlusions treated (total number)	45
Location	
– Left main	1 (2%)
– LAD	12 (27%)
– LCX	10 (22%)
– RCA	18 (40%)
– OM (any)	4 (9%)
Lesion characteristics	
– Proximal Cap morphology	
Ambiguous	21 (47%)
Blunt	13 (29%)
Tapered	11 (24%)
– Tortuosity	7 (16%)
– Length > 20 mm	27 (60%)
– Moderate or heavy calcification	36 (80%)
– Prior PCI attempt	3 (7%)
– Absent interventional collaterals	34 (76%)
Japanese CTO score (mean ± SD)	2.3 ± 0.7
PROGRESS CTO score (mean ± SD)	1.8 ± 0.7
Radiation time (min, mean ± SD)	37 ± 14
– CTO PCI only[a] (min, mean ± SD)	29 ± 9
– CTO + non-CTO PCI[a] (min, mean ± SD)	39 ± 12
Radiation dose (mGy, mean ± SD)	3513 ± 1229
– CTO PCI only[a] (mGy, mean ± SD)	3120 ± 840
– CTO + non-CTO PCI[a] (mGy, mean ± SD)	3577 ± 1356
Contrast volume (cc, mean ± SD)	208 ± 71
– CTO PCI only[a] (cc, mean ± SD)	186 ± 58
– CTO + non-CTO PCI[*] (cc, mean ± SD)	204 ± 67

Abbreviations: CTO, chronic total occlusion; LAD, left anterior descending artery; LCX, left circumflex artery; mGy, milligray; OM, obtuse marginal; PCI, percutaneous coronary interventions; RCA, right coronary artery.
[a]Mean values calculated from 36 cases for which detailed information was available.

taking at least two or more anti-anginal medications. The baseline patient demographic and clinical details are summarized in Table 1.

3.2 | Baseline lesion characteristics

A total of 45 CTOs were treated in the study population. The average Japanese CTO and PROGRESS CTO Scores were 2.28 ± 0.7 and 1.8 ± 0.7 respectively. There was a high prevalence of complex CTO features: ambiguous or blunt cap in 34 lesions (76%); length > 20 mm in 27 lesions (60%); and moderate or heavy calcification in 36 lesions (80%).

3.3 | Procedural details

The CTO target vessels included the left main (n = 1), the left anterior descending (n = 12), the left circumflex (n = 10), and the right coronary artery ($n = 17$). Two patients underwent PCI of a LCX bifurcation involving occlusion of adjacent obtuse marginal (OM) branches, and one patient had CTO PCI of a single OM. One patient underwent staged left anterior descending artery (LAD) and right coronary artery (RCA) CTO interventions. CTO PCI had previously been attempted in three patients (7%). Non-CTO PCI was performed during the same procedure in 25 cases (58%). Intravascular ultrasound (IVUS) was used to guide the PCI in 14 of 43 cases (33%). The mean cumulative radiation dose was 3513 ± 1229 milligray (mGy) (range 1070–5840 mGy), the mean fluoroscopy time was 37 ± 14 min (range 14–75 min), and the mean contrast volume was 208 ± 71 mL (range 80–390 mL). The lesion and procedural details are summarized in Table 2.

3.4 | Outcomes

HDR was used to treat 45 CTOs in 43 patients with 100% technical success. There were no complications (coronary perforation, myocardial infarction or death). Complete information on guidewire crossing times was available for 36 CTO PCIs. The mean and median crossing times were 12.9 ± 9.7 and 12 min, respectively. The median number of wires needed to cross the occlusion and perform the entire CTO PCI were 3 (range 2–5) and 4 (range 3–7) respectively. The presence of an ambiguous or blunt as opposed to tapered proximal cap was associated with longer crossing (10 ± 1 vs. 16.7 ± 3.4 min, $p = 0.04$) and procedure times (38.6 ± 2.6 vs. 28.9 ± 2.4 min, $p = 0.02$). The technical outcomes are summarized in Table 3.

TABLE 3 Technical data for CTO PCI utilizing HDR.[a]

Total number of occlusions	**38**
No. of modified Carlino injections (median)	2 (range 1–7)
Microcatheters utilized	41
– Turnpike LP (Teleflex)	35 (85%)
– Mamba flex (Boston Scientific)	6 (15%)
Guidewires utilized during CTO crossing[b]	
– 2 wires	12 (32%)
– 3 wires	18 (47%)
– 4 or more wires	8 (21%)
Intraplaque crossing guidewire	
– Fielder XT (Asahi Intecc)	23 (61%)
– Fighter (Boston Scientific)	1 (2%)
– Gladius MG (Asahi Intecc)	13 (34%)
– Sion Black (Asahi)	1 (2%)
CTO crossing time (min, mean ± SD)	12.9 ± 9.7
Crossing time by cap morphology	
– Ambiguous ($n = 16$) (min, mean ± SD)	16.8 ± 13
– Blunt ($n = 12$) (min, mean ± SD)	9.4 ± 3.9
– Tapered ($n = 10$) (min, mean ± SD)	10.8 ± 5.7
Cases with additional non-CTO PCI	25 (66%)
Stents deployed per case, all PCIs (mean)	2.5 ± 1.2
Stents deployed per case, CTO only (mean)	1.6 ± 0.7
Total stent length, CTO segment (mean, mm)	50 ± 23
Total stent length, non-CTO segment (mean, mm)	34 ± 23

Abbreviations: CTO, chronic total occlusion; PCI, percutaneous coronary interventions.

[a]This table contains information from 36 cases for which complete technical data were available. See text for definitions;

[b]Guidewires used for CTO crossing include the wire used to penetrate the proximal cap, all intraplaque crossing wires, and any wires used to mark side branches or stabilize the guide catheter.

4 | DISCUSSION

This is the first description of a new CTO crossing strategy, HDR. The distinctive feature of HDR is intraplaque injection of a small volume of contrast (modified Carlino technique) within the proximal cap followed by use of polymer jacketed wires to cross the occlusion. We describe our initial experience of using this technique to treat appropriately selected CTOs with a high success rate and no complications. In patients with favorable CTO anatomy (well defined proximal cap and distal target), HDR allowed CTO crossing without the need for wire escalation or entry into the extraplaque space and a high rate of side branch preservation. Intravascular imaging (when performed) showed intraplaque wire passage in all cases (Figure 3). These observations suggest HDR is a promising new technique that may offer significant advantages over standard CTO crossing strategies.

The role of contrast modulation during CTO PCI has significantly evolved since it was first described by Carlino et al. in 2008.[7] The original technique, known as contrast-guided subintimal tracking and reentry (STAR), was designed to be used *after* the operator had entered the extraplaque space, intentionally or otherwise. It mandated forceful injection of large volumes (3–5 mL) of contrast into the intimal dissection plane to create one or more fenestrations for wire reentry into the distal true lumen. Unfortunately, this maneuver was unpredictable in achieving vessel reentry, had the potential to cause extensive vessel injury, and was associated with high restenosis rates. The authors subsequently refined their technique by describing more precise methods of puncturing the proximal CTO cap (to minimize chances of entry into the extraplaque space) and using modest (<3 mL) intraplaque injections of contrast mixed with nitroglycerin. This was called the microchannel technique,[8] and its objective was to create a path for polymer jacketed wire passage by recruiting small blood vessels within the CTO. Later observations that gentle injections of even smaller volumes of contrast can favorably modify plaque properties led to the development of a “micro” injection maneuver (modified Carlino technique)[9] in which a microcatheter is

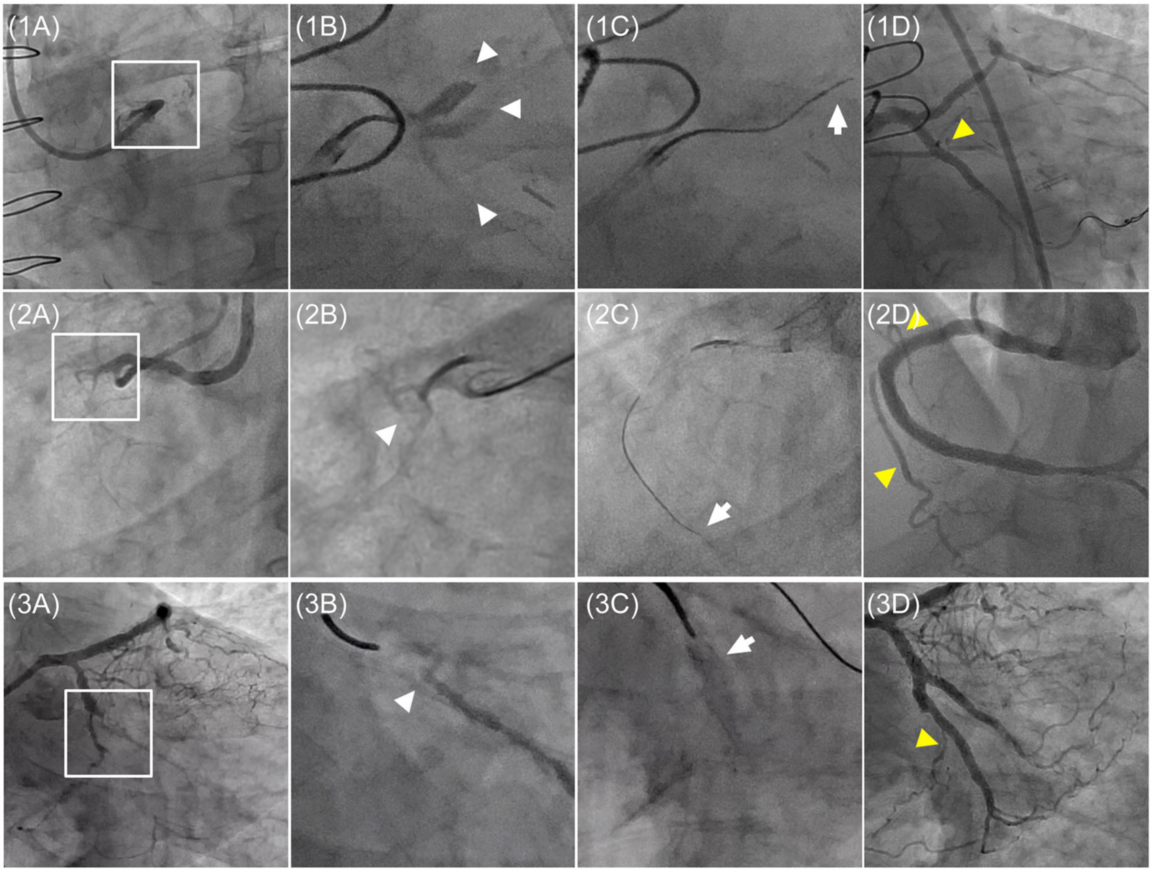


FIGURE 2 Hydrodynamic contrast recanalization representative cases. The top row shows successful PCI of an occluded left main using HDR (panel 1A). Intraplaque injection of contrast creates a trifurcating stain (arrowheads, panel 1B) with features of both pattern 1 and 2 (see text for details). A Fielder XT wire (arrow, panel 1C) passes easily into the ramus intermedius. Final angiography shows successful revascularization of the ramus and left circumflex arteries with preserved side branches (arrowheads, panel 1D). The middle row shows successful PCI of an occluded RCA with HDR (panel 2A). Intraplaque injection of contrast creates a linear stain (arrowhead, panel 2B) with a pattern 1 morphology (see text). A Fielder XT wire (arrow, panel 2C) easily crosses the long RCA occlusion. Final angiography shows successful revascularization of the RCA with preservation of side branches (arrowheads, panel 2D). (Figure 3 shows the IVUS findings following HDR from this case). The bottom row shows successful PCI of two occluded obtuse marginal branches utilizing HDR (panel 3A). Microinjection of contrast across the proximal cap of the OM1 yields a stain with a type 2A pattern (arrowhead, panel 3B). A second microinjection of contrast across the proximal cap of the OM2 creates a type 2B stain (arrow, panel 3C). Final angiography after reconstruction of the left circumflex system shows preserved side branches (arrowheads, panel 3D). CTO, chronic total occlusion; IVUS, intravascular ultrasound; HDR, HydroDynamic contrast Recanalization; OM, obtuse marginal; PCI, percutaneous coronary interventions; RCA, right coronary artery. [Color figure can be viewed at wileyonlinelibrary.com]

used to deliver ≤ 0.5 mL of contrast inside the plaque at a variable distance from the proximal cap.[3] The differences between these forms of contrast modulation and HDR are highlighted in Table 4.

Despite encouraging data from observational studies about the effectiveness and safety of small volume contrast modulation, this approach has not gained widespread acceptance as a routine strategy for CTO PCI. There are several reasons for this, including concerns about vessel trauma stemming from experience with the original (and now outdated) contrast-guided STAR technique, unfamiliarity with newer methods of contrast modulation, lack of standardization of the microinjection technique, limited awareness of the utility of the maneuver in various stages of CTO PCI other than proximal cap modification,[4] fear of vessel disruption limiting further crossing strategies/techniques; and perhaps most significantly, an incomplete understanding of the intraplaque stain which appears following contrast delivery (that may be mistaken for a perforation). Nevertheless, the application of various forms of the Carlino technique as an adjunctive maneuver has been reported in a wide array of CTO scenarios.[5,6,9–16] At present the main use of contrast modulation in CTO PCI is as a bail-out strategy in hostile CTO anatomies to disrupt impenetrable caps and to resolve vessel ambiguity. The utility of contrast modulation as a wire crossing strategy early in the crossing algorithm has not been described.

An important aspect of HDR is recognition and interpretation of the stain that is seen after intraplaque contrast delivery. The angiographic appearance of the contrast deposit is determined by the interaction between the contrast medium and tissue within the plaque. We have identified three distinct pattern types based on the

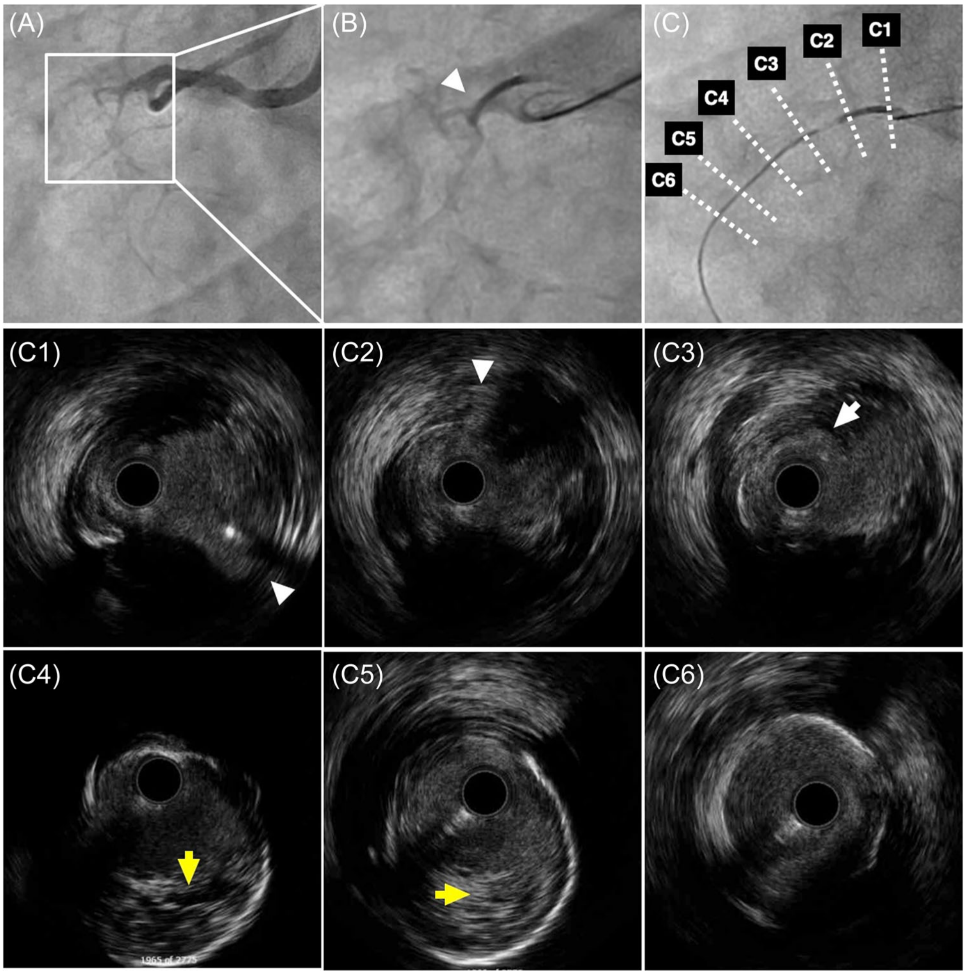


FIGURE 3 IVUS findings after HDR (from Case 2 in Figure 2). Legend: The top row shows HDR of an occluded RCA (panels A, B, and C). Following wire passage, angioplasty was performed with a 2 mm balloon to facilitate passage of an IVUS catheter. IVUS pullback images are shown from six locations: proximal RCA with branches (arrowheads, panels C1 and C2), proximal cap entry point (arrow, panel C3), intraplaque channels saturated with contrast (arrowheads, panels C4 and C5), and distal cap exit into true lumen (panel C6). Note that the IVUS catheter is intraluminal at each site. (See Videos S7 and S8 for complete recordings). HDR, HydroDynamic contrast Recanalization; IVUS, intravascular ultrasound. [Color figure can be viewed at wileyonlinelibrary.com]

morphology of the stain seen during HDR in our series (Central Illustration 1):

1. Pattern type 1 has a patchy appearance with soft edges and typically forms in proximity to the microcatheter tip. It is often seen in long (>20 mm) occlusions.
2. Pattern type 2 has a more defined (often linear) appearance and ends in either the distal true lumen (type 2A) or in a side branch (type 2B).
3. Pattern type 3 has morphologic features of both types 1 and 2 and may be seen in occlusions of any length and duration. It is patchy in appearance at its origin and becomes more defined as it reaches the distal true lumen or a side branch.

The exact mechanisms underlying HDR have yet to be determined. It is our hypothesis that a patchy stain denotes infiltration of contrast into soft lipid-rich areas of the plaque, whereas a linear pattern arises when there is recruitment of many adjacent soft areas to create a path of least resistance for wire passage across the occluded artery. The concept of intralesional tissue modification by contrast (either mechanically or chemically) is supported by the observation that post-HDR IVUS imaging often reveals echolucent areas within occlusive plaque but not proximal or distal to it (Figure 3). Additional studies are needed to confirm this putative mode of action of HDR.

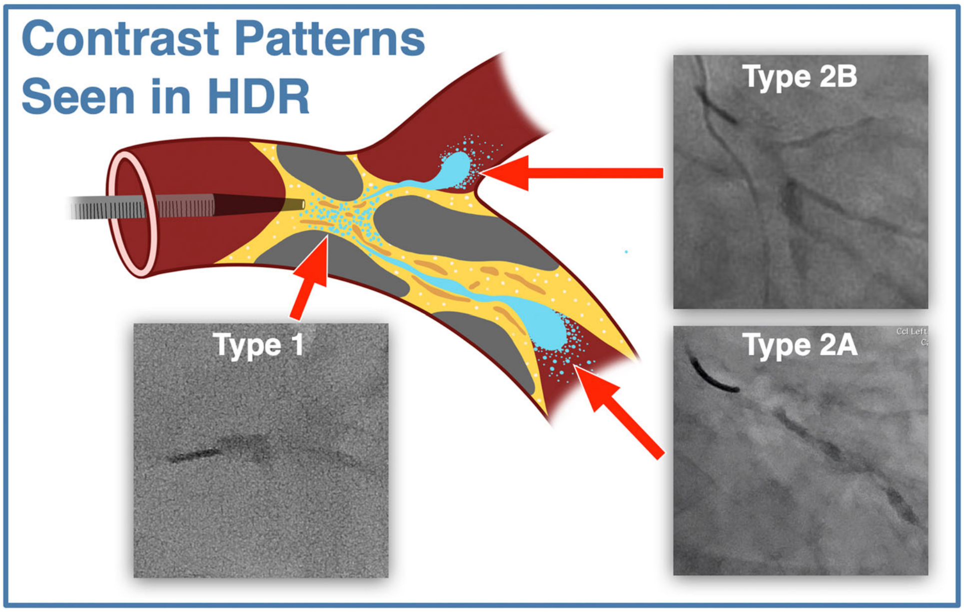
HDR may offer CTO operators several advantages over other crossing techniques such as antegrade or retrograde wire escalation and dissection and re-entry. It is a simple maneuver that yields important diagnostic information such as the true CTO length and plaque composition at the outset of the intervention. In most cases a low tip weight polymer jacketed wire can be used to cross the CTO immediately after HDR without causing significant plaque disruption. Contrast microinjections can be repeated as needed if the occlusion is long or tortuous and, most importantly, failure to cross with HDR

TABLE 4 The Evolution of Contrast Modulation.

Technique (first reported)	Contrastguided STAR (2008)[7]	Microchannel Technique (2008)[8]	Modified Carlino (Microinjection) Technique (2016)[3]	Power Carlino Technique (2021)[10]	Hydrodynamic Recanalization Technique (2024)
Mechanism of action	Hydraulic dissection in the extraplaque space with the aim of re-entering into the true lumen	Recruitment of intraplaque microchannels	Contrast modulation within the plaque	Disruption of the plaque-extraplaque boundary at the proximal cap (in case of wire impenetrable CTOs)	Contrast modulation within the plaque
Location of microcatheter tip	Within the extraplaque space	Within the plaque, a variable distance from the proximal cap	Anywhere within the plaque, usually determined by resistance to wire advancement	At or adjacent to the proximal CTO cap	Within the plaque, no more than 2–4 mm from the proximal cap
Volume of contrast (injectate)	3–5 mL	<3 mL	0.5 mL or less	Variable	0.5 mL or less
Forcefulness of injection	Firm to forceful	Firm	Gentle	Forceful	Gentle
Crossing wires typically needed	Polymer jacketed and non-jacketed CTO wires	Polymer jacketed wires with low and medium tip load	Polymer jacketed wires with a variable tip load, according to plaque characteristics	Variable, usually medium to high tip load polymer jacketed knuckling wires	Polymer jacketed wires with low to medium tip load
Possibility of intraplaque crossing	No	Yes	Yes	No	Yes

Note: A comparison of the various contrast-based CTO PCI techniques that have been reported in the literature.

Abbreviations: CTO, chronic total occlusion; IVUS, intravascular ultrasound; OM, obtuse marginal; PCI, percutaneous coronary interventions; STAR, subintimal tracking and reentry.



CENTRAL ILLUSTRATION 1 Contrast patterns seen in hydrodynamic contrast recanalization. The various types of staining patterns that may be seen after intraplaque contrast delivery. The cartoon shows the postulated mechanism underlying HDR: "recruitment" of soft lipid-rich areas within the plaque to create pathways that favor wire crossing. Type 1 has a "patchy" appearance and is seen when there is accumulation of contrast close to the microcatheter tip. Type 2 denotes successful intraplaque crossing of contrast into either the distal true lumen (type 2A), or the side branches (type 2B). The contrast trail may be absent close to the origin of the stain as seen in these two examples. Type 3 (not shown) has features of both type 1 and 2 stains (patchy appearance proximally and definite connections with the distal true lumen or a side branch). HDR, HydroDynamic contrast Recanalization. [Color figure can be viewed at wileyonlinelibrary.com]

does not preclude use of other CTO PCI techniques. On the contrary, HDR may improve the success rate of other crossing methods by favorably modifying the plaque to facilitate advancement of wires and other devices. HDR is very successful in preserving side branches following stent implantation (Figure 2). We hypothesize that this is due the ability of contrast to simultaneously create multiple intraplaque pathways some of which are connected to side branches (Figure 4). As a result, HDR may be more appealing over other CTO crossing strategies when the occluded segment involves major branch points.

Our experience suggests that HDR is safer than previous iterations of contrast modulation such as contrast-guided STAR and the microchannel technique and is comparable to other crossing strategies. The observed safety of HDR in our series may be related to the methodology of the modified Carlino technique. We hypothesize that the small contrast volumes coupled with gentle pressure required to perform the contrast microinjection are too low to cause vessel perforation or other complications. Furthermore, the protracted nature of the maneuver allows operators to stop mid injection if they are not confident about the location of the microcatheter tip relative to the adventitial layer of the vessel wall or the morphology of the contrast stain. The balance with contrast volume and injection pressure can be readily taught and learned, as HDR has a short learning curve in our experience.

The main advantages of the HDR technique are that it (a) is simple and effective; (b) can be readily used and does not require specialized equipment/devices; (c) is versatile and can be used in diverse CTO anatomies; (d) has short learning curve and can be easily adopted by operators with varying levels of experience; and (e) is not mutually exclusive and may compliment other subsequent crossing strategies that may be employed in the hybrid algorithm.

4.1 | Study limitations

The current study is a nonrandomized, retrospective case series in which patients were strategically selected for HDR based on anatomic suitability. A procedural success rate of 100% implies selection bias, but also indicates the importance of patient selection for a successful HDR strategy. The study size is small, and this does not allow us to determine CTO morphologies where HDR strategy may not be useful. We do not have long-term clinical outcomes of the patients included in this series, although all patients were alive and reported symptomatic improvement without the need for repeat revascularization at the time of submission. Intravascular imaging was only performed in 33% of cases, which limits our ability to generalize the findings to all successful HDR cases. The mean radiation dose was higher than expected for contemporary CTO PCI, however this may be reflective of the anatomic and procedural complexity of the PCIs included in our series (Table 3) and the X-ray settings used rather than the HDR technique. The findings of this study are hypothesis-generating, and the widespread applicability and reproducibility of HDR needs to be established in larger, prospective, multicenter studies.

5 | CONCLUSIONS

HDR is a novel technique based on the principle of intraplaque contrast modulation to facilitate wiring in CTO PCI. It provides a new perspective and potential paradigm shift over the current use of contrast modulation as a "last resort" maneuver in CTO PCI, where contrast modulation is used earlier in the crossing algorithm. HDR appears to be a safe promising novel primary contrast-based crossing strategy in selected patients undergoing CTO PCI. This strategy warrants further evaluation in larger, prospective studies.

ACKNOWLEDGMENTS

The authors would like to acknowledge Maliha Arain's contributions to the graphic design and realization of the figures and illustrations.

CONFLICT OF INTEREST STATEMENT

Dr. Azzalini has received consulting/speaker honoraria from Abbott Vascular, Abiomed, Cardiovascular Systems, Inc. (CSI), GE Healthcare, Reflow Medical, and Teleflex. He serves on the advisory board of Abiomed and GE Healthcare, and owns equity in Reflow Medical. Dr. Arain has received consulting/speaker honoraria from Boston Scientific, Canon USA, and Teleflex. He serves on the advisory board of Boston Scientific. Dr. Brilakis has received consulting/speaker honoraria from Abbott Vascular, American Heart Association (Associate Editor Circulation), Biotronik, Boston Scientific, Cardiovascular Innovations Foundation (Board of Directors), CSI, Elsevier, GE Healthcare, IMDS, Medtronic, and Teleflex. He has received research support from Boston Scientific and GE Healthcare. He is owner of Hippocrates LLC, and holds equity in MHI Ventures, Cleerly Health, Stallion Medical. Dr. Iqbal has received funding, honoraria and consulting fees from St. Judes Medical, Teleflex, Shockwave Medical, Biotronik, Boston Scientific and Terumo Medical. The remaining authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Mauro Carlino http://orcid.org/0000-0003-2326-4749
Emmanouil S. Brilakis http://orcid.org/0000-0001-9416-9701
Sunao Nakamura http://orcid.org/0000-0002-0651-0090
Lorenzo Azzalini http://orcid.org/0000-0001-9758-0360
Salman A. Arain http://orcid.org/0000-0002-5810-4991

REFERENCES

1. Rempakos A, Alexandrou M, Mutlu D, et al. Predictors of successful primary antegrade wiring in chronic total occlusion percutaneous coronary intervention. *J Invas Cardiol*. 2024; 36(6).
2. Wu EB, Brilakis ES, Mashayekhi K, et al. Global chronic total occlusion crossing Algorithm. *J Am Coll Cardiol*. 2021;78(8):840-853.
3. Carlino M, Ruparelia N, Thomas G, et al. Modified contrast microinjection technique to facilitate chronic total occlusion recanalization. *Catheter Cardiovasc Interv*. 2016;87(6):1036-1041.
4. Carlino M, Azzalini L. Letter: what is the carlino technique? *EuroIntervention*. 2023;18(16):e1388-e1389.
5. Alexandrou M, Rempakos A, Al Ogaili A, et al. Use of the carlino technique in chronic total occlusion percutaneous coronary intervention. *Am J Cardiol*. 2023;207:305-313.
6. Azzalini L, Boudou N, Avran A, et al. Role of the retrograde carlino technique for chronic total occlusion percutaneous coronary intervention. *Catheter Cardiovasc Interv*. 2023;101(3):563-568.
7. Carlino M, Godino C, Latib A, Moses JW, Colombo A. Subintimal tracking and re-entry technique with contrast guidanc: a safer approach. *Catheter Cardiovasc Interv*. 2008;72(6):790-796.
8. Carlino M, Latib A, Godino C, Cosgrave J, Colombo A. CTO recanalization by intraocclusion injection of contrast: the microchannel technique. *Catheter Cardiovasc Interv*. 2008;71(1):20-26.
9. Azzalini L, Uretsky B, Brilakis ES, Colombo A, Carlino M. Contrast modulation in chronic total occlusion percutaneous coronary intervention. *Catheter Cardiovasc Interv*. 2019;93(1):E24-E29.
10. Megaly M, Basir MB, Brilakis E, Alaswad K. Power carlino". *JACC Cardiovas Intervent*. 2021;14(22):2521-2522.
11. Azzalini L, Tzanis G, Mashayekhi K, et al. Solving challenging situations and complications in everyday percutaneous coronary intervention using chronic total occlusion techniques. *J Invasive Cardiol*. 2020;32(3):63.
12. Carlino M, Uretsky BF, Azzalini L, et al. STAR procedure becomes SAFER: first-in-man case series of a new antegrade dissection re-entry technique. *Catheter Cardiovasc Interv*. 2023;102(4):577-584.
13. Amsavelu S, Carlino M, Brilakis ES. Carlino to the rescue: use of intralesion contrast injection for bailout antegrade and retrograde crossing of complex chronic total occlusions. *Catheter Cardiovasc Interv*. 2016;87(6):1118-1123.
14. Karacsonyi J, Brilakis ES, Chandwaney RH. Guide-Extension carlino: A novel technique for crossing a microcatheter uncrossable proximal cap during chronic total occlusion interventions. *Catheter Cardiovasc Interv*. 2022;99(7):2038-2042.
15. Marukyan N, et al Carlino-Like technique for retrograde recanalization of chronic thromboembolic pulmonary artery occlusion. *JACC Cardiovasc Interv*. 2024;17(11):1394-1396.
16. Sonsoz MR, Püşüroğlu H, Güler A, Uzun F. Retrograde use of intralesional contrast injection: Carlino technique as a bailout strategy for crossing of complex chronic total occlusion. *Coron Artery Dis*. 2023;34(7):531-532.

SUPPORTING INFORMATION

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

How to cite this article: Carlino M, Nascimbene A, Brilakis ES, et al. HydroDynamic contrast Recanalization (HDR): Description of a new crossing technique for coronary chronic total occlusions. *Catheter Cardiovasc Interv*. 2024;1-10. doi:10.1002/ccd.31243