THE ANATOLIAN JOURNAL OF CARDIOLOGY

Official journal of the TURKISH SOCIETY OF CARDIOLOGY

Association of Coronary Vessel Tapering with Postprocedural Residual Diameter Stenosis After Drug-Coated Balloon Angioplasty: A Retrospective Registry Study

ABSTRACT

Objective: To evaluate whether proximal-to-distal coronary tapering is associated with registry-designated post-drug-coated balloon (DCB) percentage diameter stenosis.

Methods: This retrospective single-center registry analysis included 1 designated index-lesion row per patient. Eligibility required observed post-DCB diameter stenosis and at least 1 observed preprocedure proximal or distal reference-vessel diameter (RVD). Tapering was defined from the phase 0 preprocedure RVDs as (proximal RVD—distal RVD)/mean RVD. The adjusted linear model used heteroskedasticity-consistent standard errors and 50 chained-equation imputations for missing exposure/covariate data; the outcome was not imputed.

Results: Of 509 source records, 354 were eligible. Per 0.10 greater tapering, the adjusted difference in post-DCB diameter stenosis was 0.32 percentage points (95% CI, −0.10 to 0.74; $P = .132$). Estimates were similar across complete-case, restriction, inverse-probability-weighted, influence, and median-regression analyses. Observed-only secondary analyses showed lower post-DCB minimal lumen diameter (−0.033 mm; 95% CI, −0.049 to −0.018; $P < .001$) and normalized acute gain (−0.014; 95% CI, −0.023 to −0.005; $P = .002$).

Conclusion: The adjusted primary estimate did not demonstrate a statistically discernible association between coronary tapering and post-DCB percentage diameter stenosis, although small effects in either direction could not be excluded. Secondary absolute-lumen findings require prospective core-laboratory validation and do not support empirical balloon oversizing.

Keywords: Acute lumen gain, coronary tapering, drug-coated balloon, minimal lumen diameter, quantitative coronary angiography

ORIGINAL INVESTIGATION

INTRODUCTION

Drug-coated balloon (DCB) intervention delivers antiproliferative therapy without a permanent metallic scaffold. Contemporary consensus documents emphasize lesion preparation, accurate vessel sizing, acceptable residual stenosis, and management of flow-limiting dissection.[1-3] Randomized and pooled evidence supports DCB use in selected small-vessel and in-stent restenosis settings.[4-6]

Coronary arteries normally taper from proximal to distal segments, so 1 mean reference-vessel diameter (RVD) may incompletely represent a long treated segment.[7] A cylindrical balloon can be relatively undersized proximally and oversized distally. Previous studies have examined achieved lumen, balloon-to-artery ratio, follow-up angiographic outcomes after DCB treatment, and proximal–distal reference mismatch in stented lesions.[8-10] Whether continuous coronary tapering is associated with registry-designated post-DCB percentage diameter stenosis remains uncertain.

We hypothesized that greater tapering would be associated with higher registry-designated post-DCB percentage diameter stenosis. The continuous tapering index and post-DCB percentage stenosis constituted the single primary estimand.

Copyright@Author(s) - Available online at anatoljcardiol.com.
Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Sezgin Uzunoğlan[1]
Hasan Burak İşleyen[2,3]
Behice Hande Şişman Uzunoğlan[1]
Oğuzhan Abanoz[3]
Esra Danışman[3]
Mahmut Uluganyan[3]

[1]*Department of Cardiology, Kırklareli Training and Research Hospital, Kırklareli, Türkiye*
[2]*Department of Cardiology, Faculty of Medicine, Nişantaşı University, İstanbul, Türkiye*
[3]*Department of Cardiology, Faculty of Medicine, Bezmialem Vakıf University, İstanbul, Türkiye*

Corresponding author:
Sezgin Uzunoğlan
✉ uzunoglan.sezgin@gmail.com

Received: August 3, 2026
Accepted: October 22, 2026
Available Online Date: November 24, 2026

Cite this article as: Uzunoğlan S, İşleyen HB, Uzunoğlan BHŞ, Abanoz O, Danışman E, Uluganyan M. Association of coronary vessel tapering with postprocedural residual diameter stenosis after drug-coated balloon angioplasty: a retrospective registry study. *Anatol J Cardiol.* 2026;XX(X):X-X.

DOI: 10.14744/AnatolJCardiol.2026.6920

Post-DCB minimal lumen diameter (MLD), normalized acute gain, residual stenosis > 30%, and interactions were supportive; absolute acute gain was evaluated post hoc.

METHODS

Study Design and Population

This retrospective single-center registry analysis followed Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations.[11] The analytical file contained 509 unique patient identifiers and 1 designated index-lesion row per patient for procedures from September 16, 2023, through July 1, 2026. Investigators confirmed that the proximal/distal RVD, device, treated-length, and post-procedural Quantitative Coronary Angiography (QCA) fields within each row referred to the same lesion. The upstream operational rule used to select the designated lesion in multilesion procedures was not retained in the analytical file. Eligibility required an observed post-DCB percentage diameter stenosis and at least 1 observed RVD. Records without the primary outcome were excluded because the endpoint could not be evaluated and was not imputed. Among outcome-observed records, those with neither proximal nor distal RVD were excluded because tapering could not be calculated; both exposure components were not imputed when simultaneously absent. Records with 1 observed RVD were retained, with only the missing counterpart imputed.

The study was approved by the institutional non-interventional research ethics committee. Individual consent was waived because of the retrospective design, and the study followed the Declaration of Helsinki.

Angiographic Measurements, Exposure, and Outcomes

Registry QCA included phase 0 preprocedure proximal and distal RVD measurements, as well as post-predilation and post-DCB measurements. The tapering exposure was derived exclusively from the phase 0 preprocedure proximal and distal RVDs; post-predilation measurements were not used to define tapering. Mean RVD was the arithmetic mean of these proximal and distal RVDs, and tapering was calculated as (proximal RVD—distal RVD)/mean RVD. Intravascular ultrasound (IVUS)-derived reference diameters were not incorporated into the tapering calculation and were not retained in the analytical dataset. The registry label "post-DCB" was retained; the source data did not specify whether this measurement preceded bailout stenting or represented the final procedural QCA. A restriction to DCB-only procedures was therefore included as a sensitivity analysis. The source archive did not retain the QCA software/version, calibration procedure, analyst blinding, reference-contour algorithm, repeatability assessment, or metadata confirming use of a bifurcation-dedicated QCA algorithm.

The primary outcome was registry-designated post-DCB percentage diameter stenosis. Prespecified secondary outcomes were post-DCB MLD, normalized acute lumen gain ([post-DCB MLD—pre-DCB MLD]/mean RVD), and residual stenosis > 30%. Secondary outcome components were not imputed. Absolute acute gain was evaluated post hoc to address concern about the shared mean-RVD denominator. Nominal DCB diameter was used only in the secondary mismatch analysis. The registry did not retain the operator's intended balloon-to-artery ratio or whether nominal DCB sizing was based on the proximal, distal, mean, or another reference diameter.

Covariates and Missing Data

The primary model adjusted for mean RVD, baseline percentage stenosis, treated length, lesion type, target vessel, chronic total occlusion (CTO), bifurcation, calcification, and IVUS guidance. Fifty chained-equation imputations were generated. Continuous variables used Gaussian-perturbed linear conditional models with predictive mean matching; binary variables used binomial generalized linear models; multicategory variables used bootstrap-perturbed multinomial logistic draws. Estimates were combined with finite-degrees-of-freedom Rubin rules.[12] The primary outcome informed covariate imputation but was not itself imputed. Variable-specific missingness within the eligible cohort is reported in Supplementary Table 6.

All 67 observed pre-DCB MLD values of 0 mm coincided with 100% pre-DCB stenosis, zero pre-DCB lumen area and maximum diameter, and both RVDs missing. These records were treated as observed total occlusions with unmeasured RVD, not as zero-valued RVDs; none met primary exposure eligibility. Of these 67 records, 2 were excluded at step 1 because post-DCB percentage stenosis was missing; the remaining 65 had an observed outcome and were excluded at step 2, corresponding to the total-occlusion pattern shown in Figure 1.

Statistical Analysis

Continuous variables are summarized as median (interquartile range) and categorical variables as n/available n (%). The study size was determined by the number of eligible records in the available registry period; no a priori sample-size calculation was performed. For descriptive presentation only, Table 1 divided the 352 patients with both RVDs observed at the median observed tapering value. This median split was not a clinical threshold and was not used in the regression analyses, in which tapering remained continuous. Primary linear regression used heteroscedasticity-consistent covariance estimator 3 (HC3) standard errors. A natural cubic spline with fixed knots at the observed 10th, 50th, and 90th tapering percentiles was compared with the linear specification using the prespecified Akaike Information Criterion (ΔAIC) criteria described in the Supplementary Methods.

HIGHLIGHTS

- Coronary tapering was evaluated as a continuous anatomical exposure.
- The adjusted difference was 0.32 percentage points per 0.10 greater tapering.
- The 95% CI remained compatible with small effects in either direction.
- Secondary absolute-lumen associations require prospective validation.

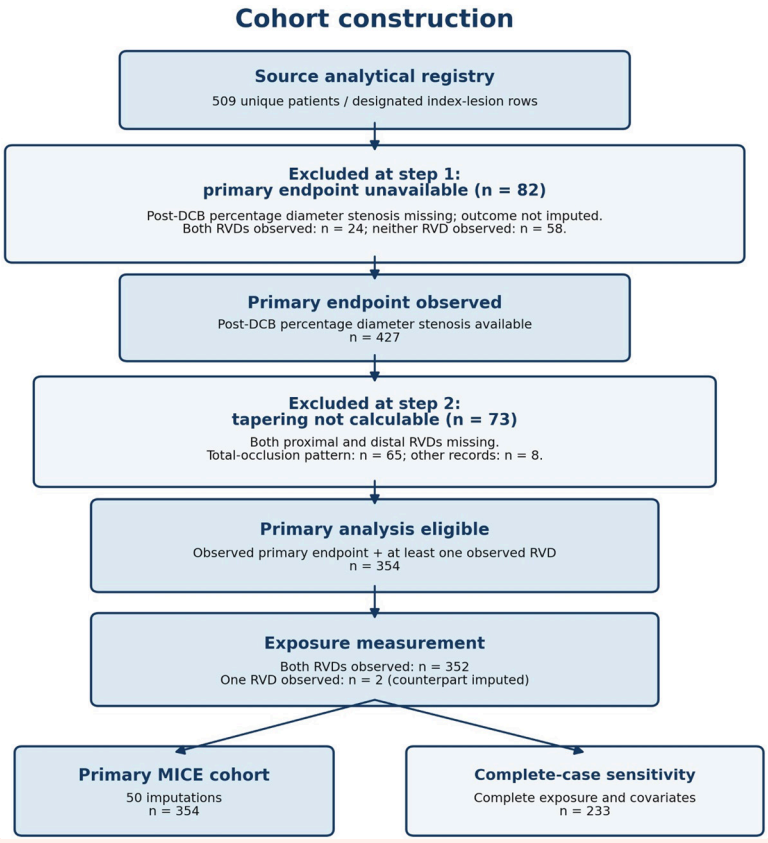


Figure 1. Cohort construction. Eighty-two records were excluded because post-DCB percentage diameter stenosis was missing and the primary endpoint could not be evaluated. Among outcome-observed records, 73 were excluded because both RVDs were missing and tapering could not be calculated; 65 showed the total-occlusion pattern and 8 had other missing-RVD patterns. Of 354 eligible records, 352 had both RVDs observed and 2 had 1 observed RVD, with the missing counterpart imputed. DCB, drug-Coated Balloon; RVD, reference-vessel diameter.

Sensitivity analyses included complete cases; non-CTO, de novo, DCB-only, and 2024-2025 subsets; alternative tapering definitions; age/sex adjustment; exclusion of potentially downstream treated-length/IVUS covariates; inverse-probability weighting for analysis eligibility; Cook-distance influence exclusion; and median regression. Subgroup sizes are reported as median (minimum-maximum) across imputations. Secondary and interaction analyses were exploratory without multiplicity adjustment. The mismatch analysis was considered interpretable only if imputed and complete-case estimates were directionally concordant. Two-sided $P < .05$ was used for the primary analysis. As an independent software cross-check, the primary multivariable model and key secondary analyses were repeated using IBM Statistical Package for the Social Sciences (SPSS) Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA). The SPSS results were concordant with the Python outputs and did not alter the reported estimates or interpretation.

Table 1. Descriptive Characteristics by Observed Tapering Group

Characteristic	Lower Tapering (n = 176)	Higher Tapering (n = 176)	SMD
Age, years	58.50 [52.00, 68.00]	61.00 [53.00, 70.00]	0.11
Mean RVD, mm	2.28 [1.80, 2.64]	2.28 [1.88, 2.61]	-0.02
Pre-DCB diameter stenosis, %	58.00 [48.00, 66.00]	59.00 [48.00, 69.00]	0.08
Treated length, mm	25.00 [20.00, 30.00]	30.00 [20.00, 40.00]	0.26
Male	140/176 (79.5%)	143/176 (81.2%)	0.04
In-stent restenosis	29/166 (17.5%)	34/167 (20.4%)	0.07
CTO	6/166 (3.6%)	13/167 (7.8%)	0.18
Bifurcation	27/166 (16.3%)	18/167 (10.8%)	−0.16
IVUS guided	32/166 (19.3%)	27/167 (16.2%)	−0.08

Values are median (interquartile range) or n/available n (%). Groups were divided at the median observed tapering value within the eligible cohort. CTO, chronic total occlusion; DCB, drug-coated balloon; IVUS, intravascular ultrasound; RVD, reference-vessel diameter; SMD, standardized mean difference.

Python and package versions are provided in the reproducibility supplement. Additional model diagnostics and analytic decisions are reported in Supplementary Tables 3 and 4.

Exploratory analyses used observed data. Effect modification by bifurcation status was assessed using an HC3-robust linear model including tapering, mean RVD, baseline percentage stenosis, bifurcation status, and a tapering-by-bifurcation interaction. Target-vessel heterogeneity was assessed with an HC3-robust linear interaction model using left anterior descending (LAD), left circumflex (LCx), right coronary artery (RCA), and other-vessel groups and the same adjustment for mean RVD and baseline percentage stenosis. Post-DCB dissection severity was examined by ordinal logistic regression ordered as no dissection, type A, type B, and type C. A parsimonious anatomical model adjusted for mean RVD and bifurcation status. An extended sensitivity model additionally adjusted for baseline percentage stenosis, treated length, in-stent restenosis (ISR) status, target-vessel group, CTO, and IVUS guidance. Because dissection documentation varied substantially over calendar time, the extended analysis was repeated in the 2024 subgroup, in which dissection ascertainment was nearly complete. Ordinal-model stability was examined with threshold-specific binary logistic fits across the cumulative dissection cut points. These analyses were exploratory and were not adjusted for multiplicity.

Artificial intelligence–assisted technology was used solely for language editing. It was not used to generate data, perform statistical analyses, select results, or make scientific decisions. All content was reviewed and approved by the authors, who take full responsibility for the submitted work.

RESULTS

Cohort

The sequential cohort construction is shown in Figure 1 and Supplementary Table 1. Of 509 source records, 82 were excluded first because post-DCB percentage diameter stenosis was missing and the primary endpoint was therefore not evaluable. Of these first-step exclusions, 24 had both RVDs recorded and 58 had neither RVD recorded; the missing outcome remained the governing exclusion reason. Among the 427 records with an observed outcome, a further 73 were excluded because neither proximal nor distal RVD was available and tapering could not be calculated. This second group comprised 65 records with the internally concordant total-occlusion pattern and 8 other records without that pattern. The final eligible cohort therefore contained 354 records: both RVDs were observed in 352, whereas 1 RVD was observed and the missing counterpart was imputed in 2. The complete-case sensitivity included 233 records. Excluded records had a higher observed prevalence of CTO and higher baseline stenosis than eligible records (Supplementary Table 5). The inverse-probability-weighted analysis examined sensitivity to selection explained by measured variables but could not address unmeasured or missing-not-at-random selection.

Among the 352 eligible records with both RVDs observed, division at the median tapering value produced 2 equal descriptive groups of 176 lesions (Table 1). The groups showed modest differences in treated length and lesion features, which were included in the adjusted analyses.

Target-vessel data were available in 337 patients: 107 (31.8%) LAD, 60 (17.8%) LCx, 60 (17.8%) RCA, and 110 (32.6%) other coronary branches (41 obtuse marginal, 33 diagonal, 16 intermediate branch, 12 posterior descending artery, and 8 posterolateral branch). Intravascular ultrasound guidance was documented in 60 of 335 patients with available IVUS-status data (17.9%). Post-DCB residual diameter stenosis was ≤30% in 264 of 354 patients (74.6%). Bailout stenting was documented in 4 of 335 patients with available data (1.2%).

Primary Outcome

The unadjusted difference in post-DCB stenosis was 0.16 percentage points per 0.10 taper (95% CI, −0.25 to 0.57; $P = .453$). The fully adjusted difference was 0.32 percentage points (95% CI, −0.10 to 0.74; $P = .132$; Table 2). The spline did not improve fit (median ΔAIC, 0.93; 0% of imputations had ΔAIC < −2); the linear form was retained (Figure 2).

Sensitivity Analyses

Estimates were similar across the supplied sensitivity analyses, and none demonstrated a statistically discernible association (Table 3; Supplementary Table 2). Complete-case beta was 0.46 (95% CI, −0.03 to 0.95; $P = .065$); denotes inverse-probability weighting (IPW) beta was 0.26 (95% CI, −0.20 to 0.72; $P = .273$); Cook-distance exclusion beta was 0.16 (95% CI, −0.21 to 0.53; $P = .402$); and median-regression beta was 0.12 (95% CI, −0.34 to 0.58; $P = .600$).

Secondary and Exploratory Outcomes

Per 0.10 greater tapering, observed-only normalized acute gain was lower by −0.014 (95% CI, −0.023 to −0.005; $P = .002$) and post-DCB MLD was lower by −0.033 mm (95% CI, −0.049 to −0.018; $P < .001$). Post hoc absolute acute gain was lower by −0.030 mm (95% CI, −0.045 to −0.016; $P < .001$), remaining similar after excluding 6 negative-gain observations (−0.029 mm; $P < .001$). Residual stenosis > 30% was not associated with tapering (odds ratio [OR], 1.04; 95% CI, 0.95-1.14; $P = .399$; 90 events). The tapering-by-ISR interaction was not supported ($P = .398$). (Table 4).

The DCB-mismatch estimates differed in direction between the multiply imputed and complete-case analyses, while nominal DCB size was missing in 125 of 354 eligible records (35.3%). The mismatch association was therefore considered indeterminate, and more complex directional, spline, and

Table 2. Primary Models of Post-DCB Percentage Diameter Stenosis

Model	n	Difference Per 0.10 Taper (95% CI)	*P*
Unadjusted	354	0.16 (−0.25 to 0.57)	.453
Age/sex/size adjusted	354	0.24 (−0.17 to 0.64)	.249
Fully adjusted (primary)	354	0.32 (−0.10 to 0.74)	.132

Estimates are percentage-point differences with HC3 standard errors; multiply imputed estimates combine 50 datasets with finite-degrees-of-freedom Rubin rules.
DCB, drug-coated balloon.

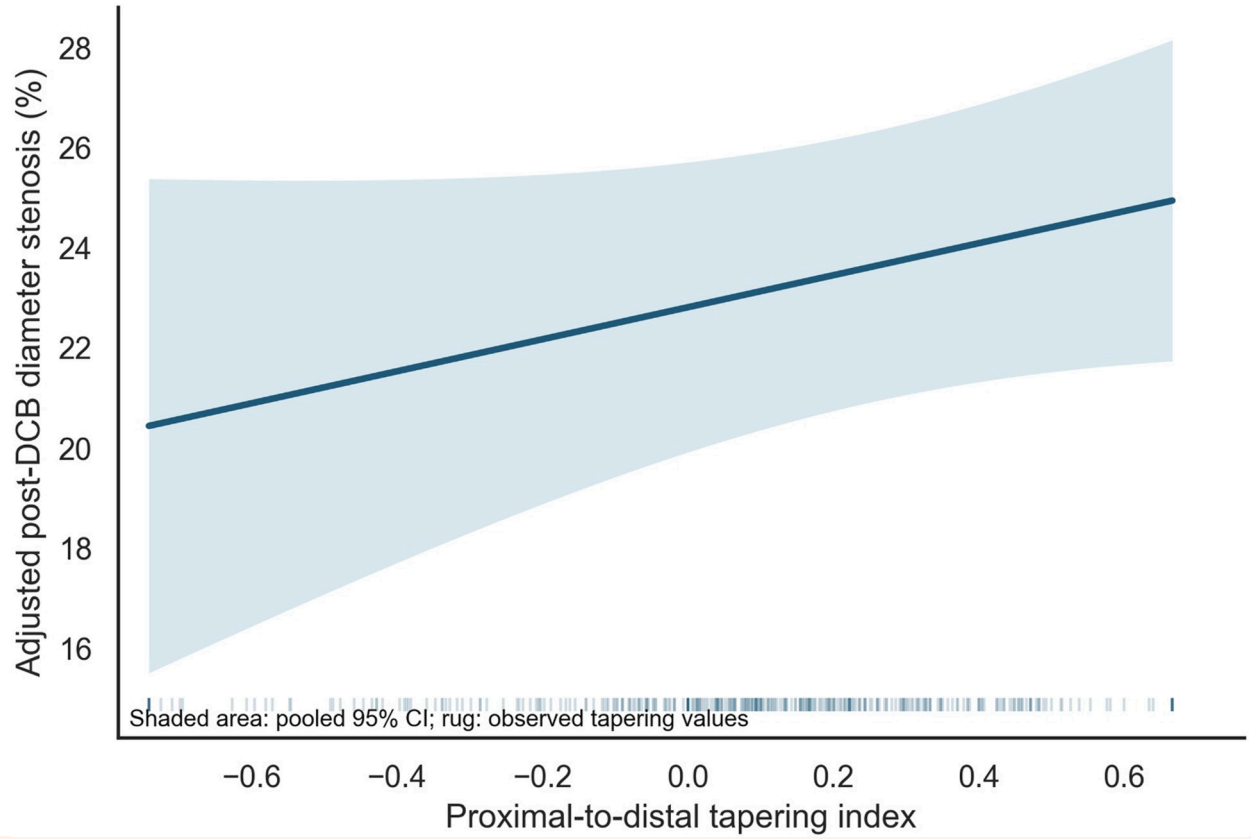


Figure 2. Pooled adjusted post-DCB percentage diameter stenosis across the tapering index. The line is the pooled adjusted mean, the band is the pooled 95% CI, and rug marks show observed tapering values. DCB, drug-coated balloon.

inflation-adjusted mismatch models were not interpreted. The penalized bailout-stent model failed to converge, so no effect estimate was reported.

In exploratory analyses, the adjusted difference per 0.10 greater tapering was 0.27 percentage points among bifurcation lesions (95% CI, −0.50 to 1.05; *P* = .489) and 0.21 percentage points among non-bifurcation lesions (95% CI, −0.30 to 0.72; *P* = .426), with no evidence of interaction (*P* = .889). A LAD/LCx/RCA/other target-vessel interaction analysis also did not identify evidence of heterogeneity (global interaction *P* = .919). Dissection grade was available in 240 of 354 eligible patients (107 no dissection, 88 type A, 29 type B, and 16 type C). Ordinal dissection estimates were model-sensitive: the OR for greater dissection severity per 0.10 greater tapering was 1.11 (95% CI, 1.03-1.20; *P* = .007) after parsimonious

Table 3. Sensitivity Analyses

Analysis	n	Difference per 0.10 Taper (95% CI)	*P*
Primary MICE	354	0.32 (−0.10 to 0.74)	.132
Complete case	233	0.46 (−0.03 to 0.95)	.065
Exclude CTO	334 [332–335]	0.36 (−0.06 to 0.78)	.096
De novo only	288 [284–290]	0.15 (−0.35 to 0.65)	.552
DCB-only procedures	282 [279–286]	0.27 (−0.17 to 0.72)	.232
Add age and sex	354	0.31 (−0.11 to 0.73)	.148
Exclude potentially downstream treated length and IVUS	354	0.33 (−0.07 to 0.74)	.107
Stable documentation period (2024-2025)	344	0.28 (−0.13 to 0.69)	.185
Absolute taper difference	354	0.08 (−0.24 to 0.39)	.630
Proximal/distal ratio	354	0.36 (−0.04 to 0.75)	.076
Inverse-probability weighted for primary-analysis eligibility	354	0.26 (−0.20 to 0.72)	.273
Exclude Cook's distance > 4/n within each imputation	332 [328-336]	0.16 (−0.21 to 0.53)	.402
Median regression	354	0.12 (−0.34 to 0.58)	.600

For imputation-dependent restrictions, n is median [minimum-maximum] across imputations.
CTO, chronic total occlusion; DCB, drug-coated balloon; IPW, inverse-probability weighting; IVUS, intravascular ultrasound.

Table 4. Secondary and Exploratory Outcomes

Outcome	Effect per 0.10 Taper (95% CI)	*P*
Normalized acute gain (prespecified)	−0.014 (−0.023 to −0.005)	.002
Post-DCB MLD, mm (prespecified)	−0.033 (−0.049 to −0.018)	<.001
Absolute acute gain, mm (post hoc)	−0.030 (−0.045 to −0.016)	<.001
Residual stenosis > 30%, odds ratio	1.04 (0.95-1.14)	.399
Tapering × ISR interaction	0.40 (−0.52 to 1.31)	.398

Secondary and interaction analyses were exploratory and not adjusted for multiplicity. MLD and gain components were restricted to observed values.
DCB, drug-coated balloon.

anatomical adjustment and 1.08 (95% CI, 0.99-1.18; *P* = .076) after extended adjustment. In the 2024-only extended sensitivity analysis, the OR was 1.07 (95% CI, 0.97-1.17; *P* = .172; Supplementary Table 7).

DISCUSSION

In 354 eligible DCB-treated index lesions, the adjusted primary estimate did not demonstrate a statistically discernible association between proximal-to-distal tapering and registry-designated post-DCB percentage diameter stenosis. The CI remained compatible with small adverse or favorable associations. Observed-only secondary analyses suggested smaller post-DCB MLD and acute lumen gain with greater tapering. These findings must be interpreted in the context of registry QCA that was not adjudicated by a blinded core laboratory and lacked software, calibration, reference-contour, analyst-blinding, and repeatability records. The absolute-lumen findings remain hypothesis-generating and do not convert the primary analysis into a positive confirmatory study.

The divergence between percentage stenosis and absolute lumen measures is anatomically plausible and partly reflects variable construction. Percentage stenosis expresses MLD relative to an estimated reference contour, whereas tapering incorporates both proximal and distal RVD. A tapered segment can therefore have a smaller absolute postprocedural lumen without proportionately higher percentage stenosis. The absolute-gain analysis removed the shared mean-RVD denominator but did not eliminate dependence arising from common vessel dimensions; the secondary signal therefore remains exploratory.

The present analysis differs from previous studies in both exposure and outcome definition. Kang et al[8] evaluated predictors of angiographic success at follow-up and identified post-DCB MLD and balloon-to-artery ratio as relevant variables; coronary tapering was not the exposure, and the endpoint was not postprocedural residual stenosis. Yu et al[9] similarly developed a follow-up angiographic prediction model incorporating immediate gain, residual stenosis, and DCB/RVD ratio. Phan et al[10] examined proximal–distal reference mismatch during IVUS-guided stented PCI, where scaffold geometry and expansion introduce mechanisms absent from a DCB-only strategy. Against this background, the present contribution is narrow: the adjusted primary estimate did not show a clear relationship between continuous tapering and registry-designated post-DCB percentage stenosis, while the absolute-lumen associations remain exploratory.

Exploratory analyses did not identify evidence that the association between tapering and residual percentage stenosis differed materially by bifurcation status or target-vessel group. Post-DCB dissection analyses were less stable: a parsimonious anatomically adjusted model suggested greater dissection severity with increasing tapering, whereas the estimate attenuated after broader adjustment and in a stable-documentation sensitivity analysis. These findings should not be interpreted as evidence that tapering independently causes dissection, particularly because dissection ascertainment was incomplete and varied over calendar time.

The present study also does not establish an association between tapering and subsequent restenosis. Follow-up angiography was available only in a selected subset and was not suitable for an unbiased long-term angiographic analysis. Likewise, the continuous primary analysis and prespecified spline provided no empirical basis for a clinically actionable tapering threshold. Deriving a post hoc cutoff from these data would therefore risk overfitting and should not be used to guide tapered-balloon selection or empirical balloon oversizing.

The present results should not be interpreted as support for empirical balloon oversizing because actual inflated balloon dimensions and distal-vessel injury were not evaluated. A practical research implication is to document both reference diameters, actual inflated balloon dimensions, lesion preparation, and physiologic outcome prospectively, ideally with a blinded core laboratory.

Limitations of the Study

The retrospective single-center design permits selection bias and residual confounding. Although each analytical row contained internally linked lesion, device, and QCA fields, the upstream rule for choosing the designated lesion in multilesion procedures was unavailable. The tapering exposure was derived from preprocedure angiographic QCA; IVUS guidance was used in 17.9% of patients with available IVUS-status data, but IVUS-derived reference diameters were not retained and angiographic–IVUS concordance could not be assessed. QCA software/version,

calibration, analyst blinding, reference-contour algorithm, repeatability, and use of bifurcation-dedicated QCA were not retained. The operator's intended DCB-sizing rule and target reference segment were also unavailable, and nominal DCB diameter was missing in 35.3% of eligible patients, leaving mismatch analyses indeterminate. For ISR cases, the exact relationship of proximal and distal reference measurements to the previous stent and stent edges could not be reconstructed.

Dissection documentation was incomplete and varied substantially over calendar time; exploratory dissection analyses were therefore model-sensitive and should be interpreted cautiously. Only 16 observed cases were type C, further limiting precision for higher-grade dissection. The exact timing of the registry-designated post-DCB measurement relative to bailout stenting was unavailable, and bailout indications were not coded. Exclusion of 155 of 509 records limits generalizability despite IPW sensitivity. The 2 eligible records with 1 missing RVD required imputation. Secondary endpoints were not multiplicity-adjusted, and absolute gain was post hoc. Finally, follow-up angiography was available only in a selected subset, so the present study cannot establish associations with restenosis, revascularization, or clinical benefit and does not define a clinically actionable tapering cutoff.

CONCLUSION

The adjusted primary estimate did not demonstrate a statistically discernible association between coronary tapering and registry-designated post-DCB percentage diameter stenosis, although small effects in either direction could not be excluded. Prespecified observed-only MLD and normalized-gain analyses, together with a post hoc absolute-gain analysis, identified exploratory absolute-lumen associations. These secondary findings require prospective core-laboratory validation and do not support empirical balloon oversizing.

Ethics Committee Approval: This study was approved by the Ethics Committee of Bezmialem Vakif University (meeting no. 8, decision no. 18, August 24, 2024).

Artificial Intelligence Usage Statement: Artificial intelligence–assisted technology was used solely for language editing. It was not used to generate data, perform statistical analyses, select results, or make scientific decisions. All content was reviewed and approved by the authors, who take full responsibility for the submitted work.

Informed Consent: The requirement for individual informed consent was waived due to retrospective design of study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – S.U., H.B.I.; Design – B.H.S.U., H.B.I.; Supervision – M.U., S.U.; Materials – O.A., E.D.; Data Collection and/or Processing – S.U., B.H.S.U., O.A., E.D.; Analysis and/or Interpretation – H.B.I., S.U.; Literature Search – H.B.I., O.A.; Writing – S.U., H.B.I., B.H.S.U.; Critical Review – H.B.I., M.U.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declare that this study received no financial support.

REFERENCES

1. Jeger RV, Eccleshall S, Wan Ahmad WA, et al. Drug-coated balloons for coronary artery disease: third report of the International DCB Consensus Group. *JACC Cardiovasc Interv*. 2020;13(12):1391-1402. [CrossRef]
2. Her AY, Ahmad WAW, Bang LH, et al. Drug-coated balloons-based intervention for coronary artery disease: the second report of Asia-Pacific Consensus Group. *JACC Asia*. 2025;5(6):701-717. [CrossRef]
3. Fezzi S, Scheller B, Cortese B, et al. Definitions and standardized endpoints for the use of drug-coated balloon in coronary artery disease: consensus document of the Drug Coated Balloon Academic Research Consortium. *Eur Heart J*. 2025;46(26):2498-2519. [CrossRef]
4. Jeger RV, Farah A, Ohlow MA, et al. Drug-coated balloons for small coronary artery disease (BASKET-SMALL 2): an open-label randomised non-inferiority trial. *Lancet*. 2018;392(10150):849-856. [CrossRef]
5. Cortese B, Di Palma G, Guimaraes MG, et al. Drug-coated balloon versus drug-eluting stent for small coronary vessel disease: PICCOLETO II randomized clinical trial. *JACC Cardiovasc Interv*. 2020;13(24):2840-2849. [CrossRef]
6. Giacoppo D, Alfonso F, Xu B, et al. Paclitaxel-coated balloon angioplasty vs. drug-eluting stenting for the treatment of coronary in-stent restenosis: A comprehensive, collaborative, individual patient data meta-analysis of 10 randomized clinical trials (DAEDALUS study). *Eur Heart J*. 2020;41(38):3715-3728. [CrossRef]
7. Zubaid M, Buller C, Mancini GBJ. Normal angiographic tapering of the coronary arteries. *Can J Cardiol*. 2002;18(9):973-980.
8. Kang DO, Lee JS, Kim B, et al. Predictors of optimal angiographic lesion outcomes in drug-coated balloon treatment for de novo coronary artery disease. *Sci Rep*. 2025;15(1):9391. [CrossRef]
9. Yu X, Wang Y, Zhang W, et al. Establishment of a nomogram for predicting the suboptimal angiographic outcomes of coronary de novo lesions treated with drug-coated balloons. *Adv Ther*. 2023;40(3):975-989. [CrossRef]
10. Phan QT, Nguyen HL, Lee WS, et al. Impact of reference mismatch on procedure outcomes of percutaneous coronary intervention. *Angiology*. 2023;74(5):417-426. [CrossRef]
11. von Elm E, Altman DG, Egger M, et al. The STROBE statement. *Prev Med*. 2007;45(4):247-251. [CrossRef]
12. White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. *Stat Med*. 2011;30(4):377-399. [CrossRef]

SUPPLEMENTARY METHODS

Source procedures spanned September 16, 2023, through July 1, 2026. Primary eligibility required observed post-DCB percentage diameter stenosis and at least one observed Phase 0 pre-procedure proximal or distal RVD. Fifty chained-equation imputations were generated: Gaussian-perturbed linear conditional models with predictive mean matching for continuous variables, binomial generalized linear models for binary variables, and bootstrap-perturbed multinomial logistic draws for multicategory variables. Primary estimates used HC3 standard errors and finite-degrees-of-freedom Rubin pooling.

The prespecified natural-spline analysis used fixed empirical knots at the observed 10th, 50th, and 90th tapering percentiles; the nonlinear form required a median ΔAIC below −2 and ΔAIC below −2 in at least 75% of imputations. These criteria were not met, and the linear specification was retained. Secondary MLD and gain components were restricted to observed measurements. Because DCB-mismatch estimates differed in direction between imputed and complete-case analyses in the setting of substantial DCB-size missingness, this association was considered indeterminate. The stable-documentation sensitivity analysis was restricted to 2024–2025 because RVD coverage declined sharply in 2026.

Exploratory analyses were performed on observed data. Bifurcation effect modification used an HC3-robust linear interaction model adjusted for mean RVD and baseline percentage stenosis. Target-vessel heterogeneity was assessed with an HC3-robust linear interaction model across LAD, LCx, RCA, and other-vessel groups, likewise adjusted for mean RVD and baseline percentage stenosis. Dissection severity was modeled ordinally as no dissection, Type A, Type B, and Type C. The parsimonious anatomical model adjusted for mean RVD and bifurcation; the extended model additionally included baseline percentage stenosis, treated length, ISR status, target-vessel group, CTO, and IVUS guidance. Because dissection documentation varied over calendar time, the extended analysis was repeated in the 2024 subgroup. Threshold-specific binary logistic fits were used as

Supplementary Table 1. Cohort derivation and data completeness

Item	Count
Source analytical rows / unique patient IDs	509 / 509
Excluded at step 1: post-DCB percentage stenosis missing; primary endpoint not evaluable	82
Step 1 exclusions with both RVDs observed	24
Step 1 exclusions with neither RVD observed	58
Excluded at step 2: outcome observed but both RVDs missing; tapering not calculable	73
Step 2 exclusions with total-occlusion pattern	65
Step 2 exclusions with other missing-RVD patterns	8
Primary eligible cohort	354
Eligible with both RVDs observed	352
Eligible with one RVD observed	2
Complete-case primary model	233
Observed pre-DCB MLD=0	67
RVD <1.0 mm values confirmed	16
Negative recalculated acute gain	6

Supplementary Table 2. Full sensitivity set

Analysis	n	Beta (95% CI)	*P*
Primary MICE	354	0.320 (-0.096 to 0.736)	0.132
Complete case	233	0.461 (-0.028 to 0.949)	0.065
Exclude CTO	334 [332–335]	0.360 (-0.064 to 0.785)	0.096
De novo only	288 [284–290]	0.150 (-0.345 to 0.645)	0.552
DCB-only procedures	282 [279–286]	0.273 (-0.175 to 0.720)	0.232
Add age and sex	354	0.309 (-0.109 to 0.727)	0.148
Exclude potentially downstream treated length and IVUS	354	0.335 (-0.073 to 0.742)	0.107
Stable documentation period (2024-2025)	344	0.280 (-0.134 to 0.694)	0.185
Absolute taper difference	354	0.077 (-0.237 to 0.391)	0.630
Proximal/distal ratio	354	0.358 (-0.037 to 0.752)	0.076
Inverse-probability weighted for primary-analysis eligibility	354	0.258 (-0.203 to 0.719)	0.273
Exclude Cook's distance >4/n within each imputation	332 [328–336]	0.158 (-0.211 to 0.526)	0.402
Median regression	354	0.122 (-0.335 to 0.580)	0.600

Supplementary Table 3. Model and imputation diagnostics

Diagnostic	Result	Interpretation
Maximum VIF	1.67	No material multicollinearity
Condition number	442.8	Affected by raw variable scaling; VIF remained low
Residual skewness	0.235	Limited asymmetry
Residual excess kurtosis	-0.078	Near normal-tail reference
Cook >4/n, first imputation	22	Influence-exclusion analysis yielded a similar estimate
Primary FMI	0.020	Low missing-information fraction for primary coefficient

Supplementary Table 4. Analysis decisions and their rationale

Item	Disposition
Exposure eligibility	Required an observed primary endpoint and at least one observed RVD so that both the outcome and tapering exposure were estimable.
Three-knot spline	Used fixed 10th, 50th, and 90th empirical knots; the predefined criteria favored the linear specification.
Multicategory imputation	Used bootstrap-perturbed multinomial logistic draws.
Mismatch analyses	Considered indeterminate because DCB-size missingness was substantial and imputed and complete-case estimates differed in direction.
Absolute acute gain	Post hoc analysis examining whether the normalized-gain result depended on the shared mean-RVD denominator; interpreted as exploratory.
Index-lesion selection	One unique patient-level analytical row supplied; upstream multilesion selection rule unavailable and disclosed as a limitation.
QCA provenance	Software/calibration/blinding/reference-contour/repeatability metadata unavailable; no procedures were invented.
Post-DCB measurement timing	The source data did not retain whether the registry-designated post-DCB QCA measurement preceded bailout stenting or represented final procedural QCA; a DCB-only restriction was included as a sensitivity analysis.

an ordinal-model stability check and yielded directionally similar tapering coefficients across cumulative cut points. These analyses were exploratory and were not adjusted for multiplicity.

Bifurcation and target-vessel analyses used observed-data HC3-robust linear regression. Both interaction models adjusted for mean RVD and baseline percentage stenosis; target vessels were grouped as LAD, LCx, RCA, or other. Dissection severity was ordered as no dissection, Type A, Type B, and Type C. The anatomical ordinal model adjusted for mean RVD and bifurcation; the extended model additionally included baseline percentage stenosis, treated length, ISR status, target-vessel group, CTO, and IVUS guidance. Threshold-specific binary fits showed directionally similar tapering coefficients across cumulative dissection cut points. Analysis n reflects complete observed inputs for the corresponding model. All analyses were exploratory and were not adjusted for multiplicity.

Reproducibility

The analysis used deterministic seeds (42 for the core analysis and 42001 for multinomial imputations). Software versions were Python 3.13.11, pandas 2.3.3, NumPy 2.4.2, SciPy 1.17.0,

Supplementary Table 5. Eligible-versus-excluded record comparison

Variable	Excluded available n	Excluded summary	Eligible available n	Eligible summary
Age, years	114	mean 58.4; median 57.5	354	mean 60.3; median 59.5
Baseline diameter stenosis, %	102	mean 88.2; median 100.0	350	mean 57.5; median 58.0
Treated length, mm	95	mean 33.4; median 30.0	335	mean 29.0; median 30.0
Male sex	155	80.0%	354	80.2%
In-stent restenosis	95	11.6%	335	18.8%
Chronic total occlusion	95	62.1%	335	5.7%
Bifurcation	95	15.8%	335	13.4%
IVUS guidance	95	25.3%	335	17.9%

Summaries are based on available values. Continuous variables are shown as mean and median; binary variables are shown as proportions. These comparisons are descriptive and were not used as hypothesis tests.

Supplementary Table 6. Variable-specific missingness in the eligible cohort

Variable	Missing n	Missing %	Analytic role
Proximal RVD	1	0.3%	Exposure component
Distal RVD	1	0.3%	Exposure component
Baseline diameter stenosis	4	1.1%	Primary covariate or auxiliary variable
Pre-DCB MLD	1	0.3%	Secondary-outcome component
Post-DCB MLD	3	0.8%	Secondary-outcome component
Treated length	19	5.4%	Primary covariate or auxiliary variable
Nominal DCB diameter	125	35.3%	Mismatch analysis only
Inflation pressure	32	9.0%	Auxiliary imputation variable
Inflation duration	30	8.5%	Auxiliary imputation variable
In-stent restenosis	19	5.4%	Primary covariate or auxiliary variable
Chronic total occlusion	19	5.4%	Primary covariate or auxiliary variable
Bifurcation	19	5.4%	Primary covariate or auxiliary variable
IVUS guidance	19	5.4%	Primary covariate or auxiliary variable
Calcification	117	33.1%	Primary covariate or auxiliary variable
Target vessel group	17	4.8%	Primary covariate or auxiliary variable
Smoking category	25	7.1%	Auxiliary imputation variable
Dissection grade	114	32.2%	Exploratory outcome
Bailout stenting	19	5.4%	Descriptive exploratory outcome

The denominator is the 354-record primary eligible cohort. The primary outcome was not imputed. Observed-only secondary outcome components were not imputed.

Supplementary Table 7. Exploratory analyses

Analysis	n	Effect estimate	95% CI	*P*
Non-bifurcation lesions, adjusted slope	285	0.21 percentage points	−0.30 to 0.72	.426
Bifurcation lesions, adjusted slope	44	0.27 percentage points	−0.50 to 1.05	.489
Tapering × bifurcation interaction	329	—	—	.889
Target-vessel-group interaction	331	—	—	.919
Dissection severity, unadjusted	240	OR 1.01	0.95 to 1.08	.727
Dissection severity, anatomical adjustment	240	OR 1.11	1.03 to 1.20	.007
Dissection severity, extended adjustment	236	OR 1.08	0.99 to 1.18	.076
Dissection severity, 2024 extended sensitivity	202	OR 1.07	0.97 to 1.17	.172

statsmodels 0.14.6, scikit-learn 1.8.0, and Matplotlib 3.10.8. Reproducibility materials include the row-level eligibility classification, patient-to-index-lesion linkage, included-versus-excluded comparison, imputation diagnostics, multicollinearity and influence diagnostics, model tables, run manifest, and file checksums. These exploratory analyses were independently reproduced using Python 3.13.5, NumPy 2.3.5, SciPy 1.17.0, and statsmodels 0.14.6.