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Guidewire Utilization Burden and CTO Crossing Failure in Chronic Total Occlusion PCI: A Single-Center Registry Study

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Abstract

Background.

Guidewire escalation is central to chronic total occlusion (CTO) percutaneous coronary intervention (PCI), but its relation to crossing failure is unclear. We assessed the association between guidewire utilization burden and crossing failure after adjustment for lesion complexity and procedural characteristics.

Methods.

We analyzed 520 consecutive CTO PCI procedures (2013–2023) from a single-center, single-operator registry. Crossing failure was defined as inability to cross the occlusion with a guidewire. Guidewire count was analyzed continuously and in predefined categories (1–3, 4–6, ≥ 7). Logistic regression was adjusted for J-CTO score, SYNTAX score, prior bypass surgery, target vessel, access site, and crossing approach.

Results.

Crossing failed in 40 procedures (7.7%). Failure rates were 4.9%, 8.8%, and 18.8% with 1–3, 4–6, and ≥ 7 guidewires (P for trend = 0.0002). Discrimination of guidewire count was modest (area under the curve [AUC] 0.646; 95% CI 0.557–0.736). After adjustment, continuous guidewire count was not significantly associated with failure (OR 1.13 per wire; 95% CI 0.98–1.30; P = 0.082), whereas ≥ 7 versus 1–3 guidewires remained associated (adjusted OR 3.22; 95% CI 1.23–8.45; P = 0.018). J-CTO score was the most consistent independent predictor (adjusted OR 2.19 per point; 95% CI 1.25–3.85; P = 0.006). Model AUC was 0.711 without and 0.733 with guidewire count (optimism-corrected 0.670).

Conclusions.

Higher guidewire burden was associated with higher crossing-failure rates but appears to function mainly as a marker of procedural difficulty rather than a stand-alone predictor. These exploratory findings, from a single-operator registry with few events and possible reverse causation, require confirmation.

Background

Techniques for percutaneous coronary intervention (PCI) of chronic total occlusions (CTO) have evolved substantially over the past two decades. Dedicated wires and microcatheters, retrograde techniques, dissection-reentry strategies, and structured algorithms have raised procedural success rates in experienced centers [1–3]. Failure nevertheless remains more frequent than in non-CTO PCI and carries

a higher rate of in-hospital complications than successful recanalization [4, 5]. In the crossing algorithms used to guide these procedures, the inability to cross the occlusion with a guidewire is the central technical obstacle [2, 3].

Guidewire selection and escalation lie at the core of antegrade wire crossing. Operators usually begin with a softer, more tapered wire and move to stiffer or more penetrating wires, or to parallel-wire and other techniques, when the first attempt does not progress [2, 3, 6, 7]. The number of wires used therefore reflects how much wire manipulation a case required, and it is easy to extract from procedural records.

Several scores, including the J-CTO score, the PROGRESS CTO score, and the CL-score, estimate the likelihood of successful crossing or the time required to achieve it from angiographic features [8–10]. These scores describe the lesion before the procedure starts, whereas guidewire count accumulates as the case proceeds. The literature does not clarify whether a high count simply reflects a difficult lesion, carries information about failure beyond lesion complexity, or is largely a consequence of a procedure that is not progressing [6, 11].

We therefore analyzed a consecutive single-operator CTO PCI registry to examine the association between the number of guidewires used and crossing failure, and to determine whether this association persists after adjustment for lesion complexity and procedural characteristics.

Methods

Study design and population

This was a retrospective analysis of a prospectively maintained single-center, single-operator CTO PCI registry at a university hospital in Türkiye. All procedures were performed by a single dedicated CTO operator, an experienced high-volume CTO PCI operator who worked at this institution until 2017. All consecutive CTO PCI procedures performed between January 2013 and December 2023 were included (n = 520). The unit of analysis was the procedure. Chronic total occlusion (CTO) was defined as a complete coronary artery occlusion with TIMI 0 antegrade flow and an estimated duration of at least 3 months. No additional exclusion criteria were applied. Data from this registry have been reported previously in studies examining CTO scoring systems and the impact of prior coronary artery bypass grafting on CTO PCI outcomes. The present analysis addresses a distinct research question focused on guidewire utilization burden and CTO crossing failure.

Data source and variable definitions

Data were extracted from the registry database. The primary endpoint was crossing failure, defined as failure to cross the occlusion with a guidewire. In the source database this outcome was recorded in the field describing the wire-crossing result and was labeled "Occlusion could not be crossed". Procedures

not carrying this label were classified as crossing success. Crossing success was defined as successful guidewire crossing of the occluded segment irrespective of the crossing strategy used, including antegrade and retrograde approaches. Crossing failure was defined as inability to successfully cross the occluded segment with a guidewire. This is a procedural crossing endpoint and does not represent technical success (final angiographic result) or clinical success, which were not analyzed. The original database entries were written in Turkish and are reported here in English translation.

The primary exposure was guidewire utilization burden, defined as the total number of guidewires used during the procedure, as recorded by the operator in the procedural record. Each distinct guidewire was counted once, regardless of subsequent reuse during the procedure. It was analyzed as a continuous variable and in three predefined categories: 1–3, 4–6, and ≥ 7 guidewires.

Lesion and procedural covariates were the J-CTO score, SYNTAX score, prior coronary artery bypass grafting (CABG), target vessel (right coronary artery, left anterior descending artery, left circumflex artery, or other/multiple), vascular access (radial or femoral/combined), crossing approach (antegrade or retrograde/combined), and procedure time in minutes.

Initial guidewire classification. The initial guidewire was defined as the first guidewire selected by the operator to cross the occlusion, as recorded in the registry. Wire names were standardized for spelling and formatting variations and classified according to their design characteristics into four categories: (A) conventional workhorse wires (BMW, Whisper LS, Sion); (B) polymer-jacketed or sliding wires (Pilot 50 and the Fielder family); (C) intermediate CTO wires (Pilot 150, Pilot 200, Gaia First, Ultimate Bros 3); and (D) high-penetration CTO wires (Miracle series, Gaia Second, and Conquest Pro). Entries listing more than one wire were assigned to the common category when all wires belonged to the same category, and otherwise according to the first-listed wire; entries that could not be identified as a specific wire (n = 5) were not classified. Initial guidewire category was analyzed as an exploratory, descriptive comparison only; it was not a primary exposure and was not part of the multivariable model.

Data audit

Before analysis, the dataset was audited for completeness and internal consistency. Procedure time was missing in 8 procedures, SYNTAX score in 3, crossing approach in 18, and vascular access in 1. J-CTO score, guidewire count, prior CABG, and target vessel were complete. Two SYNTAX entries that could not be interpreted unambiguously were treated as missing, and no values were imputed. In 7 further procedures, a failure annotation appeared in another field while the crossing-result field carried a named wire. These procedures were classified as successes in the primary analysis and were included as failures in a sensitivity analysis (47 failures in total).

Statistical Analysis

Continuous variables are presented as mean ± standard deviation and as median with interquartile range (IQR), and categorical variables as counts and percentages. Procedures with crossing success and failure were compared with the Mann–Whitney U test for continuous variables, the Fisher exact test for binary variables, and a Monte Carlo permutation chi-square test for categorical variables with more than two levels. Initial guidewire category was compared descriptively between successful and failed procedures using a Monte Carlo permutation chi-square test and was not included in multivariable modeling because of the limited number of failure events. A Cochran–Armitage test [12] was used for the trend in failure rate across guidewire categories, and the Kruskal–Wallis test for continuous variables across categories. Proportions are reported with Wilson 95% confidence intervals [13].

Discrimination of guidewire count for crossing failure was assessed with the area under the receiver operating characteristic curve (AUC), with 95% confidence intervals by the DeLong method [14]. The optimal threshold was identified with the Youden index [15], and sensitivity, specificity, positive predictive value, and negative predictive value were calculated. The stability of the threshold was examined in 2,000 bootstrap resamples.

Univariable logistic regression was performed for J-CTO score (per point), SYNTAX score (per 5 points), prior CABG, target vessel, vascular access, crossing approach, procedure time (per 10 minutes), and guidewire count (per additional wire). The primary multivariable model included guidewire count, J-CTO score, SYNTAX score, prior CABG, target vessel, access, and approach. Procedure time was not included in the primary model because it is recorded after the exposure and is closely correlated with guidewire count. A more parsimonious model (guidewire count, J-CTO score, SYNTAX score, and prior CABG) was fitted because the number of events per estimated parameter in the primary model was low (approximately four) [16, 17]. Guidewire burden was also entered as a categorical variable (reference 1–3 guidewires), and the contribution of guidewire count was tested with likelihood ratio tests. Sensitivity analyses comprised Firth penalized logistic regression [18], the broader outcome definition (47 failures), a model treating missing crossing approach as a separate category, a model omitting crossing approach, and an exploratory Firth penalized model with procedure time added. Analyses were complete-case unless stated.

The primary multivariable model was evaluated for discrimination (AUC with and without guidewire count), optimism-corrected AUC and calibration slope from 500 bootstrap resamples, the Hosmer–Lemeshow test (10 groups), and the Brier score. Spearman correlation coefficients were used to describe relationships between guidewire count, procedure time, and J-CTO score. All tests were two-sided with a significance level of 0.05. No adjustment was made for multiple comparisons, and all secondary and subgroup analyses should be regarded as exploratory. Analyses were performed in Python 3 using the NumPy, SciPy, and pandas libraries, and figures were prepared with Matplotlib. Logistic regression, Firth penalized regression, DeLong confidence intervals, and bootstrap procedures were implemented with custom code based on these libraries. This study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

Use of artificial intelligence. An artificial intelligence assistant was used for assist with writing the statistical analysis code, language editing and manuscript preparation support. All statistical analyses, results, interpretations, and conclusions were reviewed and approved by the authors, who take full responsibility for the content of the manuscript .

Results

Study population and data completeness

A total of 520 consecutive CTO PCI procedures were included. Crossing failure occurred in 40 procedures (7.7%), and crossing was successful in 480 (92.3%). The median number of guidewires was 3 (IQR 2–5; range 1–12) (Fig. 1). Of the 520 procedures, 308 (59.2%) used 1–3 guidewires, 148 (28.5%) used 4–6 guidewires, and 64 (12.3%) used ≥ 7 guidewires. J-CTO scores ranged from 0 to 3. Lesion and procedural characteristics according to crossing outcome are shown in Table 1. Procedures with crossing failure used more guidewires than those with success (median 4 versus 3; P = 0.002) and had higher J-CTO scores (mean 1.3 versus 0.9; P = 0.002). SYNTAX score, prior CABG, procedure time, target vessel, crossing approach, and initial guidewire category did not differ significantly between groups (exploratory comparison, P = 0.70). Radial access was recorded more often among failed than successful procedures (48.7% versus 31.9%; P = 0.035). Patient age was not available in the dataset.

Table 1
Lesion and procedural characteristics according to crossing outcome

Characteristic	Overall (n = 520)	Crossing success (n = 480)	Crossing failure (n = 40)	P value
J-CTO score, mean ± SD	1.0 ± 0.8	0.9 ± 0.7	1.3 ± 0.7	0.002
J-CTO score, median (IQR)	1 (0–1.25)	1 (0–1)	1 (1–2)	
SYNTAX score, mean ± SD (n = 517)	16.8 ± 9.6	16.7 ± 9.5	18.7 ± 10.7	0.26
SYNTAX score, median (IQR)	15.0 (9.0–22.5)	14.5 (9.0–22.5)	17.5 (9.5–24.2)	
Procedure time, min, mean ± SD (n = 512)	82.2 ± 48.7	81.5 ± 48.4	92.6 ± 51.4	0.15
Procedure time, min, median (IQR)	71.0 (44.8–109.0)	70.0 (43.0–108.0)	74.0 (60.0–115.0)	
Number of guidewires, mean ± SD	3.6 ± 2.5	3.5 ± 2.4	4.8 ± 2.8	0.002
Number of guidewires, median (IQR)	3 (2–5)	3 (2–5)	4 (2.8–7)	
Prior CABG, n (%)	102 (19.6)	92 (19.2)	10 (25.0)	0.41
Target vessel, n (%)				0.38
— Right coronary artery	253 (48.7)	236 (49.2)	17 (42.5)	
— Left anterior descending artery	142 (27.3)	133 (27.7)	9 (22.5)	
— Left circumflex artery	102 (19.6)	90 (18.8)	12 (30.0)	
— Other or multiple	23 (4.4)	21 (4.4)	2 (5.0)	
Vascular access, n (%) (n = 519)				0.035
— Radial	172 (33.1)	153 (31.9)	19 (48.7)	
— Femoral or combined	347 (66.9)	327 (68.1)	20 (51.3)	
Crossing approach, n (%) (n = 502)				1.00
— Antegrade	459 (91.4)	424 (91.4)	35 (92.1)	
— Retrograde or combined	43 (8.6)	40 (8.6)	3 (7.9)	
Initial guidewire category, n (%) (n = 515)*				0.70

Characteristic	Overall (n = 520)	Crossing success (n = 480)	Crossing failure (n = 40)	P value
— Conventional workhorse wires	127 (24.7)	115 (24.2)	12 (30.0)	
— Polymer-jacketed/sliding wires	277 (53.8)	258 (54.3)	19 (47.5)	
— Intermediate CTO wires	26 (5.0)	23 (4.8)	3 (7.5)	
— High-penetration CTO wires	85 (16.5)	79 (16.6)	6 (15.0)	
Guidewire burden category, n (%)				< 0.001
— 1–3 guidewires	308 (59.2)	293 (61.0)	15 (37.5)	
— 4–6 guidewires	148 (28.5)	135 (28.1)	13 (32.5)	
— ≥7 guidewires	64 (12.3)	52 (10.8)	12 (30.0)	

Continuous variables were compared with the Mann–Whitney U test, binary variables with the Fisher exact test, and categorical variables with more than two levels with a Monte Carlo permutation chi-square test. *Initial guidewire category is shown descriptively as an exploratory comparison and was not included in the multivariable model. Percentages are calculated among the 515 procedures (475 successes, 40 failures) with an identifiable initial wire; 5 procedures could not be classified (none had crossing failure). Abbreviations: CABG, coronary artery bypass grafting; CTO, chronic total occlusion; IQR, interquartile range; J-CTO, Multicenter CTO Registry in Japan; SD, standard deviation; SYNTAX, Synergy Between Percutaneous Coronary Intervention With Taxus and Cardiac Surgery.

Failure rate according to guidewire burden

Crossing failure rates increased across guidewire burden categories (Table 2; Fig. 2). Failure occurred in 15 of 308 procedures (4.9%) requiring 1–3 guidewires, 13 of 148 (8.8%) requiring 4–6 guidewires, and 12 of 64 (18.8%) requiring ≥ 7 guidewires (P for trend = 0.0002). The unadjusted odds of failure with ≥ 7 guidewires were approximately 4.5 times those with 1–3 guidewires. Fifteen of the 40 failures (37.5%) occurred in procedures that used no more than three guidewires.

Table 2
Procedural outcome and lesion characteristics according to guidewire burden category

Characteristic	1–3 guidewires (n = 308)	4–6 guidewires (n = 148)	≥ 7 guidewires (n = 64)	P value
Crossing success, n (%)	293 (95.1)	135 (91.2)	52 (81.3)	
Crossing failure, n (%)	15 (4.9)	13 (8.8)	12 (18.8)	0.0002 (trend)
Failure rate, % (95% CI)	4.9 (3.0–7.9)	8.8 (5.2–14.4)	18.8 (11.1–30.0)	
Procedure time, min, median (IQR)	53.5 (35.0–86.2)	90.0 (60.0–120.0)	120.0 (100.0–151.5)	< 0.001
Procedure time, min, mean ± SD	66.7 ± 42.1	96.2 ± 48.5	124.4 ± 44.1	
J-CTO score, median (IQR)	1 (0–1)	1 (1–2)	2 (1–2)	< 0.001
SYNTAX score, median (IQR)	13.2 (9.0–21.5)	17.5 (9.0–23.5)	16.0 (10.0–23.5)	0.037

Failure rates are shown with Wilson 95% confidence intervals. P for trend by the Cochran–Armitage test; continuous variables compared across groups with the Kruskal–Wallis test. Abbreviations: CI, confidence interval; IQR, interquartile range; J-CTO, Multicenter CTO Registry in Japan; SYNTAX, Synergy Between Percutaneous Coronary Intervention With Taxus and Cardiac Surgery.

Higher guidewire burden accompanied greater procedural complexity. Median procedure time was 53.5, 90, and 120 minutes across the three categories ($P < 0.001$), and median J-CTO scores were 1, 1, and 2, respectively ($P < 0.001$). Guidewire count correlated with procedure time (Spearman $\rho = 0.50$) and with J-CTO score ($\rho = 0.47$) (Fig. 4).

Discrimination of guidewire count

The AUC of guidewire count for crossing failure was 0.646 (95% CI 0.557–0.736) (Fig. 3A). The Youden-optimal threshold was ≥ 4 guidewires, with a sensitivity of 62.5%, a specificity of 61.0%, a positive predictive value of 11.8%, and a negative predictive value of 95.1%. This threshold was selected as optimal in 54% of bootstrap resamples. For comparison, the AUC was 0.638 for J-CTO score and 0.575 for procedure time.

Univariable and multivariable analyses

In univariable analysis (Table 3), each additional guidewire was associated with a 20% increase in the odds of crossing failure (OR 1.20; 95% CI 1.07–1.34; $P = 0.002$), and each additional J-CTO point with a doubling of the odds (OR 2.01; 95% CI 1.29–3.13; $P = 0.002$). Femoral or combined access was

associated with lower odds of failure than radial access (OR 0.49; 95% CI 0.26–0.95; P = 0.035). SYNTAX score, procedure time, prior CABG, target vessel, and crossing approach were not significantly associated with failure.

Table 3
Logistic regression analysis for crossing failure

Variable	Univariable OR (95% CI)	P	Model A: adjusted OR (95% CI)	P	Model B: adjusted OR (95% CI)	P
Number of guidewires, per additional wire	1.20 (1.07–1.34)	0.002	1.13 (0.98–1.30)	0.082	—	—
Guidewire burden 4–6 vs 1–3	1.88 (0.87–4.06)	0.108	—	—	1.55 (0.66–3.62)	0.311
Guidewire burden ≥ 7 vs 1–3	4.51 (2.00–10.18)	< 0.001	—	—	3.22 (1.23–8.45)	0.018
J-CTO score, per point	2.01 (1.29–3.13)	0.002	2.19 (1.25–3.85)	0.006	2.13 (1.22–3.72)	0.008
SYNTAX score, per 5 points	1.10 (0.95–1.29)	0.21	1.03 (0.81–1.32)	0.79	1.02 (0.80–1.30)	0.88
Prior CABG	1.41 (0.66–2.98)	0.37	1.12 (0.37–3.35)	0.85	1.22 (0.41–3.66)	0.73
Target vessel: LAD vs RCA	0.94 (0.41–2.17)	0.88	0.95 (0.35–2.62)	0.92	0.97 (0.35–2.70)	0.96
Target vessel: LCx vs RCA	1.85 (0.85–4.03)	0.12	2.40 (1.02–5.64)	0.046	2.52 (1.06–5.96)	0.036
Target vessel: other or multiple vs RCA	1.32 (0.29–6.12)	0.72	2.01 (0.35–11.37)	0.43	2.05 (0.36–11.69)	0.42
Femoral or combined vs radial access	0.49 (0.26–0.95)	0.035	0.43 (0.20–0.89)	0.022	0.43 (0.21–0.90)	0.025
Retrograde or combined vs antegrade approach	0.91 (0.27–3.09)	0.88	0.47 (0.13–1.74)	0.26	0.47 (0.13–1.73)	0.26
Procedure time, per 10 minutes	1.04 (0.98–1.12)	0.20	Not included	—	Not included	—

The primary multivariable model included guidewire count (continuous), J-CTO score, SYNTAX score, prior CABG, target vessel, access, and approach (n = 499; 37 events). Model A includes guidewire count as a continuous variable; Model B is identical except that guidewire count was replaced by burden category (reference 1–3 guidewires). A parsimonious model (guidewire count, J-CTO, SYNTAX, prior CABG; n = 517; 39 events) gave an adjusted OR of 1.12 (95% CI 0.99–1.28; P = 0.073) for guidewire

count. Abbreviations: CABG, coronary artery bypass grafting; CI, confidence interval; J-CTO, Multicenter CTO Registry in Japan; LAD, left anterior descending artery; LCx, left circumflex artery; OR, odds ratio; RCA, right coronary artery; SYNTAX, Synergy Between Percutaneous Coronary Intervention With Taxus and Cardiac Surgery.

The primary multivariable model comprised 499 procedures and 37 failures. After adjustment, the association for continuous guidewire count was attenuated and no longer statistically significant (adjusted OR 1.13 per wire; 95% CI 0.98–1.30; P = 0.082). J-CTO score remained independently associated with crossing failure (adjusted OR 2.19 per point; 95% CI 1.25–3.85; P = 0.006). In this model, a left circumflex target (adjusted OR 2.40 versus right coronary artery; 95% CI 1.02–5.64; P = 0.046) and femoral or combined access (adjusted OR 0.43 versus radial; 95% CI 0.20–0.89; P = 0.022) were also associated with failure; these estimates are based on few events and should be interpreted cautiously. In the parsimonious model (517 procedures, 39 failures), the adjusted OR for guidewire count was 1.12 (95% CI 0.99–1.28; P = 0.073).

When guidewire burden was analyzed by category, procedures requiring ≥ 7 guidewires had approximately threefold higher adjusted odds of crossing failure than those requiring 1–3 guidewires (adjusted OR 3.22; 95% CI 1.23–8.45; P = 0.018). The overall likelihood ratio test for the three burden categories was P = 0.065. The adjusted OR for 4–6 versus 1–3 guidewires was 1.55 (95% CI 0.66–3.62; P = 0.311). The estimate for continuous guidewire count was essentially unchanged in the Firth penalized model (adjusted OR 1.13; 95% CI 0.99–1.29; P = 0.077), with the broader outcome definition (adjusted OR 1.12; 95% CI 0.98–1.28; P = 0.083), and when missing crossing approach was retained as a separate category (adjusted OR 1.13; 95% CI 0.98–1.30; P = 0.082) (Supplementary Table S1 [Additional file 1]). When procedure time was added to the model, the association for guidewire count reached nominal significance (adjusted OR 1.18 per wire; 95% CI 1.02–1.38; P = 0.029; Firth model, 492 procedures, 31 events). Because procedure time is recorded after the exposure and correlates closely with it, and because this model has about three events per parameter, we regard this analysis as exploratory.

Model performance

The primary multivariable model had an apparent AUC of 0.733 (95% CI 0.644–0.822) (Fig. 3B). Without guidewire count, the AUC was 0.711. Addition of guidewire count increased the apparent AUC to 0.733, representing an apparent difference of 0.022. The optimism-corrected AUC of the full model was 0.670, and the bootstrap calibration slope was 0.61, indicating overfitting. The Hosmer–Lemeshow test showed no significant lack of fit (P = 0.107), although the power of this test is limited with 37 events. The Brier score was 0.064, compared with 0.071 for a model without predictors (Supplementary Figure S1 [Additional file 1]).

Discussion

In this consecutive single-operator registry of 520 CTO PCI procedures, crossing failure became more frequent as the number of guidewires increased, from 4.9% with 1–3 wires to 18.8% with ≥ 7 wires. The association with continuous guidewire count was no longer statistically significant after adjustment for lesion complexity and procedural variables, whereas procedures requiring ≥ 7 guidewires retained higher adjusted odds of failure (OR 3.22). J-CTO score remained independently associated with failure. Adding guidewire count to the multivariable model improved discrimination only marginally. Taken together, these findings suggest that guidewire count is best understood as a marker of procedural difficulty, with a possible threshold effect at the upper end of the distribution, rather than as an independent determinant of failure.

The attenuation after adjustment fits the way guidewire count arises in practice. Lesions with higher J-CTO scores, which reflect factors such as calcification, tortuosity, blunt stump, and prior failed attempt, require more wire manipulation, and they also fail more often [8]. In our data, guidewire count correlated with both J-CTO score and procedure time, and a large part of its crude association with failure appears to be accounted for by these variables. The adjusted odds ratio of 1.13 per wire had a confidence interval that included 1, and the parsimonious model, which had a more adequate number of events per parameter, gave a similar estimate. We therefore cannot conclude that the per-wire association is independent in this cohort.

The categorical result also calls for cautious interpretation. The adjusted odds ratio of 3.22 for ≥ 7 versus 1–3 guidewires was statistically significant, but the confidence interval was wide (1.23–8.45) and the estimate rests on 12 events in the highest category. The overall test across the three categories did not reach conventional significance (P = 0.065). The categories were predefined, so ≥ 7 is not a data-driven cut-point. The Youden-derived threshold of ≥ 4 guidewires, by contrast, was selected in only about half of the bootstrap resamples and had a positive predictive value of 11.8%; it should not be used as a decision rule. The negative predictive value of 95.1% largely reflects the low overall failure rate of 7.7%.

Reverse causation is the main interpretive problem. The number of guidewires is known only at the end of the procedure, and it is partly the product of the outcome it is meant to explain. A procedure that ends in failure has usually gone through an escalation sequence that did not work, and an operator who reaches a high wire count has typically already been unsuccessful with earlier wires. The odds ratio for ≥ 7 wires therefore cannot be read as the effect of using more wires, and it should not be taken to imply that limiting wire use would reduce failure. The data also show the opposite pattern in a substantial minority of failures: 15 of the 40 occurred in procedures that used three or fewer guidewires, which may reflect early abandonment or a change of strategy rather than wire exhaustion. Guidewire count therefore does not identify all failures, and a low count does not exclude a difficult lesion.

Procedure time showed a similar gradient across the burden categories, rising from a median of 53.5 minutes with 1–3 wires to 120 minutes with ≥ 7 wires. Procedure time itself was not significantly associated with failure and was not included in the primary model. This suggests that wire count, procedure time, and lesion complexity capture overlapping aspects of one phenomenon, a difficult

occlusion that consumed more resources. Adjusting for procedure time would also mean adjusting for a consequence of the exposure.

Two secondary observations deserve brief mention but cannot be developed further with these data. First, radial access was recorded more often among failed procedures, and femoral or combined access was associated with lower odds of failure after adjustment. This may reflect guide-catheter size and backup support, which were not analyzed here, and the estimate rests on few events. Second, a left circumflex target was associated with higher adjusted odds of failure than the right coronary artery. Both are hypothesis-generating at most.

The full multivariable model contained approximately four events per estimated parameter, so we also examined a parsimonious model and a Firth penalized model and reported optimism-corrected performance. The bootstrap calibration slope of 0.61 and the optimism-corrected AUC of 0.670, compared with an apparent AUC of 0.733, indicate that the full model is overfitted and that its apparent discrimination should not be taken at face value. The gain in apparent AUC from adding guidewire count (0.711 to 0.733) was small.

Published CTO PCI series describe wire use mainly by wire type rather than by the total number of wires. In a multicenter U.S. registry of antegrade wire escalation, the mean number of wire types used was 2.2 ± 1.4, polymer-jacketed wires were used most often, and final technical success was 91% [6]. In a prospective multicenter study of procedures using dedicated wires, microcatheters, and guide extensions, the mean number of study guidewires per procedure was 4.8 ± 2.6 in a population with high lesion complexity [11]. The median of 3 wires in our series is in line with these reports, although the counts are not strictly comparable because the definition of a wire differs between studies. A single-center series of 306 patients from Pakistan similarly reported a mean of 3.5 ± 1.9 guidewires per procedure, with failure to cross the occlusion with a guidewire as the most frequent cause of procedural failure [19]. Studies of procedural failure have mainly examined lesion characteristics; in the EXPLORE subanalysis of patients with STEMI and a concurrent CTO, lesion length greater than 20 mm was the only independent predictor of failure [5], and the J-CTO score was derived to predict guidewire crossing within 30 minutes [8]. Our results agree with this literature: lesion complexity, expressed by the J-CTO score, remained independently associated with failure after adjustment, whereas guidewire count added little.

Clinical Implications

The results do not support using a specific number of guidewires as a trigger to stop or to change strategy. They do suggest that a high guidewire count, particularly seven or more wires, accompanies a subgroup of procedures with a higher likelihood of failure, although part of this risk is already apparent from the J-CTO score. An operator who has used several wires without progress may treat this as one of several signals to reassess the approach, for example by reviewing the angiographic features of the lesion, the need for additional support, or an alternative crossing technique. Such a decision should rest on the whole procedural picture, not on a count alone. For research and benchmarking, guidewire count

may be useful as a simple descriptor of procedural difficulty, provided it is reported alongside lesion complexity scores and interpreted as a process measure.

Strengths

The strengths of this study include consecutive inclusion of procedures from a single-operator registry, complete data for guidewire count and J-CTO score, and predefined guidewire burden categories. The main findings were also tested in several sensitivity analyses (a parsimonious model, Firth penalized regression, an alternative outcome definition, and alternative handling of missing crossing approach), and the estimates for guidewire count were consistent across them.

Limitations

This study has several limitations. First, it is a retrospective, single-center, single-operator analysis, which limits generalizability to other operators, techniques, and institutions. Second, the number of crossing-failure events was limited (n = 40), and the full multivariable model included approximately four events per estimated parameter. Estimates are therefore imprecise and may be overfitted, as reflected by the optimism-corrected AUC (0.670) and the bootstrap calibration slope (0.61). The parsimonious and Firth penalized models gave consistent estimates for guidewire count. Third, guidewire count accumulates during the procedure and partly reflects its outcome, so reverse causation cannot be excluded; it should be interpreted as a marker of procedural difficulty rather than as a modifiable risk factor. Fourth, J-CTO scores in this registry ranged only from 0 to 3, with few procedures in the highest category, which may limit the precision of risk estimates across the full spectrum of lesion complexity. Fifth, patient age, lesion calcification, occlusion length, and collateral grade were not available for adjustment, and residual confounding may remain. Sixth, guidewire count does not capture wire type, stiffness, or escalation strategy, and the exploratory threshold of ≥ 4 guidewires was not stable across bootstrap resamples. Seventh, the primary outcome was taken from a single registry field, and seven additional procedures carried a failure annotation elsewhere in the database; the findings were consistent when these were included. The endpoint also reflects crossing only, not final angiographic or clinical success. Eighth, the registry reflects CTO PCI practice between 2013 and 2023. Subsequent advances in CTO-specific devices, guidewires, and crossing algorithms may limit the applicability of these findings to contemporary practice, and the absolute failure rate and wire-count distribution observed here should not be taken as a benchmark for current outcomes. The findings are better interpreted as describing the relationship between procedural burden and crossing failure in a consistently performed single-operator series; whether this relationship persists in more recent practice should be examined in contemporary registries. Finally, long-term clinical outcomes were not available, and the study addresses only the procedural endpoint of crossing failure.

Conclusions

Greater guidewire utilization burden was associated with higher procedural complexity and higher crossing-failure rates in this single-operator CTO PCI registry. The association with continuous guidewire

count was attenuated and no longer statistically significant after multivariable adjustment, whereas procedures requiring ≥ 7 guidewires had higher adjusted odds of failure (OR 3.22). J-CTO score remained independently associated with failure, and guidewire count added little to model discrimination. Guidewire burden appears to reflect how difficult the procedure was rather than to act as a stand-alone predictor of crossing failure. These exploratory findings require confirmation in other cohorts.

Abbreviations

AUC
area under the receiver operating characteristic curve
CABG
coronary artery bypass grafting
CI
confidence interval
CTO
chronic total occlusion
IQR
interquartile range
J-CTO
Multicenter CTO Registry in Japan
OR
odds ratio
PCI
percutaneous coronary intervention
ROC
receiver operating characteristic
SD
standard deviation
STEMI
ST-elevation myocardial infarction
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
SYNTAX
Synergy Between Percutaneous Coronary Intervention With Taxus and Cardiac Surgery
TIMI
Thrombolysis in Myocardial Infarction

Declarations

Author Contribution

H.T. conceptualized the study, curated the data, performed the statistical analysis, interpreted the data, drafted the manuscript, and critically revised it. M.N. contributed to the methodology, interpreted the data, and critically revised the manuscript. M.U. contributed to the methodology, interpreted the data, and critically revised the manuscript. Ö.G. conceived the study, performed the procedures, oversaw the registry, acquired the data, supervised the work, interpreted the data, and critically revised the manuscript. All authors read and approved the final manuscript.

Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request, subject to institutional and ethical restrictions.

References

1. Brilakis ES, Banerjee S, Karmpaliotis D et al (2015) Procedural outcomes of chronic total occlusion percutaneous coronary intervention: a report from the NCDR (National Cardiovascular Data Registry). JACC Cardiovasc Interv 8:245–253. 10.1016/j.jcin.2014.08.014
2. Brilakis ES, Grantham JA, Rinfret S et al (2012) A percutaneous treatment algorithm for crossing coronary chronic total occlusions. JACC Cardiovasc Interv 5:367–379. 10.1016/j.jcin.2012.02.006
3. Wu EB, Brilakis ES, Mashayekhi K et al (2021) Global chronic total occlusion crossing algorithm: JACC state-of-the-art review. J Am Coll Cardiol 78:840–853. 10.1016/j.jacc.2021.05.055
4. Khan MF, Brilakis ES, Wendel CS, Thai H (2015) Comparison of procedural complications and in-hospital clinical outcomes between patients with successful and failed percutaneous intervention of coronary chronic total occlusions: a meta-analysis of observational studies. Catheter Cardiovasc Interv 85:781–794. 10.1002/ccd.25712
5. Kolk MZH, van Veelen A, Agostoni P et al (2021) Predictors and outcomes of procedural failure of percutaneous coronary intervention of a chronic total occlusion: a subanalysis of the EXPLORE trial. Catheter Cardiovasc Interv 97:1176–1183. 10.1002/ccd.28904
6. Karatasakis A, Tarar MN, Karmpaliotis D et al (2017) Guidewire and microcatheter utilization patterns during antegrade wire escalation in chronic total occlusion percutaneous coronary intervention: insights from a contemporary multicenter registry. Catheter Cardiovasc Interv 89:E90–E98. 10.1002/ccd.26568
7. Galassi AR, Vadalà G, Maniscalco L et al (2023) Wire-based antegrade dissection re-entry technique for coronary chronic total occlusions percutaneous revascularization: experience from the ERCTO Registry. Catheter Cardiovasc Interv 102:864–877. 10.1002/ccd.30827
8. Morino Y, Abe M, Morimoto T et al (2011) Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. JACC Cardiovasc Interv 4:213–221. 10.1016/j.jcin.2010.09.024

9. Christopoulos G, Kandzari DE, Yeh RW et al (2016) Development and validation of a novel scoring system for predicting technical success of chronic total occlusion percutaneous coronary interventions: the PROGRESS CTO score. JACC Cardiovasc Interv 9:1–9. 10.1016/j.jcin.2015.09.022
10. Alessandrino G, Chevalier B, Lefèvre T et al (2015) A clinical and angiographic scoring system to predict the probability of successful first-attempt percutaneous coronary intervention in patients with total chronic coronary occlusion. JACC Cardiovasc Interv 8:1540–1548
11. Kandzari DE, Alaswad K, Jaffer FA et al (2022) Safety and efficacy of dedicated guidewire, microcatheter, and guide catheter extension technologies for chronic total coronary occlusion revascularization: primary results of the Teleflex Chronic Total Occlusion Study. Catheter Cardiovasc Interv 99:263–270. 10.1002/ccd.29962
12. Armitage P (1955) Tests for linear trends in proportions and frequencies. Biometrics 11:375–386
13. Wilson EB (1927) Probable inference, the law of succession, and statistical inference. J Am Stat Assoc 22:209–212. 10.2307/2276774
14. DeLong ER, DeLong DM, Clarke-Pearson DL (1988) Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics 44:837–845. 10.2307/2531595
15. Youden WJ (1950) Index for rating diagnostic tests. Cancer 3:32–35. 10.1002/1097-0142(1950)3:1<32::AID-CNCR2820030106>3.0.CO;2-3
16. Peduzzi P, Concato J, Kemper E, Holford TR, Feinstein AR (1996) A simulation study of the number of events per variable in logistic regression analysis. J Clin Epidemiol 49:1373–1379. 10.1016/S0895-4356(96)00236-3
17. Riley RD, Snell KIE, Ensor J et al (2019) Minimum sample size for developing a multivariable prediction model: Part II—binary and time-to-event outcomes. Stat Med 38:1276–1296. 10.1002/sim.7992
18. Firth D (1993) Bias reduction of maximum likelihood estimates. Biometrika 80:27–38. 10.1093/biomet/80.1.27
19. Suleman M, Arif N, Khan MI et al (2024) The outcomes and complications of percutaneous interventions in chronic total coronary occlusion. Egypt Heart J 76:62. 10.1186/s43044-024-00490-6

Figures

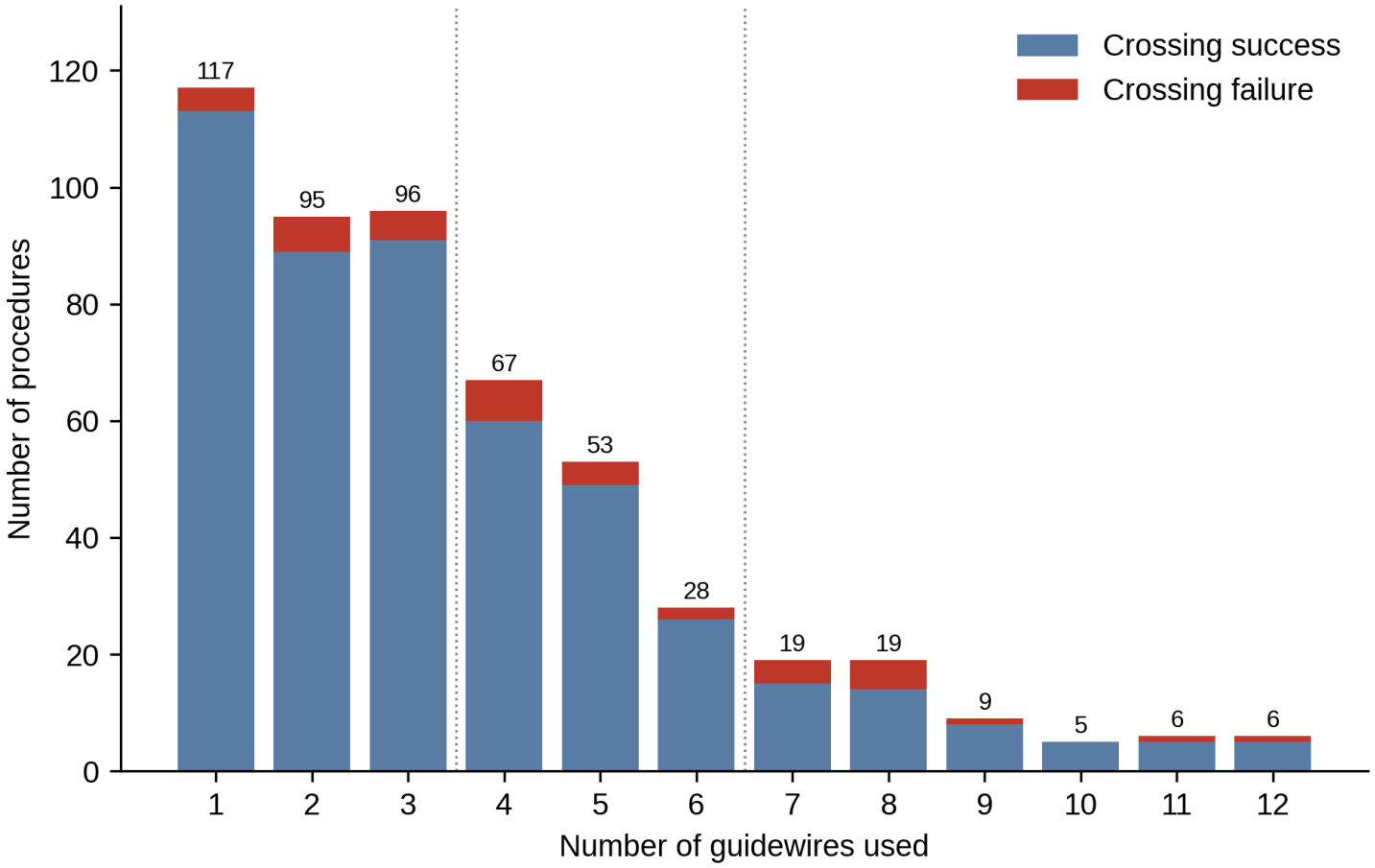


Figure 1

Distribution of the number of guidewires used, stratified by crossing outcome. Data are from 520 CTO PCI procedures. Bars show the number of procedures for each guidewire count; successful and failed crossings are shown in different colors. Dotted vertical lines indicate the predefined burden categories (1–3, 4–6, and ≥7 guidewires). The distribution is right-skewed, with a median of 3 guidewires. Abbreviations: CTO, chronic total occlusion; PCI, percutaneous coronary intervention.

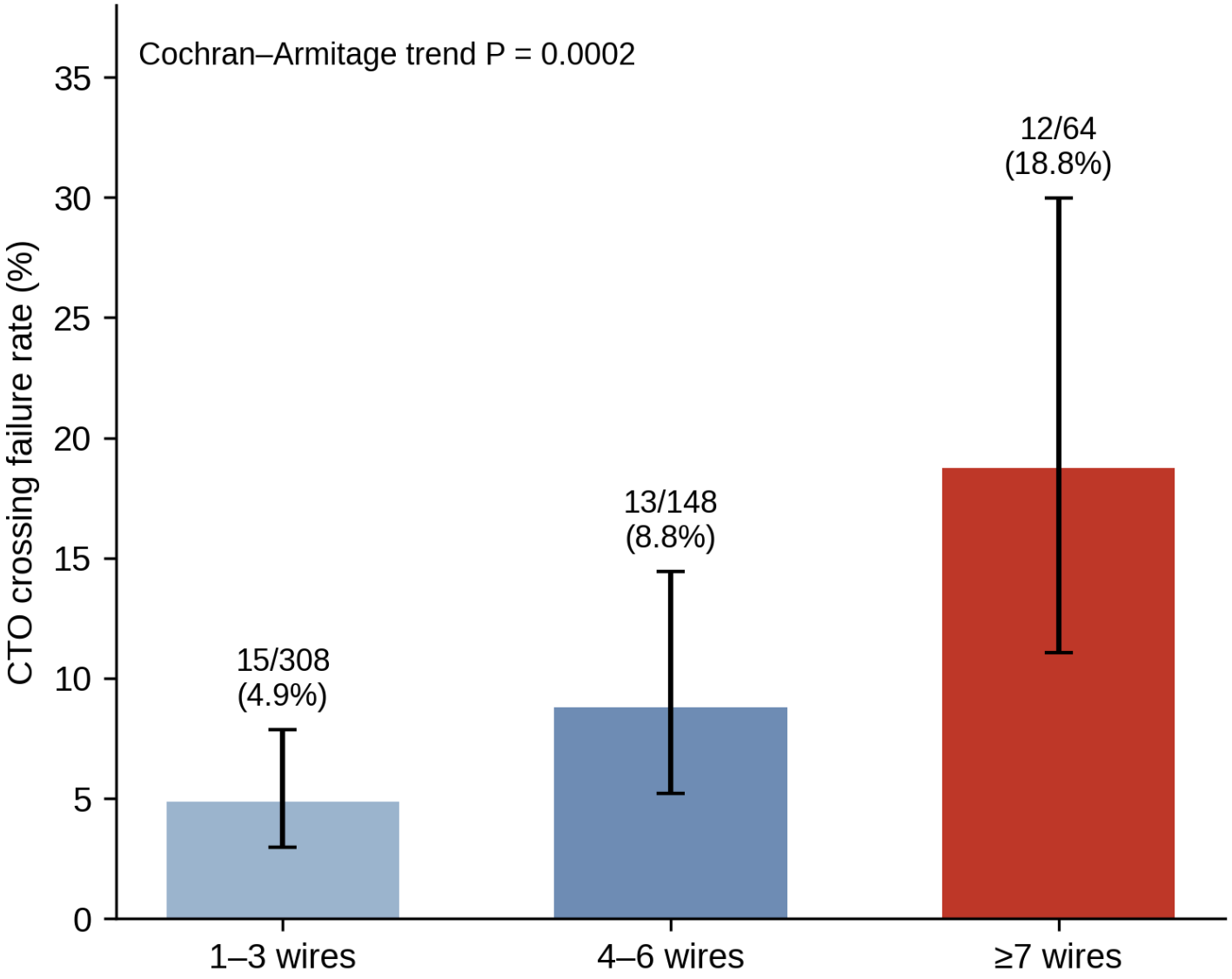


Figure 2

Crossing failure rate according to guidewire burden category. Bars show the percentage of procedures with crossing failure; error bars represent Wilson 95% confidence intervals, and the labels above the bars show failures/total procedures. Failure rates were 4.9% (15/308) for 1–3 guidewires, 8.8% (13/148) for 4–6 guidewires, and 18.8% (12/64) for ≥7 guidewires (Cochran–Armitage P for trend = 0.0002).

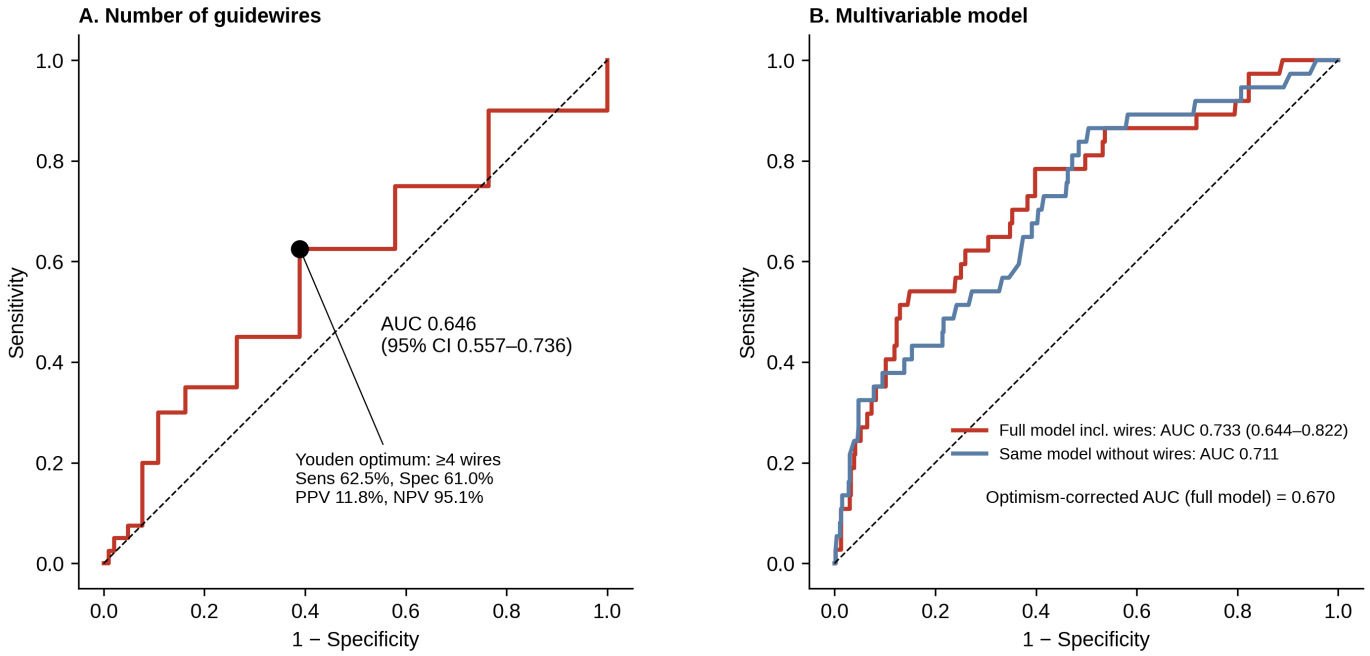


Figure 3

Receiver operating characteristic (ROC) curves for crossing failure. (A) Guidewire count alone (AUC 0.646; 95% CI 0.557–0.736); the marked point indicates the Youden-optimal threshold of ≥4 guidewires (sensitivity 62.5%, specificity 61.0%). (B) Primary multivariable model with and without guidewire count (apparent AUC 0.733 and 0.711, respectively); the optimism-corrected AUC of the full model was 0.670. Abbreviations: AUC, area under the curve; CI, confidence interval; ROC, receiver operating characteristic.

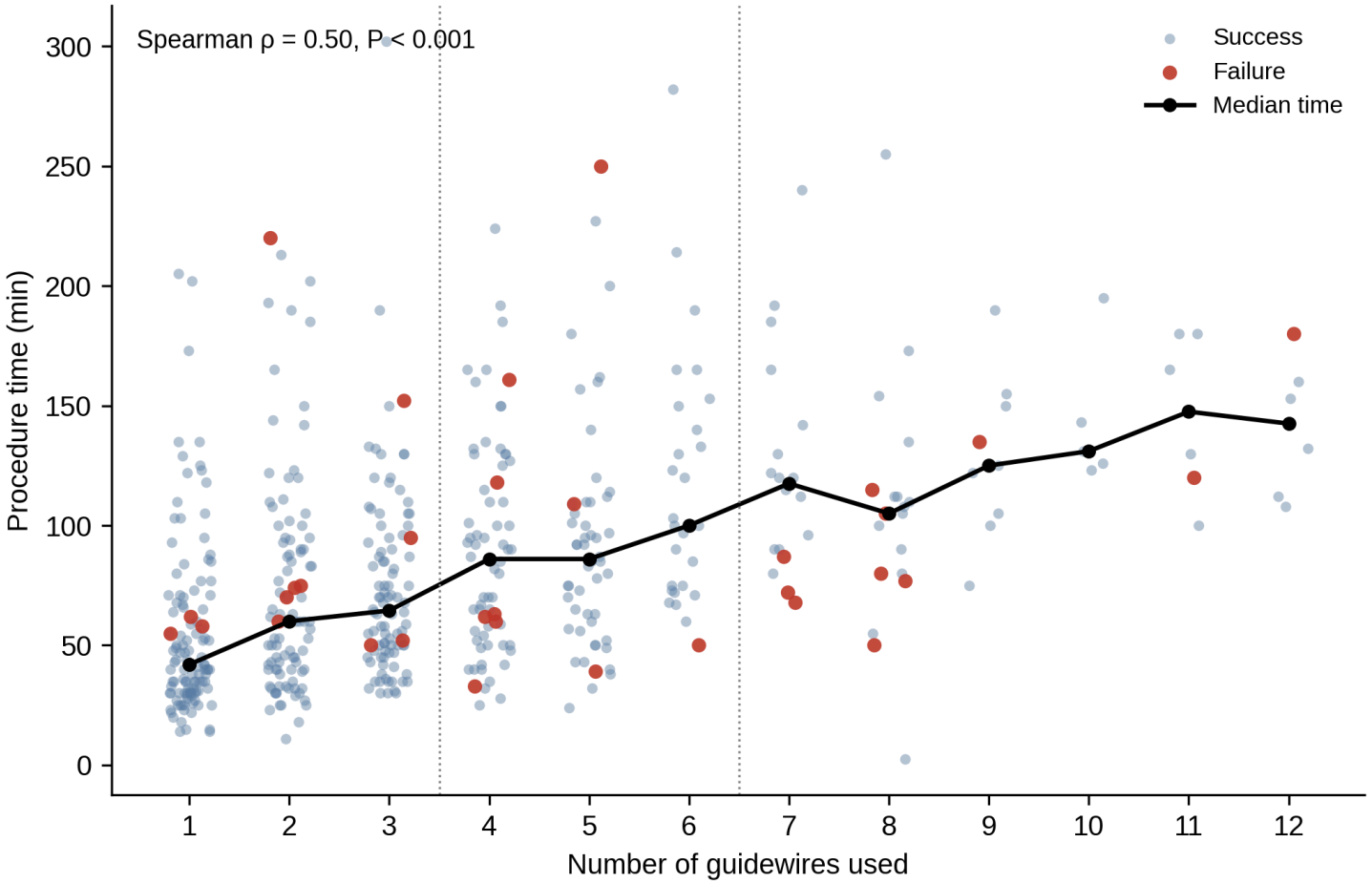


Figure 4

Procedure time according to the number of guidewires used. Each point represents one procedure (horizontal jitter added for display); failed crossings are shown in a different color. The solid line connects the median procedure time for each guidewire count. Procedure time increased with guidewire count (Spearman ρ = 0.50; P < 0.001). Eight procedures with missing procedure time are not shown.

Supplementary Files

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