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Percutaneous coronary intervention of chronic total occlusions involving a bifurcation: Insights from the PROGRESS-CTO registry

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Percutaneous coronary intervention of chronic total occlusions involving a bifurcation: Insights from the PROGRESS-CTO registry

Keywords: chronic total occlusion percutaneous coronary intervention bifurcation

ABSTRACT

Background: The impact of bifurcations at the proximal or distal cap on the outcomes of chronic total occlusion (CTO) percutaneous coronary intervention (PCI) has received limited study. *Methods:* We analyzed the clinical, angiographic, and procedural data of 4,584 cases performed in patients between 2012 and 2020 in a global CTO PCI registry. We compared 4 groups according to the bifurcation location: "proximal cap," "distal cap," "proximal and distal cap," and "no bifurcation." *Results:* The CTO involved a bifurcation in 67% cases, as follows: proximal cap (n = 1451, 33%), distal cap (n = 622, 14%), or both caps (n = 954, 21%). "Proximal and distal cap" cases had higher J-CTO compared with "proximal cap," "distal cap," and "no bifurcation" cases (2.9 ± 1.1 vs 2.5 ± 1.1 vs 2.4 ± 1.2 vs 2.0 ± 1.2 , P < 0.0001), and they were also associated with a lower technical success rate (79% vs 85% vs 85% vs 90%, P < 0.0001), higher pericardiocentesis rate (1% vs 1% vs 0.2% vs 0.3%, P = 0.02), and higher emergency coronary artery bypass graft surgery rate (0.3% vs 0% vs 0%, vs 0%, P = 0.01). *Conclusion:* More than two-thirds of CTO PCIs involve a bifurcation, which is associated with lower technical success and higher risk of complications.

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The impact of a side branch in the proximal or distal cap on the success and complication rates of chronic total occlusion percutaneous coronary intervention (CTO PCI) has received limited study.

We analyzed clinical, angiographic, and procedural data of 4,584 CTO PCIs performed in 4,479 patients between 2012 and 2020 in a global CTO PCI registry (NCT02061436). We compared 4 groups according to the bifurcation location: "proximal and distal," "proximal cap," "distal cap," and "no bifurcation." The study was approved by the Institutional Review Board of each center.

Bifurcations were defined by the presence of a side branch of diameter >2 mm within 5 mm of the proximal or distal cap of the CTO lesion. The presence of a bifurcation was visually assessed by the operator after dual injection and before any attempt to cross. A procedure was defined as retrograde if an attempt was made to cross the lesion through a collateral vessel or bypass graft supplying the target vessel distal to the lesion; if not, the procedure was classified as antegrade-only. Technical success was defined as successful CTO revascularization (main vessel only) with an achievement of <30% residual diameter stenosis and Thrombolysis in Myocardial Infarction (TIMI) 3 antegrade flow. In-hospital major adverse cardiovascular events (MACE) include death, myocardial infarction, recurrent angina requiring urgent repeat target vessel or target lesion revascularization (with PCI or coronary artery bypass graft surgery), stroke, and tamponade requiring pericardiocentesis.

Myocardial infarction was defined as per the Third Universal Definition of Myocardial Infarction Type 4¹.

Categorical variables are presented as percentages and were compared with the chi-square test. Continuous variables are summarized by mean \pm standard deviation or median [interquartile range] and compared with the t-test, analysis of variance, or Wilcoxon rank-sum test. All *P*-values refer to overall significance testing between the four groups, unless reported otherwise.

The CTO involved a bifurcation in 67% of all cases, as follows: proximal cap (n = 1451, 32%), distal cap (n = 622, 14%), or both proximal and distal caps (n = 954, 21%). "Proximal and distal cap" patients were more likely to have had myocardial infarction compared with "proximal cap," "distal cap," and "no bifurcation" patients and also had a higher J-CTO score, greater use of the retrograde approach (Table), and lower technical success (Fig.). Inhospital MACE rates differed significantly between the groups, driven by difference in rates of emergency Coronary Artery Bypass Grafting (CABG) and pericardiocentesis (Table). Two of the three emergency CABG surgeries happened in cases with perforation that required pericardiocentesis. Perforation rates, especially Ellis class 2 and cavity spilling, were higher in the "proximal" and "proximal and distal cap" groups (Table). The mechanism of perforation did not differ according to the location of the bifurcation (Table).

We performed logistic regression analysis adjusting for lesion characteristics (blunt/no stump, lesion length>20 mm, moderate/ severe proximal tortuosity, and moderate/severe calcification), the presence of the bifurcation, and intravascular ultrasound (IVUS) use. After adjustment, presence of a bifurcation was significantly

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Table

Clinical technical and procedural characteristics and outcomes according to the presence of a bifurcation at the proximal or distal cap or both.

Age, years, mean \pm SD 67 \pm 10 67 \pm 10 65 \pm 10 64 \pm 10 0.4 Previous ML % 40 41 35 47 .0001 Target vessel, %	VARIABLE	No bifurcation $n = 1,557$	Proximal cap n = 1,451	Distal Cap n = 622	Proximal and distal caps $n = 954$	<i>P</i> -value
Previous ML 3 40 41 35 47 7 60001 Targer vessel, X 5 5 5 5 5 IAD 26 35 16 25 21 IAD 26 35 16 25 21 ICC 26 35 16 25 21 ICD 2 2 2 3 1 - ICO score, mean ± SD 2 ± 1.2 2.5 ± 1.1 2.4 ± 1.2 2.9 ± 1 <0001	Age. years. mean + SD	67 + 10	67 + 10	65 + 10	64 + 10	0.4
Target sets is a set of the	Previous MI. %	40	41	35	47	<.0001
Normal 33 45 56 55 Normal IAD 26 35 16 23 1 ICA 19 18 25 21 Other 2 2 3 1 ICO score, mean ±SD 2 ± 1.2 2.5 ± 1.1 2.4 ± 1.2 2.9 ± 1 <0001	Target vessel.%					<.0001
$i \ DD$ 26 35 16 23 23 23 21 $i \ UCX$ 19 12 2 3 1 -1001 $i \ UCX$ 2 ± 1.2 $2 \pm 1.$	• RCA	53	45	56	55	
· LCX191825211· Other231.I-CTO sore, mean ± SD2±1.22.5±1.12.4±1.22.9±1.1<.0001	• LAD	26	35	16	23	
•Other22311J-CTO sore, men ± 502±1.22.5±1.12.4±1.22.9±1.22.9±1.00.001Crosine, strategies used, X98785.0<0.001	• LCX	19	18	25	21	
j-Choore, mean ± SD2 ± 1.22.5 ± 1.12.4 ± 1.22.9 ± 1<0001Crossing strategies used, X908785<0001• AWR89908785<0001• AWR222424260.06• Retrograde17273543<0001• AWR86868185<0001• AWR669117• AWR86868185<0001• AWR679117• AWR8686813• AWR8686813• AWR8686813• AWR8686813• AWR91161311• AWR362.4191.1• AWR362.419313 [91.1904.001• AWR362.4120 [85.131133 [91.1904.001• Orophylactic2.3191.11.40.0001• Orophylactic2.3191.13 [74.166]120 [85.131133 [91.1904.001• Orophylactic0.33460.00014.00014.0001• Orophylactic0.334.60.00014.0001• Orophylactic0.3331.01.0001• Orophylactic0.3 <td>• Other</td> <td>2</td> <td>2</td> <td>3</td> <td>1</td> <td></td>	• Other	2	2	3	1	
Crossing strategies used, X International and the arrow of the arrow	I-CTO score, mean + SD	$\frac{-}{2}$ + 1.2	-2.5 + 1.1	2.4 + 1.2	2.9 ± 1	<.0001
AVE 89 90 87 85 <0001 ADR 22 24 26 0.06 Retrograde 17 27 35 43 <.0001	Crossing strategies used. %	_				
• ADR222424266.00• Retronsing strategy, %First crossing strategy, %• AVNE86868185<001	• AWE	89	90	87	85	<.0001
ektrograde17273543<.001FirstUextrograde868187<.001ADR66818135<.001ARtograde6691117USuccesful crossing strategy, %VVVVAWE655041ADR17161315VAUR9142222VRetrograde91422240Prophylactic3324131402Prophylactic914212400Prophylactic9185784001010Procedure time, min, median [IQR]201 [50,300]201 [55,300]201 [70,300]4001Outrast volume, mi, median [IQR]201 [50,300]201 [55,300]201 [70,300]4001Perforation, %91832444230.001Christian dose, Gy, median [IQR]23242444230.001Evention332444230.0011011010.001Perforation, %91839191919191919191Util time, min, median [IQR]3391 <td>• ADR</td> <td>22</td> <td>24</td> <td>24</td> <td>26</td> <td>0.06</td>	• ADR	22	24	24	26	0.06
First constraint of the set of th	Retrograde	17	27	35	43	<.0001
ANE S6 S6 S6 S1 S5 <001 ADR 6 4 6 3 Retrograde 6 9 11 17 Successful crossing strategy, % 11 17 AWE 65 50 41 <0001	First crossing strategy, %					
ADR 6 4 6 3 3 $ketrograde$ 6 9 1 7 AWE 65 56 50 41 $<$ AWE 65 56 50 41 $<$ $<$ ADR 9 14 22 22 22 $Retrograde$ 9 14 22 22 08 $Prophylactic233.62.41.92.40.08Prophylactic233.62.41.92.40.02Urgent0.50.30.50.70.45Procedure time, min, median [IQR]01 [67.150]131 [74.166]120 [85.173]133 [91.190]<0001Contrast volume, m., median [IQR]209 [150.300]220 [155.300]220 [155.300]240 [170.300]<0001AK radiatio dose, Gy, median [IQR]201 [150.300]220 [155.300]240 [170.300]<0001AK radiatio dose, Gy, median [IQR]2112.3.5]211.3.423 [13.3.8]240 [170.300]<0001Cattrostrostrostrostrostrostrostrostrostro$	• AWE	86	86	81	85	<.0001
• Retrograde691117Successful crossing strategy, %6565041<.li>• AVR65565041<.li><.li>• ADR17161313<.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li><.li>	• ADR	6	4	6	3	
Successful crossing strategy, % . <t< td=""><td>Retrograde</td><td>6</td><td>9</td><td>11</td><td>17</td><td></td></t<>	Retrograde	6	9	11	17	
AWE 65 56 50 41 <.0001 • ADR 17 16 13 15 . Retrograde 9 14 22 22 . MCS use, % 3.6 2.4 1.9 2.4 0.08 • Prophylatic 2.3 1.9 1.1 1.4 0.2 Urgent 0.5 0.3 0.5 0.7 0.45 Technical success, % 91 85 85 78 <.0001	Successful crossing strategy, %					
• ADR 17 16 13 15 • Retrograde 9 14 22 22 MCS use, % 36 24 19 24 0.08 • Prophylactic 2.3 1.9 1.1 1.4 0.2 • Urgent 0.5 0.3 0.5 0.7 0.45 Technical success, % 91 85 85 78 <0001	• AWE	65	56	50	41	<.0001
· Retrograde 9 14 22 22 MCsues, % 36.0 2.4 1.9 2.4 0.8 · Prophylactic 2.3 1.9 1.1 1.4 0.2 · Urgent 0.5 0.3 0.5 0.7 0.45 Technical success, % 91 85 85 78 0.001 Procedure time, min, median [IQR] 0.10 [67,150] 13 [74,166] 120 [85,173] 133 [91,190 .0001 Contrast volume, mL, median [IQR] 209 [150,300] 220 [155,300] 220 [155,300] 240 [170,300] .0001 Perforation dose, Gy, median [IQR] 2.3 [1.2,3.5] 2 [1.3.4] 2.3 [1.3.3.8] 2.5 [1.5,4.1] .0001 Perforation dose, Gy, median [IQR] 3.3 2.4 [1.3.4] 2.3 [1.3.3.8] 2.5 [1.5,4.1] .0001 Class	• ADR	17	16	13	15	
MCS use, % 3.6 2.4 1.9 2.4 0.8 • Prophylactic 2.3 1.9 1.1 1.4 0.2 • Urgent 0.5 0.3 0.5 0.7 0.45 Technical success, % 91 85 85 78 .0001 Procedure time, min, median [IQR] 101 [67,150] 113 [74,166] 120 [85,173] 133 [91,190] .0001 Contrast volume, mL, median [IQR] 2.3 [1.2,35] 2 [1.1,34] 23 [1.3,38] 2.5 [1.5,4,1] .0001 AK radiation dose, Gy, median [IQR] 2.3 [1.2,35] 2 [1.1,34] 23 [1.3,38] 2.5 [1.5,4,1] .0001 Perforation, % 1.93 3.8 3 4.6 0.0009 Class - 11.3 [4] 2.7 [1.5,300] 2.5 [1.5,4,1] .001 • Ellis 1 3 3.7 9 0.8 .001 .0000 • Ellis 2 1.1 2.4 4.4 2.3 (1.2,3.5) .0.8 .0.8 .0.8 .0.8 .0.8 .0.8 .0.8	Retrograde	9	14	22	22	
• Prophylactic 2.3 1.9 1.1 1.4 0.2 • Urgent 0.5 0.3 0.5 0.7 0.45 Technical success, % 91 85 85 78 <0001	MCS use. %	3.6	2.4	1.9	2.4	0.08
• Urgent 0.5 0.3 0.5 0.7 0.45 Technical success, % 91 85 85 78 <.0001	Prophylactic	2.3	1.9	1.1	1.4	0.2
Technical success, % 91 85 85 78 <001 Procedure time, min, median [IQR] 101 [67,150] 113 [74,166] 120 [85,173] 133 [91,190] <.0001	• Urgent	0.5	0.3	0.5	0.7	0.45
Procedure time, min, median [IQR] 101 [67,150] 113 [74,166] 120 [85,173] 133 [91,190] <0001 Contrast volume, ml, median [IQR] 209 [150,300] 220 [155,300] 220 [155,300] 240 [170,300] <0001	Technical success. %	91	85	85	78	<.0001
Contrast volume, ml, median [10k]209 [150,300]220 [155,300]220 [155,300]240 [170,300]<001AK radiation dose, Gy, median [10k]2.3 [1.2,3.5]2 [1.1,3.4]2.3 [1.3,3.8]2.5 [1.5,4.1]<0001	Procedure time, min, median [IOR]	101 [67,150]	113 [74,166]	120 [85,173]	133 [91,190]	<.0001
AK radiation dose, Gy, media [IQR] 2.3 [1.2,3.5] 2 [1.1,3.4] 2.3 [1.3,3.8] 2.5 [1.5,4.1] <.0001	Contrast volume, mL, median [IOR]	209 [150,300]	220 [155,300]	220 [155,300]	240 [170.300]	<.0001
Perforation, % 1.93 3.8 3 4.6 0.0009 Class	AK radiation dose, Gy, median [IOR]	2.3 [1.2.3.5]	2 [1.1.3.4]	2.3 [1.3.3.8]	2.5 [1.5.4.1]	<.0001
Class 33 24 44 23 0.08 • Ellis 1 32 22 40 37 51 • Ellis 2 22 40 37 51 19 13 • Ellis 3 41 27 19 13 19 13 • Cavity-spilling 37 9 0 10 7 10 11 11 11 11 12 0.18 • Microcatheter 3 9 0 12 0.18 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.18 0.92 0.78 0.44 0.44 0.44 0.44 0.44 0.44 0.44 0.44 0.44 0.44 0.44 0.45 0.21 0.78 0.78 0.44 0.41 0.21 0.79 0.79 0.79 0.79 0.79 0.79 0.79 0.79 0.79 0.3 <td< td=""><td>Perforation. %</td><td>1.93</td><td>3.8</td><td>3</td><td>4.6</td><td>0.0009</td></td<>	Perforation. %	1.93	3.8	3	4.6	0.0009
• Ellis 1 33 24 44 23 0.08 • Ellis 2 22 40 37 51 • Ellis 3 41 27 19 13 • Cavity-spilling 3.7 9 0 13 • Cavity-spilling 3.7 9 0 13 • Mechanism - - - - • Wire 38 51 26 51 0.18 • Microcatheter 3 9 0 12 0.18 • Balloon 7 11 11 12 0.92 • Stent 10 7 11 24 0.44 In-hospital MACE, % 1 2 1 0.4 0.4 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 0.79 • Re-CABG 0 0 0 0.3 0.01 0.79 • Stroke 0.1 0.2 0.2 0.2 0.94 • Stroke	Class					
• Ellis 2 22 40 37 51 • Ellis 3 41 27 19 13 • Cavity-spilling 3.7 9 0 13 Mechanism - - - - • Wire 38 51 26 51 0.18 • Microcatheter 3 9 0 12 0.18 • Balloon 7 11 11 12 0.92 • Stent 10 7 11 2 0.44 In-hospital MACE, % 1 2 1 0.44 • Balloon 0.4 0.3 0.2 0.2 0.78 • Balloon 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-CABG 0 0 0 0.79 0.79 • Rericardiocenteris 0.3 0.2 0.2 0.90	• Ellis 1	33	24	44	23	0.08
• Ellis 3 41 27 19 13 • Cavity-spilling 3.7 9 0 13 Mechanism - - - - • Wire 38 51 26 51 0.18 • Microcatheter 3 9 0 12 0.18 • Balloon 7 11 11 2 0.92 • Stent 10 7 11 2 0.44 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 0.21 • Re-CABG 0 0 0 0.3 0.01 • Stroke 0.1 0.2 0.2 0.79 • Re-CABG 0.1 0.2 0.2 0.94 • Stroke 0.1 0.2 0.2 0.94 • Pericardiocenteris 0.3 0.1 0.2 0.2 0.94	• Ellis 2	22	40	37	51	
• Cavity-spilling3.79013Mechanism• Wire385126510.18• Microcatheter390120.18• Balloon71111120.92• Stent107112.40.44In-hospital MACE, %12.40.040.30.20.78• MI0.30.50.710.210.79• Re-PCI0.10.1000.79• Re-CABG0.10.20.20.910.92• Breicardiocentesis0.310.20.20.92	• Ellis 3	41	27	19	13	
Mechanism • Wire 38 51 26 51 0.18 • Microcatheter 3 9 0 12 0.18 • Balloon 7 11 11 12 0.92 • Stent 10 7 11 2 0.44 In-hospital MACE, % 1 2 1 0.2 0.78 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0.799 0.799 • Re-CABG 0 0 0.2 0.2 0.94 • Stroke 0.1 0.2 0.2 0.2 0.94	Cavity-spilling	3.7	9	0	13	
• Wire 38 51 26 51 0.18 • Microcatheter 3 9 0 12 0.18 • Balloon 7 11 11 12 0.92 • Stent 10 7 11 2 0.44 In-hospital MACE, % 1 2 1 2.4 0.04 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 0.21 • Re-PCI 0.1 0.1 0 0 0.799 0.799 • Re-CABG 0 0 0.2 0.2 0.92 0.91 • Stroke 0.1 0.2 0.2 0.2 0.91 0.91	Mechanism					
• Microcatheter 3 9 0 12 0.18 • Balloon 7 11 11 12 0.92 • Stent 10 7 11 12 0.92 • Stent 10 7 11 2 0.44 In-hospital MACE, % 1 2 1 2.4 0.04 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0.799 0.799 • Re-CABG 0 0 0.2 0.2 0.94 • Stroke 0.1 0.2 0.2 0.94 0.94	• Wire	38	51	26	51	0.18
• Balloon 7 11 11 12 0.92 • Stent 10 7 11 2 0.44 In-hospital MACE, % 1 2 1 2.4 0.04 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0 0.79 • Re-CABG 0 0 0.3 0.01 0.1 0.2 0.2 0.92 • Stroke 0.1 0.2 0.2 0.2 0.94 0.92 0.94	 Microcatheter 	3	9	0	12	0.18
• Stent 10 7 11 2 0.44 In-hospital MACE, % 1 2 1 2.4 0.04 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0.79 • Re-CABG 0 0 0.3 0.01 • Stroke 0.1 0.2 0.2 0.94	• Balloon	7	11	11	12	0.92
In-hospital MACE, % 1 2 1 2.4 0.04 • Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0 0.79 • Re-CABG 0 0 0.3 0.01 0.79 • Stroke 0.1 0.2 0.2 0.94 0.94	• Stent	10	7	11	2	0.44
Death 0.4 0.3 0.2 0.2 0.78 • MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0 0.79 • Re-CABG 0 0 0 0.3 0.01 • Stroke 0.1 0.2 0.2 0.2 0.94	In-hospital MACE. %	1	2	1	2.4	0.04
• MI 0.3 0.5 0.7 1 0.21 • Re-PCI 0.1 0.1 0 0.79 • Re-CABG 0 0 0.3 0.01 • Stroke 0.1 0.2 0.2 0.2 0.94 • Periordiocentesis 0.3 1 0.2 1 0.02	• Death	0.4	0.3	0.2	0.2	0.78
Re-PCI 0.1 0.1 0 0.79 • Re-CABG 0 0 0 0.3 0.01 • Stroke 0.1 0.2 0.2 0.94 • Periordiocentesis 0.3 1 0.2 0.2 0.02	• MI	0.3	0.5	0.7	1	0.21
• Re-CABG 0 0 0 0.01 • Stroke 0.1 0.2 0.2 0.94 • Periordiocentesis 0.3 1 0.2 0.2 0.02	• Re-PCI	0.1	0.1	0	0	0.79
• Stroke 0.1 0.2 0.2 0.2 0.94	• Re-CABG	0	0	0	0.3	0.01
- Derivardiocentesis 0.3 1 0.7 1 0.07	Stroke	0.1	0.2	0.2	0.2	0.94
	Pericardiocentesis	0.3	1	0.2	1	0.02

CTO, chronic total occlusion; PCI, percutaneous coronary intervention; MI, myocardial infarction; CABG, coronary artery bypass graft; RCA, right coronary artery; LAD, left anterior descending; LCX, left circumflex; J-CTO, Japanese multicenter chronic total occlusion registry; MCS, mechanical circulatory support; AK, air kerma; Gy, gray; MACE, major adverse cardiovascular events; SD, standard deviation; IQR, interquartile range.

associated with a lower technical success when compared with absence of any bifurcation (odds ratio [OR] for the proximal cap: 0.63; 95% confidence intervals [CI]: 0.44 to 0.89; *P*-value = 0.009, OR for the distal cap: 0.59; 95% CI: 0.39 to 0.89; *P*-value = 0.01, OR for proximal and distal caps: 0.54; 95% CI: 0.37 to 0.77; *P*-value < 0.001). A first-order interaction term of intravascular ultrasound (IVUS) use and bifurcation presence was not significantly associated with a technical success (OR for the proximal cap: 1.81; 95% CI: 0.78 to 4.26; *P*-value = 0.17, OR for the distal cap: 1.57; 95% CI: 0.55 to 4.48; *P*-value = 0.39, OR for proximal and distal caps: 1; 95% CI: 0.44 to 2.25; *P*-value = 0.99).

We performed the same analysis for the endpoint of perforation. After adjustment, presence of a proximal and distal cap bifurcation was significantly associated with higher perforation rates when compared with absence of any bifurcation (OR for the proximal cap: 2.16; 95% CI: 0.97 to 4.81; *P*-value = 0.06, OR for the distal cap: 2.29; 95% CI: 0.89 to 5.87; *P*-value = 0.08, OR for proximal

and distal caps: 2.38; 95% CI: 1.05 to 5.43; *P*-value = 0.04). An interaction term of IVUS use and bifurcation presence was not associated with perforation rates (OR for the proximal cap: 0.48; 95% CI: 0.16 to 1.47; *P*-value = 0.19, OR for the distal cap: 0.38; 95% CI: 0.09 to 1.58; *P*-value = 0.18, OR for proximal and distal caps: 0.29; 95% CI: 0.08 to 1; *P*-value = 0.05).

Bifurcations involving the CTO were more common in our study compared with previous CTO PCI series that used the visual inspection of the angiogram and the same definition^{2,3}. Our study did not assess for side branches within the CTO segment, as performed in previous studies. In addition, we included any side branch present within 5 mm of the proximal or distal cap, irrespective of the degree of stenosis.

CTO lesions involving a bifurcation had lower technical success rates. As reported in previous studies, CTOs involving a bifurcation also had a higher risk of complications, namely emergency CABG^{2,3} and perforation. In contrast to previous studies⁴, the rate of

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Figure. In-hospital outcomes after chronic total occlusion percutaneous coronary intervention according to the presence of a bifurcation at the proximal or distal cap or both. MACE, major adverse cardiovascular events; CABG, coronary artery bypass graft.

periprocedural MI was not higher in lesions involving a bifurcation, possibly because systematic biomarker measurements were not performed in our study.

Our study does not assess the incidence and impact of side branch occlusion or use of specific bifurcation wiring and stenting techniques.⁵ In addition, we cannot determine which technique (antegrade wiring, dissection/re-entry, or retrograde) caused each perforation. Finally, bifurcations were operator-reported and not based on core laboratory adjudication.

In conclusion, two-thirds of CTO lesions involve a bifurcation, most commonly at the proximal cap. The presence of a bifurcation is associated with a lower technical success and higher risk of complications, especially when there is a bifurcation in both the proximal and the distal cap.

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References

- Thygesen K, Alpert JS, Jaffe AS, Simoons ML, Chaitman BR, White HD. Third Universal Definition of Myocardial Infarction. *Circulation*. 2012;126(16): 2020–2035.
- Ojeda S, Pan M, Gutiérrez A, et al. Bifurcation lesions involved in the recanalization process of coronary chronic total occlusions: Incidence, treatment and clinical implications. *Int J Cardiol.* 2017;230:432–438.
- Galassi AR, Boukhris M, Tomasello SD, et al. Incidence, treatment, and in-hospital outcome of bifurcation lesions in patients undergoing percutaneous coronary interventions for chronic total occlusions. *Coron Artery Dis.* 2015;26(2):142–149.
- Paizis I, Manginas A, Voudris V, Pavlides G, Spargias K, Cokkinos DV. Percutaneous coronary intervention for chronic total occlusions: the role of sidebranch obstruction. EuroIntervention: J EuroPCR Collab Work Group Intervent Cardiol Euro Soc Cardiol. 2009;4(5):600–606.
- Nguyen-Trong P, Rangan BV, Karatasakis A, et al. Predictors and outcomes of side-branch occlusion in coronary chronic total occlusion interventions. J Invasive Cardiol. 2016;28(4):168–173.

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