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ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

Comparative outcomes of parallel-wire and antegrade wire escalation techniques following single-wire failure in CTO PCI – a long-term follow-up study

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SUMMARY

Introduction/Objective Following the failure of the single-wire technique in percutaneous coronary intervention (PCI) for chronic total occlusions (CTO), two principal antegrade escalation strategies are commonly employed: the parallel-wire technique and antegrade wire escalation (AWE). Despite their widespread use, comparative data on the procedural characteristics and long-term clinical outcomes of these strategies remain scarce. This study aims to compare the procedural parameters and long-term outcomes of the parallel-wire and AWE techniques after single-wire failure in CTO PCI.

Methods This retrospective, single-center study included patients who underwent successful CTO PCI between January 2018 and December 2023 using either the parallel-wire or AWE technique following single-wire failure. The primary endpoint was a composite of cardiac death, myocardial infarction, stroke, or target vessel revascularization (TVR). Secondary outcomes included procedure duration, fluoroscopy time, contrast volume, and total radiation dose. Median follow-up duration was 1222 days (IQR 580–1969 days).

Results Among 270 CTO PCI procedures, 112 (41.5%) required escalation: 90 with AWE and 22 with the parallel-wire technique. Baseline clinical and angiographic characteristics were comparable. The primary composite outcome occurred in 14.4% of the parallel-wire group and 9.1% of the AWE group (p = 0.73). No significant differences were observed in individual clinical events. Procedure duration was longer (95.5 ± 43.6 *vs.* 77.0 ± 30.7 min; p = 0.064) and contrast volume higher (336.4 ± 113.3 *vs.* 271.6 ± 90.6 mL; p = 0.014) in the AWE group, with similar fluoroscopy time and radiation dose. No clinically or angiographically significant complications occurred during the periprocedural period.

Conclusion Both AWE and parallel-wire techniques demonstrate comparable safety and efficacy following single-wire failure in CTO PCI. While procedural efficiency slightly favored the parallel-wire strategy, overall outcomes support either approach, pending further prospective validation.

Keywords: chronic total occlusion; percutaneous coronary intervention; antegrade approach; wire escalation; parallel wire

INTRODUCTION

Chronic total occlusion (CTO) percutaneous coronary intervention (PCI) represents a frontier of interventional cardiology that continues to evolve in both technique and strategy [1, 2]. Despite advances in operator training, wire technology, and algorithmic approaches, procedural success remains highly dependent on the ability to cross the occlusion efficiently and safely [3, 4].

The single-wire technique is typically employed as the initial strategy during antegrade CTO PCI. However, its success is often limited in complex lesion subsets characterized by blunt or ambiguous caps, heavy calcification, or long occlusion length. In such cases, escalation is required. The parallel-wire (PW) technique, which introduces a second wire after the initial wire enters a subintimal space, enables re-engagement of the true lumen with a different trajectory. Alternatively, the antegrade wire escalation (AWE) strategy involves gradual increases in wire penetration power while maintaining the original trajectory, and is often guided by tactile feedback and intravascular imaging [4, 5].

While both approaches are widely used, comparative data on their clinical efficacy –particularly regarding long-term outcomes such as cardiac death, myocardial infarction, stroke, or target vessel revascularization (TVR) – remain limited. Most previous studies have focused on procedural endpoints, without evaluating

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whether differences in technique result in sustained clinical benefits [6–11]. Considering that patient-specific risk factors – particularly diabetes mellitus – as well as anatomical features such as bifurcation involvement, severe calcification, long occlusion length, and ambiguous proximal caps are associated with increased lesion complexity and adverse long-term outcomes following CTO PCI, understanding the interplay between clinical and anatomical variables remains crucial when assessing escalation strategies [12–16].

This study aimed to compare not only the procedural efficiency and safety of the two strategies, but also their impact on long-term clinical outcomes, thereby providing a more comprehensive understanding of how escalation techniques influence both immediate and long-term patient prognosis.

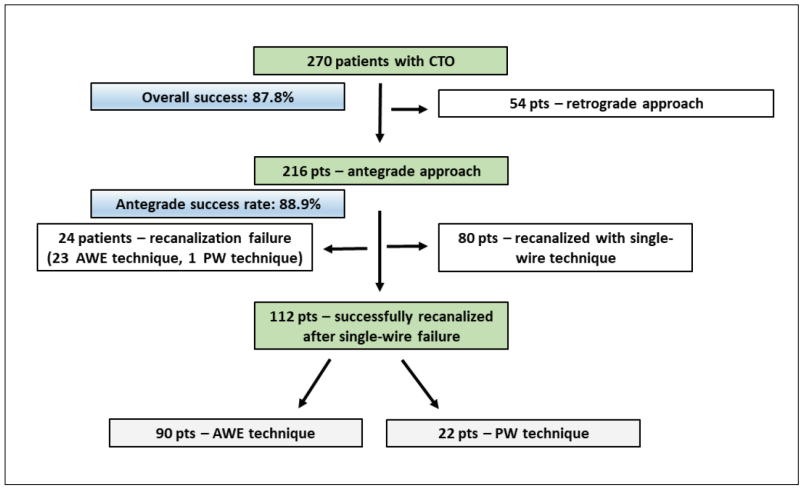

Figure 1. Study flow chart;

CTO – chronic total occlusion; pts – patients; AWE – antegrade wire escalation; PW – parallel wire

METHODS

Study design

This was a retrospective, observational single-center cohort study conducted at the tertiary university Clinical Center of Serbia, approved by the Ethics Committee of the University Clinical Center of Serbia. Patients who underwent CTO PCI between January 2018 and December 2023 were screened. Only those with failure of the initial single-wire antegrade approach, followed by treatment with either a PW or AWE technique, were included. In the analysis, we included procedures that achieved technical success, defined as successful CTO crossing with < 30% residual stenosis and achievement of TIMI 3 flow. All procedures were performed by a senior CTO operator in collaboration with two junior specialists dedicated to CTO interventions, both working under the supervision and proctorship of the senior operator.

Definitions of procedural techniques

Single-wire technique

The single-wire technique refers to the initial approach in PCI for CTO, where a single guidewire is used to attempt lesion crossing in an antegrade fashion. This method typically employs a soft or intermediate-tip wire, guided by angiographic anatomy, without immediate escalation to higher-penetration or multiple-wire strategies. It is considered a low-complexity, first-line technique and often precedes more aggressive methods if unsuccessful.

Antegrade wire escalation (AWE) technique

The AWE technique involves the sequential use of guidewires with increasing tip stiffness and penetration power to cross the occlusion through the true lumen in an antegrade direction. Escalation typically progresses from polymer-jacketed or tapered-tip wires to high-penetration wires, depending on lesion characteristics and operator judgment. This method is generally employed after the failure of the single-wire approach, aiming to overcome resistant proximal caps or ambiguous vessel course without entering the subintimal space [5].

Parallel-wire (PW) technique

The PW technique constitutes a structured escalation approach implemented after the unsuccessful application of the single-wire method. Upon confirmation – or strong suspicion – that the initial guidewire has entered an extraplaque space, a second, usually stiffer or differently tapered wire is advanced in parallel to the first. Employing a microcatheter for enhanced support and directional control, the adjunctive wire is steered along an alternative trajectory, with the explicit aim of re-engaging the true arterial lumen distal to the occlusion. By providing a distinct channel for lesion negotiation and refining torque transmission, this technique has been shown to improve crossing success rates in anatomically challenging CTOs [17].

Endpoints

The primary outcome was the composite of cardiac death, nonfatal myocardial infarction, target vessel revascularization, and stroke. Secondary endpoints included total procedure duration, fluoroscopy time, contrast volume, and the total radiation dose, defined as the cumulative air kerma at the interventional reference point (measured in mGy), recorded at the end of the procedure.

Population and eligibility

The study included patients with angiographically confirmed chronic total occlusion who were initially treated with a single-wire antegrade strategy, followed by escalation to either a PW or antegrade wire technique after failure of the initial attempt. Only patients with complete procedural data and available long-term clinical follow-up were analyzed. Patients treated with retrograde or hybrid techniques, those in whom re-entry devices such as CrossBoss or Stingray were used, as well as individuals with incomplete or unavailable follow-up data, were excluded from the study.

Follow-up

Clinical follow-up data were collected via outpatient visits, electronic medical records, and standardized phone interviews. Median follow-up duration was 1222 days (IQR 580–1969 days).

Statistical analysis

Categorical variables were expressed as counts and percentages, and continuous variables were reported as means ± standard deviations. The χ^2 test or Fisher's exact test was used to compare categorical variables, while continuous variables were compared using the independent-samples t-test or Mann–Whitney U test based on data distribution. A p-value less than 0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics version 28.0 (IBM Corp., Armonk, NY, USA).

Ethics: The study received approval from the Ethics Committee of the University Clinical Center of Serbia (Approval No. 30/4).

RESULTS

During the study period, a total of 270 patients underwent percutaneous coronary intervention for chronic total occlusion. Among them, 112 cases (41.5%) necessitated procedural escalation due to unsuccessful single-wire crossing and were subsequently managed with either an AWE strategy (n = 90) or the PW technique (n = 22) (Figure 1). This final study cohort consisted of 112 patients, the majority of whom were male (78.6%).

The mean age was 67.3 ± 10.1 years in the AWE group and 63.1 ± 8 years in the PW group, without a statistically significant difference (p = 0.07).

No significant differences were observed between the AWE and PW groups in terms of diabetes prevalence or family history of coronary artery disease. Baseline demographic, clinical, and procedural characteristics for both groups are detailed in Table 1.

Table 1. Baseline demographic, clinical, and procedural characteristics

Characteristics [n (%)]	Total	AWE	PW	p-value (AWE *vs.* PW)
No of patients	112	90	22	
Age (yrs, mean ± SD)	58.5 ± 9.5	67.3 ± 10.1	63.1 ± 8	0.43
Male (%)	88 (78.6)	70 (77.8)	18 (81.8)	0.68
Family history of CAD (%)	49 (43.8)	37 (41.1)	12 (54.5)	0.25
Diabetes (%)	32 (28.6)	23 (25.6)	9 (40.9)	0.209
– Insulin dependent	7 (6.25)	6 (6.7)	1 (4.5)	
Hypertension (%)	95 (84.8)	75 (83.3)	20 (90.9)	0.38
Hypercholesterolemia (%)	88 (78.6)	69 (76.7)	19 (86.4)	0.32
Smoking status				
– Never	61 (54.5)	46 (51.1)	15 (68.2)	0.11
– Smoker	23 (20.5)	22 (24.2)	1 (4.5)	
– Ex-smoker	28 (25)	22 (24.2)	6 (27.3)	
Previous MI (%)	50 (44.5)	38 (42.2)	12 (54.6)	0.58
– STEMI	33 (29.5)	25 (27.8)	8 (36.4)	
– NSTEMI	17 (15.2)	13 (14.4)	4 (18.2)	
Previous CABG (%)	5 (4.5)	5 (5.6)	0 (0)	0.26
Previous PCI (%)	28 (25)	23 (25.6)	5 (22.7)	0.78
CCS				
– CCS 1	15 (13.4)	13 (14.4)	2 (9.1)	0.76
– CCS 2	80 (71.4)	64 (71.1)	16 (72.7)	
– CCS 3	17 (15.2)	13 (14.4)	4 (18.2)	
CTO artery (n (%))				
– RCA	64 (58.7)	50 (56.6)	14 (66.7)	0.54
– LAD	33 (30.3)	27 (30.7)	6 (28.6)	
– Cx	12 (11)	11 (12.5)	1 (4.8)	
Localization of CTO (n (%))				
– Ostial	1 (0.9)	1 (1.1)	0 (0)	0.37
– Proximal	47 (42)	36 (40)	11 (50)	
– Medial	54 (48.2)	43 (47.8)	11 (50)	
– Distal	10 (8.9)	10 (11.1)	0 (0)	
In-stent CTO (N (%))	10 (8.9)	7 (7.8)	3 (13.6)	0.41
Diameter of CTO vessel (mm, mean ± SD)	3.0 ± 0.4	3.0 ± 0.4	3.2 ± 0.3	0.02
Stump morphology (N (%))				
– Blunt	35 (31.3)	27 (30)	8 (36.4)	0.56
– Tapered	77 (68.8)	63 (70)	14 (63.6)	
J CTO score (mean + SD)	1.69 ± 1.2	1.73 ± 1.1	1.50 ± 1.3	0.38
Side branch (%)	13 (11.6)	12 (13.3)	1 (4.5)	0.25

Data are expressed as the mean ± SD or as the number (percentage); CAD – coronary artery disease; MI – myocardial infarction; STEMI – ST-elevation myocardial infarction; NSTEMI – Non-ST-elevation myocardial infarction; CABG – coronary artery bypass grafting; CCS – Canadian Cardiovascular Society grading of angina pectoris; CTO – chronic total occlusion; LAD – left anterior descending; Cx – circumflex; RCA – right coronary artery; AWE – antegrade wire escalation; PW – parallel wire

Primary composite outcome and secondary endpoints

The primary composite outcome, defined as the occurrence of cardiac death, myocardial infarction, stroke, or TVR was documented in 13.4% of the overall study population. In the parallel wire group, this outcome occurred in 14.4% of patients, while in the AWE group, the incidence was 9.1% (Figure 2). Although the parallel wire group exhibited numerically higher event rates, none of the individual components of the composite outcome reached statistical significance between groups. Moreover, no significant differences were identified in the overall incidence

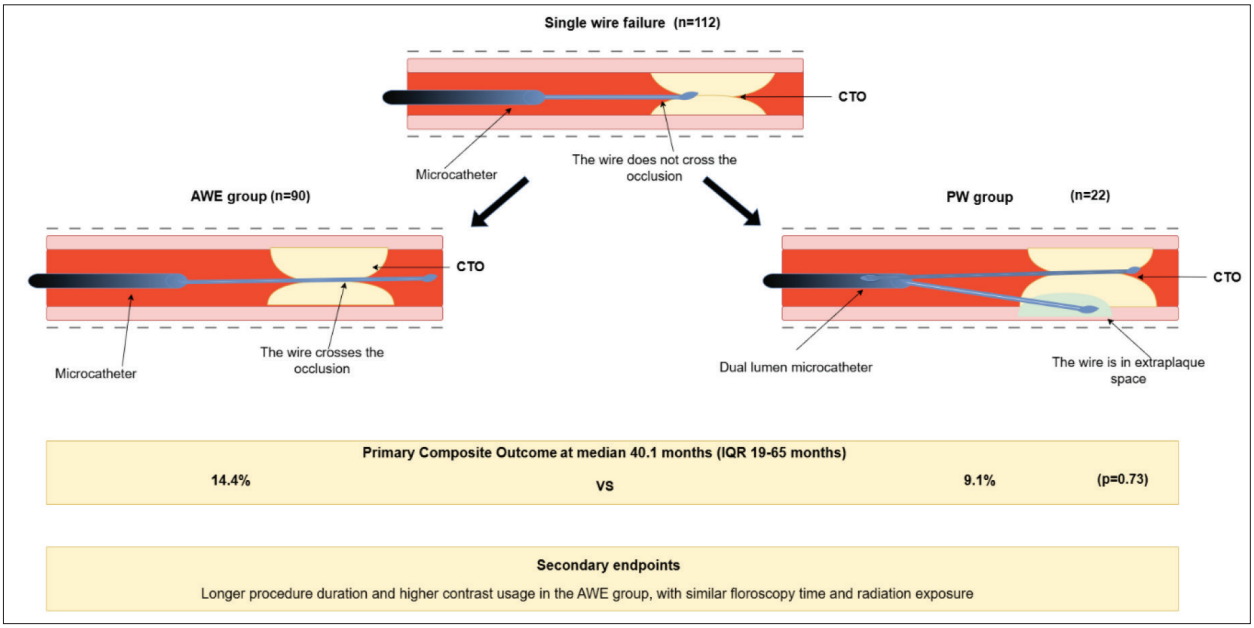

Figure 2. Central illustration;

AWE – antegrade wire escalation; PW – parallel wire; CTO – chronic total occlusion

Table 2. Primary composite outcomes during follow-up

N (%)	AWE	PW	p
Cardiac death	3 (3.3)	0 (0)	1
MI	2 (2.2)	0 (0)	1
TVR	5 (5.6)	1 (4.5)	1
Stroke	3 (3.3)	1 (4.5)	1
Total events	13 (14.4)	2 (9.1)	0.73

The data is numerical;
AWE – antegrade wire escalation technique;
PW – parallel wire techniques; MI – myocardial infarction; TVR – target-vessel revascularization

Table 3. Secondary procedural endpoints: comparison between antergrade-wire escalation and parallel-wire techniques

Parameter	Total	AWE (mean ± SD)	PW (mean ± SD)	p
Procedure time (min.)	91.84 ± 41.9	95.5 ± 43.6	77 ± 30.7	0.06
Fluoroscopy time (min.)	37.57 ± 22.3	38.1 ± 22.8	35.5 ± 21.1	0.62
Contrast volume (mL)	323.71 ± 111.88	336.4 ± 113.3	271.6 ± 90.6	0.01
Air Kerma (mGy)	1582.85 ± 987.32	1596.0 ± 1014.6	1528.9 ± 886.8	0.77

The data is numerical;
AWE – antegrade wire escalation technique; PW – parallel wire technique

of the primary composite endpoint or its constituent events between the two antegrade escalation strategies following failure of the single-wire approach. A detailed distribution of outcome types by group is provided in Table 2.

Secondary procedural endpoints included procedure duration, fluoroscopy time, contrast volume, and radiation dose. The mean procedure time was longer in the AWE group (95.5 ± 43.6 minutes) compared to the PW group (77.0 ± 30.7 minutes), with a trend toward statistical significance (p = 0.064). The contrast volume was significantly greater in the AWE group (336.4 ± 113.3 mL *vs.* 271.6 ± 90.6 mL; p = 0.014). In contrast, no statistically significant differences were observed between the groups in terms of fluoroscopy time and radiation dose (p = 0.624 and p = 0.776, respectively) (Figure 2). A comprehensive overview of these secondary outcomes is provided in Table 3. There were no clinically or angiographically significant complications observed in the periprocedural period.

Specifically, in successfully recanalized patients within the single-wire group, the following guidewires were used: Fielder family in 58 cases (72.5%), Gaia 1st in eight cases (10%), Gaia 2nd in 13 cases (16.25%), and Confianza Pro 9 in one case (1.25%).

In the AWE group, the most frequently selected initial wire was from the Fielder family in 65 cases (72%), followed by Gaia 1st in nine cases (10%), Gaia 2nd in 13 cases (15%), and Gaia 3rd in three cases (3%). Among the wires that ultimately crossed the occlusion in this group, the Gaia family predominated: Gaia 1st in 22 cases (24%), Gaia 2nd in 52 cases (59%), and Gaia 3rd in 10 cases (11%), whereas Confianza Pro – four (4%) and Confianza Pro 12 – two (2%) were used less frequently.

In the PW technique, the first-choice wires were predominantly from the Fielder family in 16 cases (73%), followed by Gaia 1st in 4 cases (18%) and Gaia 2nd in two cases (9%). Wires that successfully entered the distal true lumen included Gaia 1st in four cases (18%), Gaia 2nd in 16 cases (73%), and Gaia 3rd in two cases (9%).

DISCUSSION

While single-wire crossing remains the predominant antegrade strategy in contemporary CTO registries, there is a notable lack of robust data guiding the selection of the most appropriate alternative technique following failure

of the single-wire approach (6). This study offers a comparative analysis of two widely used antegrade escalation strategies – PW technique and AWE – employed following single-wire failure in PCI CTO. Although no statistically significant differences were observed in long-term rates of the primary composite outcome between the groups, both techniques demonstrated high procedural success and low complication rates, underscoring their clinical utility in contemporary CTO practice.

Although the PW group exhibited a numerically higher rate of adverse events, this difference did not reach statistical significance, and the small sample size in this cohort limits the power to draw definitive conclusions. Although the small size of the PW cohort limits statistical power, the absence of baseline imbalances strengthens the internal validity of the findings. The greater contrast use and trend toward longer procedural time in the AWE group may have clinical implications, particularly in patients with renal impairment or complex anatomy. These findings likely reflect the incremental and often repetitive nature of AWE, including multiple wire exchanges and re-engagement attempts. The choice between wire-escalation and PW techniques was largely dictated by procedural circumstances, with longer occlusions being more prone to extra-plaque wiring and thus more often managed by the PW approach, particularly when the initial wire course was close to the distal true lumen. Notably, the relative frequency of both techniques in our cohort is consistent with the proportions reported in major international registries.

Our findings are consistent with prior registry-based observations and expert consensus statements suggesting that both AWE and PW strategies are reasonable and effective options following initial wire failure. While direct comparative data between these two techniques remain limited, some studies comparing PW with dissection and re-entry have suggested procedural trade-offs, with ADR often achieving higher crossing success at the expense of increased contrast and radiation exposure. A comprehensive meta-analysis by Zhao et al. [18] demonstrated that extensive ADR techniques were associated with a significantly increased risk of adverse long-term outcomes – including target vessel revascularization, in-stent restenosis, and the composite of death/myocardial infarction/TVR – when compared with conventional wire escalation strategies. Conversely, limited ADR techniques, particularly those facilitated by dedicated re-entry devices, were shown to have outcomes comparable to those of wire escalation [19]. Supporting this, the PROGRESS-CTO registry analysis compared ADR and PW techniques after failed single-wire attempts and reported that ADR was associated with higher rates of major adverse cardiovascular events (3.7% *vs.* 1.9%, p = 0.029), despite demonstrating slightly higher technical success [20]. This suggests a potential trade-off between technical efficacy and procedural safety, especially in more complex or comorbid patients where ADR tends to be more frequently selected.

Furthermore, findings from the randomized CrossBoss First Trial [21] revealed no significant difference between the CrossBoss-based ADR strategy and standard wire escalation in terms of crossing time, technical or procedural success, or safety outcomes. These results emphasize that while controlled dissection and re-entry techniques may offer utility in specific anatomical scenarios, they do not universally outperform conventional wire-based strategies and should not be considered the default escalation approach.

Our findings, showing no statistically significant differences in primary outcomes between the PW and AWE strategies, are consistent with the results reported by Galassi et al. [22], who demonstrated comparable long-term clinical efficacy between wire-based ADR and conventional antegrade wiring techniques, despite higher lesion complexity in the ADR group. The convergence of clinical outcomes suggests a potential therapeutic equivalence among various wire escalation strategies employed after initial failure, reinforcing the need for prospective investigations utilizing standardized intravascular imaging and adequately powered PW cohorts to refine the decision-making algorithm in this high-risk subset of CTO patients [22].

The choice between wire-escalation and PW techniques was largely dictated by procedural circumstances, with longer occlusions being more prone to extra-plaque wiring and thus more often managed by the PW approach, particularly when the initial wire course was close to the distal true lumen. Notably, the relative frequency of both techniques in our cohort is consistent with the proportions reported in major international registries.

In this context, our data contribute to the growing body of evidence supporting individualized strategy selection based on lesion morphology, operator experience, and patient-specific risk factors. Although no statistically significant difference in long-term clinical outcomes was observed, procedural nuances and patient-related considerations may guide tailored escalation strategy selection. Given that chronic total occlusion represents one of the most complex lesion subsets in interventional cardiology, successful recanalization –despite its technical demands – can enable complete myocardial revascularization, which has been linked to improved long-term prognosis in appropriately selected patients [23, 24]. As the field continues to evolve, further randomized trials are essential to delineate optimal strategy selection and clarify the role of device-assisted techniques within the antegrade escalation hierarchy.

Study limitation

This study has several important limitations that warrant consideration. First, its retrospective and observational design inherently introduces the risk of unmeasured confounding factors, which may have influenced the observed outcomes. Additionally, the single-center nature of the investigation – conducted at a high-volume academic center specializing in CTO interventions – may limit the generalizability of the findings to other clinical settings with differing operator expertise or procedural volume. The choice of escalation strategy was determined by operator

discretion rather than randomization, potentially introducing selection bias.

Furthermore, although intravascular imaging modalities such as IVUS or OCT were utilized in select cases, their use was not standardized across the cohort. This limitation reduces the ability to systematically evaluate procedural decision-making and lesion morphology. Notably, although the PW technique is considered a part of true antegrade crossing (AW-O) according to the ARC-CTO classification, the possibility of partial or complete extra-plaque wire crossing cannot be excluded in the absence of systematic intravascular imaging, which was not implemented in the present study [25].

Another important limitation lies in the relatively small sample size, particularly within the PW group, which not only reduces statistical power but also limits the robustness of subgroup comparisons. Moreover, the sample sizes of the two comparison groups were not homogeneous (90 *vs.* 22), further impacting the reliability of comparative analyses and the generalizability of the findings.

CONCLUSION

No statistically significant differences were observed in primary composite endpoints between the PW and AWE groups; the results suggest comparable clinical efficacy and safety of both strategies in this complex subset of patients.

Further studies with standardized imaging guidance and larger PW cohorts are warranted to better define the optimal strategy after single-wire failure in CTO PCI.

Conflict of interests: None declared.

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Дугорочно праћење упоредних исхода технике паралелних жица и технике ескалације антероградне жице након неуспеха иницијалне жице у перкутаној реканализацији хроничних тоталних оклузија коронарних артерија

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САЖЕТАК

Увод/Циљ Након неуспеха технике једне жице у перкутаној коронарној интервенцији хроничних тоталних оклузија, најчешће се примењују две антероградне ескалационе стратегије: техника паралелних жица и ескалација антероградном жицом (*antegrade wire escalation – AWE*). Иако су широко коришћене, подаци који упоређују процедурне карактеристике и дугорочне клиничке исходе ових техника и даље су ограничени.

Циљ ове студије био је да се упореде процедурни параметри и дугорочни исходи технике паралелних жица и *AWE* након неуспеха технике једне жице у перкутаној коронарној интервенцији хроничних тоталних оклузија.

Методе Једноцентрична ретроспективна студија обухватила је болеснике који су од јануара 2018. до децембра 2023. имали успешну перкутану коронарну интервенцију хроничних тоталних оклузија користећи *AWE* или технику паралелних жица након иницијалног неуспеха. Примарни исход био је композитни – срчана смрт, инфаркт миокарда, мождани удар или реваскуларизација циљног суда. Секундарни исходи обухватали су трајање процедуре, време флуороскопије, количину контраста и дозу зрачења. Медијана трајања праћења болесника износила је 1222 дана, са интерквартилним опсегом од 580 до 1969 дана.

Резултати Од укупно 270 процедура, у 112 (41,5%) примењена је једна од наведених техника: 90 *AWE*, 22 технике паралелне жице. Основне карактеристике биле су сличне. Композитни исход се јавио код 14,4% у групи паралелних жица и 9,1% у *AWE* групи ($p = 0,73$). Примена контрастног средства је била значајно већа у *AWE* групи ($p = 0,014$), док остале разлике нису биле статистички значајне. Током перипроцедуралног периода праћења није било клиничких нити ангиографски значајних компликација.

Закључак Обе технике показују сличну безбедност и ефикасност. Техника паралелних жица нуди нешто већу процедуралну ефикасност, али су потребне даље проспективне студије да би дале коначан одговор.

Кључне речи: хронична тотална оклузија; перкутана коронарна интервенција; антероградни приступ; ескалација жице; паралелна жица