Predictors and Long-Term Clinical Outcome of Longitudinal Stent Deformation: Insights From Pooled Analysis of Korean Multicenter Drug-Eluting Stent Cohort

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Background—There are limited data on the frequency of and factors associated with quantitative coronary angiography (QCA)–defined longitudinal stent deformation (LSD) in various contemporary drug-eluting stents platforms. This study sought to evaluate the predictors of LSD and its long-term clinical implication.

Methods and Results—A patient-level pooled analysis was performed with 7350 lesions in 5871 patients treated with platinum-chromium–based everolimus-eluting stent (Promus Element), cobalt-chromium–based everolimus-eluting stent (Promus/Xience V), or cobalt-chromium–based zotarolimus-eluting stent (Endeavor Resolute). QCA was performed to analyze differences of stent length between immediate post-deployment and final post-procedure. Independent factors associated with LSD were identified. Clinical outcomes at 3 years were compared between those with and without QCA-based LSD. The frequency of QCA-based LSD was 1.12% (82 cases). Nine of these cases were angiographically overt. Left main or ostial lesion, bifurcation treatment with provisional side branch stenting or ballooning, additional downstream intervention of a distal lesion, intravascular ultrasound use, and adjunctive post-dilatation were independently associated with QCA-based LSD. The type of stent was not associated with QCA-based LSD. Rates of target lesion failure were nominally higher in lesions with QCA-based LSD than in those without (8.97% versus 5.88%; hazard ratio, 1.415; 95% confidence interval, 0.631–3.175; \( P = 0.399 \)).

Conclusions—LSD is uncommon with contemporary drug-eluting stents, regardless of the type of stent platform. LSD is mainly associated with procedural factors, especially with additional downstream procedures which require the passage of devices through the stent. Careful manipulation of poststent imaging or procedural devices is required to prevent LSD. More data are needed to clarify the impact of LSD on clinical events. (Circ Cardiovasc Interv. 2017;10:e005518. DOI: 10.1161/CIRCINTERVENTIONS.117.005518.)

Key Words: coronary angiography ■ drug-eluting stents ■ percutaneous coronary intervention ■ risk factors ■ stents
WHAT IS KNOWN

- Longitudinal stent deformation (LSD) has been reported previously as a potential complication of contemporary thin strut stents and was mostly reported in the Promus Element stent, but it has also been intermittently reported in other stent platforms, suggesting that there exist risk factors other than stent design for LSD.
- There are limited data on major predictors of LSD defined by quantitative methods, and the long-term clinical implication of LSD is unclear.

WHAT THE STUDY ADDS

- Any use of secondary device after stenting was the single most important independent factor related with quantitative coronary angiography–based LSD, regardless of the stent type or other lesion factors.
- Although the prognostic impact of quantitative coronary angiography–based LSD on 3-year clinical outcomes was statistically insignificant, there were numerically higher rates of target lesion failure in the quantitative coronary angiography–based LSD group.
- Careful manipulation of secondary imaging and procedure devices may decrease the incidence of LSD.

Longitudinal stent deformation (LSD) is a well-recognized complication of current drug-eluting stents (DES).1–3 The Promus Element stent has been the most frequently reported DES that is vulnerable to LSD, mainly because of its weakness against longitudinal forces which may be explained by its thin strut and offset peak-to-peak design.

Methods

Establishment of Patient-Level Pooled DES Cohort

Patient-level data were pooled from 2 nationwide multicenter studies, 1 randomized trial and 1 registry, covering a total of 9299 lesions in 6811 patients treated with platinum-chromium–based everolimus-eluting stent (Promus Element; Boston Scientific, Maple Grove, MN), cobalt-chromium–based everolimus-eluting stent (Promus or Xience V; Abbott Vascular, Santa Clara, CA), or cobalt-chromium–based zotarolimus-eluting stent (Endeavor Resolute; Medtronic, Minneapolis, MN). The HOST-ASSURE (Harmonizing Optimal Strategy for Treatment of Coronary Artery Stenosis-Safety and Effectiveness of Drug-Eluting Stents and Antiplatelet Regimen) was a prospective, randomized, multicenter trial in South Korea. The detailed study design, eligibility criteria, and 1-year outcome were published previously.10,11 In brief, the study had a 2×2 factorial design, in which randomization was performed for the type of DES (platinum-chromium–based everolimus-eluting stent versus cobalt-chromium–based zotarolimus-eluting stent) and the type of 1-month intensified antiplatelet therapy followed by conventional dual antiplatelet therapy, during the period of 2010 through 2011. The EXCELLENT (Efficacy of Xience/Promus Versus Cypher to Reduce Late Loss After Stenting) registry was a dedicated second-generation DES registry that enrolled all-comers treated with >1 everolimus-eluting stent (Xience V or Promus) without any exclusion criteria during the period of 2008 through 2010.12 Therefore, the pooled sample size was 9299 lesions in 6811 patients enrolled from 50 participating centers in South Korea. The study protocol was approved by the ethics committee at each participating center and was conducted according to the principles of the Declaration of Helsinki. All patients provided written informed consent at enrollment to each trial or registry.

Interventional Procedures and Follow-Up

Percutaneous coronary intervention was performed according to standard techniques in line with current guidelines. Unless there was an undisputed reason for discontinuing dual antiplatelet therapy, all patients were advised to take aspirin (at least 100 mg/d) indefinitely and clopidogrel (75 mg/d) for the duration determined by the protocol of each study. After the index procedure, clinical follow-ups were performed at 1, 3, 6 or 9, 13, 24 and 36 months. Among the pooled population, 448 patients (6.6% of 6811 patients) were lost to follow-up. However, the vital status of these patients was completely assessed by using unique individual identification numbers of the Korean nationwide healthcare system. The clinical events that occurred within 3-year follow-up were analyzed, and the median follow-up duration was 1096 days (interquartile range, 1068–1114 days).

Angiographic Analysis and Definition of LSD

Angiographic analysis of procedures was performed in all available and readable cases to identify LSD. Quantitative coronary analysis of angiographic images was performed at a central core laboratory. The Cardiovascular Angiography Analysis System 5.7 QCA system (Pie Medical Imaging, Maastricht, the Netherlands) was used for automated contour detection and quantification. We excluded 1939 lesions that lacked required angiographic images to accurately measure stent length or were unassessable because of stent overlap. First, a quantitative analysis was done to assess the presence of angiographically overt LSD. Angiographically overt LSD was defined as any inconsistency in the radiodensity pattern along the length of the stent or other gross irregularities or deformities. To quantitatively assess stent deformation, the relative and absolute differences of stent length between immediate post-deployment and final post-procedure were measured. Absolute difference >3 mm or relative difference >20% was defined as QCA-based LSD. After thorough review of all cases that were initially classified as LSD group, 10 cases of foreshortening or those did not use the same projection angle between immediate post-deployment...
and final post-procedure were excluded. The final analysis included 5871 patients with 7350 treated lesions (Figure 1).

Clinical End Points
The key clinical outcome target lesion failure (TLF; a composite of cardiac death, target vessel-related myocardial infarction, or a clinically indicated target lesion revascularization), and patient-oriented composite outcome (POCO; a composite of all-cause mortality, any myocardial infarction, and any repeat revascularization). A revascularization was considered clinically driven if angiography during follow-up showed a diameter stenosis ≥50% with at least one of the following: (1) history of recurrent angina pectoris, presumably related to the target vessel; (2) objective signs of ischemia at rest or during exercise test by electrocardiogram, presumably related to target vessel; (3) fractional flow reserve ≤0.80; or (4) a target lesion revascularization with a diameter stenosis ≥70% even in the absence of aforementioned ischemic signs or symptoms, according to the Academic Research Consortium definitions.13 Other clinical outcomes included individual components of TLF and POCO, and stent thrombosis defined as definite or probable according to the Academic Research Consortium definitions. The independent clinical event adjudication committee, whose members were unaware of study group assignments, assessed all of clinical end points.

Statistical Analysis
Continuous variables were presented as mean and SD and compared using the Student t test. Categorical variables were presented as counts and percentages and compared using the χ² test. Difference between immediate postdeployment and final postprocedural stent lengths among 3 groups by stent platform was assessed by analysis of variance method and Student t test, as appropriate. Multivariable logistic regression analysis with stepwise selection method was used to identify clinical, lesion, stent-related, and procedural factors independently associated with the occurrence of QCA-based LSD. Variables used in adjustment were listed as follows: age, sex, diabetes mellitus, dyslipidemia, angiographic disease extent, left main lesion, ostial lesion, severe calcification, type B2 or C lesion, stent platform design (offset peak to peak, peak to peak, or peak to valley platform), adjunctive balloon angioplasty, IVUS or optical coherence tomography use, bifurcation treatment with side branch stenting or balloononing, and additional downstream intervention of a distal lesion. Variables were selected if they were significantly different between 2 groups (P value <0.1), or if they had clinical relevance. Results of regression were presented as odds ratio with 95% confidence intervals, and the Firth penalized likelihood method was used to calculate odds ratio and 95% confidence interval for comparison groups with no events in the reference group.14 Cumulative event rates were estimated using the Kaplan–Meier method. Hazard ratios with 95% confidence interval were estimated using the marginal Cox proportional hazards method. The assumption of proportionality was examined using log-minus-log plot for each outcome. As angiographic data were composed of characteristics per lesion, a marginal regression model approach was used to adjust the effect of correlation between multiple lesions in 1 patient.15 The consistency of effects of secondary device use on LSD was assessed using Cox regression models with tests for interaction in various subgroups by lesion location (left main artery or ostium), complexity of lesion (angulation, severe calcification, type B2 or C), and type of stent platform design. All P values were 2-sided, and a value <0.05 was considered statistically significant. Statistical analyses were performed using Stata statistical software release 12 (StataCorp, College Station, TX) and SPSS statistical package version 19.0 (SPSS Inc, Chicago, IL).

Results
Baseline Characteristics
Out of a total of 7350 lesions, 82 cases (1.12%) in 81 patients with QCA-based LSD were identified. Baseline demographic features, cardiovascular risk factors, and working diagnosis...
The proportion of multi-peak-to-peak, and peak-to-valley designs in Figure 4 according to the 3 types of stent platform: offset peak-to-peak, peak-to-peak, and peak-to-valley was presented. The QCA-based stent length difference between immediate post-deployment and final post-procedure are shown to be evenly distributed (Table 4).

Change of Stent Length During Procedures by Platform Designs

The QCA-based stent length difference between immediate post-deployment and final post-procedure are shown to be evenly distributed (Table 4). Among the procedural factors, the proportion of those who used any secondary device post-stenting, including post-dilatation, IVUS, side branch ballooning or provisional stenting, and additional downstream intervention, was significantly higher in LSD group. The prevalence of lesion- or procedure-related risk factors associated with the occurrence of LSD was summarized in Figure 2.

Relative ratio and absolute differences, there were no significant differences among the 3 groups (for ratio, analysis of variance P=0.927; for absolute difference, analysis of variance P=0.679). The mean values of stent length ratio were between 0.999 and 1.000, and mean values of absolute difference varied within a very narrow range (−0.022 mm in offset peak-to-peak design, −0.059 mm in peak-to-peak design, −0.044 mm in peak-to-valley design, −0.059 mm in peak-to-peak design, −0.044 mm in peak-to-valley design). Representative cases of LSD in 3 different types of stent platforms are presented in Figure 4 and described in more detail in Figures I through III in the Data Supplement.

Factors Associated With the Occurrence of QCA-Based LSD

Factors independently associated with the occurrence of QCA-based LSD were identified by multivariable regression (Table 3). Left main lesion and ostial lesion, bifurcation treatment with provisional side branch stenting or ballooning, additional downstream intervention, IVUS use, and adjunctive post-dilatation were independent predictors of QCA-based LSD. Stent design was not associated with QCA-based LSD. The effect of any secondary device use on the occurrence of QCA-based LSD was not associated with QCA-based LSD. The effect of any secondary device use on the occurrence of QCA-based LSD was not associated with QCA, quantitative coronary angiography.

Long-Term Outcomes According to the Presence of QCA-Based LSD

The 3-year clinical outcomes were not significantly different between those with and without QCA-based LSD (Table 4; Figure IV in the Data Supplement). Differences in cumulative incidence of TLF, POCO, and individual components of lesion- or procedure-related risk factors associated with the occurrence of LSD were independent predictors of QCA-based LSD. Stent design was not associated with QCA-based LSD. The effect of any secondary device use on the occurrence of QCA-based LSD was not associated with QCA-based LSD. The effect of any secondary device use on the occurrence of QCA-based LSD was not associated with QCA, quantitative coronary angiography.

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of composite outcomes did not reach statistical significance. However, there was a consistent trend toward a numerically higher incidence of all clinical outcomes in the QCA-based LSD group (TLF rate: 8.97% versus 5.88%, \( P = 0.399 \); POCO rate: 20.15% versus 13.50%, \( P = 0.101 \); any repeat revascularization rate: 14.41% versus 8.35%, \( P = 0.105 \)).

Figure 2. Prevalence of risk factors associated with the occurrence of longitudinal stent deformation (LSD). Prevalence of (A) lesion-related and (B) procedure-related risk factors in 82 cases of LSD are presented. IVUS indicates intravascular ultrasound; OCT, optical coherence tomography; PCI, percutaneous coronary intervention; and POBA, plain old balloon angioplasty.

Figure 3. Comparison of ratio or difference between immediate post-deployment stent length and final stent length by quantitative coronary angiography (QCA), according to stent platforms. A, Relative ratio and (B) absolute difference between stent lengths of immediate post-deployment and final post-procedure are presented. The box plots show the first quartile (Q1) and third quartile (Q3) range of the data, and whiskers cover the 2.5 to 97.5 percentile range of the data. Data falling outside the 2.5 to 97.5 percentile range are plotted as outliers.
Incidence and Characteristics of Angiographically Overt LSD Cases

A total of 9 cases (7 in offset peak-to-peak design [Promus Element]; 2 in peak-to-valley design [Promus or Xience V]) of angiographically overt LSD were identified (Figure 6). All cases had secondary device use after index stenting. Only 1 case required additional stenting for LSD and 1 patient died of noncardiac cause during the follow-up period (Table 5).

Discussion

This study systematically examined effects of clinical, lesion, and procedural characteristics on the occurrence of LSD in 3 different contemporary DES platforms. We also reported the incidence of LSD using quantitative methods and its long-term clinical implications. In this patient-level analysis of a multicenter second-generation pooled DES cohort composed of 7350 lesions in 5871 patients, any use of secondary device after stenting was the single most important independent factor related with QCA-based LSD, regardless of the type of stent or other lesion factors. Although the prognostic impact of QCA-based LSD on 3-year clinical outcomes was statistically insignificant, there were numerically higher rates of TLF, POCO, and any repeat revascularization in the QCA-based LSD group.

LSD Detected by Dedicated QCA Analysis

Studies are limited that report incidence of LSD evaluated in a well-established cohort. Previous studies were anecdotal, reporting only angiographically overt LSD cases, most of which occurred in the Promus Element stents.1-3,16 The incidence of LSD was likely underreported given the difficulty in detecting LSD with visual examination. Although Kereiakes et al17 performed a pooled analysis of PERSEUS (Prospective Evaluation in a Randomized Trial of the Safety and Efficacy of the TAXUS Element Paclitaxel-Eluting Coronary Stent System) and PLATINUM trials (A Prospective, Randomized, Multicenter Trial to Assess an Everolimus-Eluting Coronary Stent System for the Treatment of Up to Two de Novo Coronary Artery Lesions) with core laboratory QCA analysis, it failed to detect any LSD case in 2403 stents. This might be explained by the highly selected population in the trials, excluding high-risk patients and complex lesion subsets.

Table 3. Multivariable Regression Analysis for the Independent Factors Associated With QCA-Based LSD

<table>
<thead>
<tr>
<th>Odds Ratio (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesion factors</td>
<td></td>
</tr>
<tr>
<td>Left main lesion</td>
<td>3.272 (1.608–6.659)</td>
</tr>
<tr>
<td>Ostial lesion</td>
<td>1.940 (1.072–3.514)</td>
</tr>
<tr>
<td>Peak-to-peak stent platform (vs offset peak-to-peak)</td>
<td>1.520 (0.771–2.995)</td>
</tr>
<tr>
<td>Peak-to-valley stent platform (vs offset peak-to-peak)</td>
<td>0.766 (0.438–1.342)</td>
</tr>
<tr>
<td>Stent-related factors</td>
<td></td>
</tr>
<tr>
<td>Procedural factors</td>
<td></td>
</tr>
<tr>
<td>Bifurcation treatment with SB stenting</td>
<td>10.55 (5.372–20.72)</td>
</tr>
<tr>
<td>Additional downstream PCI</td>
<td>3.830 (2.384–6.154)</td>
</tr>
<tr>
<td>IVUS or OCT use</td>
<td>3.291 (1.992–5.438)</td>
</tr>
<tr>
<td>Adjunctive POBA</td>
<td>3.287 (1.268–8.523)</td>
</tr>
<tr>
<td>Bifurcation treatment with SB ballooning</td>
<td>2.215 (1.243–3.944)</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; IVUS, intravascular ultrasound; OCT, optical coherence tomography; LSD, longitudinal stent deformation; PCI, percutaneous coronary intervention; POBA, plain old balloon angioplasty; QCA, quantitative coronary angiography; and SB, side branch.
We systematically examined enriched real-world population with high-risk profiles, using a dedicated QCA analysis with prespecified definition of LSD. The angiographically overt LSD occurred in only 9 of 7350 cases (0.12%) in this study, which is concordant with the scarcity with which this phenomenon occurs in routine clinical practice. However, by uniformly measuring the stent length before, immediately after implantation, and after the final procedure, the incidence of QCA-based LSD was ≤1.12%. Such a high incidence suggests that QCA-based LSD, which can be missed by simple visual assessment, still occurs in contemporary practice. Interestingly, the angiographically overt LSD showed the highest incidence in the Promus Element stent (7 of 9 cases), but the occurrence of QCA-based LSD was not significantly different among the various type of stent platform. A quantitative definition of LSD by QCA could have detected hidden LSD cases in less radio-opaque stents, such as Xience, Resolute, or Biomatrix, which were difficult to detect via visual examination of angiography.18 In line with these results, an IVUS analysis also reported that the incidence of LSD was similar among various types of second-generation DES.19 These findings suggest that factors other than the stent platform itself, such as lesion or procedural factors, may have had a greater impact on the occurrence of QCA-based LSD.

Procedural Insights on the Mechanism of LSD
The multivariable analysis showed that provisional side branch stenting or ballooning, additional downstream intervention, and use of imaging device such as IVUS were independently associated with QCA-based LSD. Similar studies supporting our results have been reported. Arnous et al4 showed that multiple stenting, and use of Guideliner, and postdilation balloon were independent predictors of LSD. In another study, LSD was significantly associated with the use of extra support guiding catheter or guidewire, or a passage of a second stent.5 In addition, aggressive guide catheter manipulation, use of imaging devices including IVUS or optical coherence tomography, and multiple ballooning have been suggested as factors associated with LSD occurrence.2,3,9,19,20

Our subgroup analysis also showed that any use of secondary devices was the single most important independent factor predicting QCA-based LSD, regardless of the lesion or stent factors. If the proximal portion of the stent is not completely apposed to the vessel wall, frequent use of secondary devices may increase the chance of contact with unsupported struts especially when wire bias exists resulting in the occurrence of LSD.4 Therefore, appropriate stent sizing and apposition, especially in the proximal portion of the stent before introduction of secondary devices, may be important. Careful manipulation of procedural devices including guiding catheters, daughter-in-mother backup support catheters, IVUS, and adjunctive balloons may reduce the occurrence of LSD.

Also, stents located in the ostium or left main coronary artery are prone to LSD by longitudinal forces, because of frequent malapposition of stents by undersizing, and because of recurrent contact with the guiding catheter which goes in and out during various device insertion and pullback, especially when there is poor alignment with the coronary artery.3,4

Clinical Implications
Although the overall impact of the QCA-based LSD on 3-year outcomes was not statistically significant, the rates of all clinical end points including TLF, POCO, and repeat revascularization were numerically higher in the QCA-based LSD group. A greater number of patients could have resulted in statistical significance. Therefore, a larger database to confirm the long-term clinical implication is needed. To date, the relationship...
between LSD and future adverse events has been uncertain. Recently, Sen et al\(^1\) reported 2-year results of the DUTCH PEERS (Durable Polymer-Based Stent Challenge of Promus Element Versus Resolute Integrity; TWENTE II [Randomized Multicenter Trial in All Comers Population Treated Within Eastern Netherlands-II]) trial, which presented that none of 9 patients with angiographically overt LSD had experienced an adverse clinical event. However, most of previous studies have reported conflicting results,\(^4,5,22\) and these have been mostly single-center reports, did not apply any precise diagnostic criteria for LSD, and did not evaluate events beyond 1 year.

Theoretically, LSD could result in the stent malapposition, incomplete plaque coverage, and reduced drug delivery. This could lead to in-stent restenosis and stent thrombosis,\(^2,23\) which may account for the nominally higher incidence of clinical outcomes observed in our study. However, most of previous studies have reported conflicting results,\(^4,5,22\) and these have been mostly single-center reports, did not apply any precise diagnostic criteria for LSD, and did not evaluate events beyond 1 year.

Study Limitations
The study population was heterogeneous as a merged cohort composed of 2 different studies was assessed. We tried to complement the heterogeneity with comprehensive patient-level pooling. A substantial proportion of patients who were lost to follow-up could be also a limitation of the study. However, the vital status of these patients was completely assessed as previously described. The study cohort only included 3 major stent platforms and not all of the commercially available diverse second-generation DES that are in clinical use. The effect of guiding catheters could not be assessed, as the cohorts did not clearly document the type of guiding catheters used during the procedure. Because our QCA analysis was based on the angiographic view with the most severe lumen obstruction, it has inherent limitations in assessing LSD and measuring stent lengths. And it can be assumed that true blinding would be difficult because of the morphological difference according to stent types. The lack of precise definition of stent edges and the potential for stent foreshortening in certain views could also limit the accuracy of QCA analysis. Further, the QCA analysis might be affected by the cases with severe

### Table 4. Clinical Outcomes According to the Presence of QCA-Based LSD After 3-Year Follow-Up

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Without LSD (n=5790)</th>
<th>With LSD (n=81)</th>
<th>Hazard Ratio (95% CI) Without LSD as Reference</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause death</td>
<td>5.27% (278)</td>
<td>7.55% (6)</td>
<td>1.572 (0.700–3.529)</td>
<td>0.273</td>
</tr>
<tr>
<td>Cardiac death</td>
<td>3.04% (158)</td>
<td>3.85% (3)</td>
<td>1.383 (0.441–4.335)</td>
<td>0.578</td>
</tr>
<tr>
<td>Any myocardial infarction</td>
<td>1.20% (63)</td>
<td>1.31% (1)</td>
<td>1.160 (0.161–8.362)</td>
<td>0.883</td>
</tr>
<tr>
<td>MI because of ST</td>
<td>0.26% (13)</td>
<td>0.00% (0)</td>
<td>0.372 (0.020–6.972)</td>
<td>0.509</td>
</tr>
<tr>
<td>MI in target vessel</td>
<td>0.54% (29)</td>
<td>1.31% (1)</td>
<td>2.520 (0.343–18.50)</td>
<td>0.363</td>
</tr>
<tr>
<td>Any repeat revascularization</td>
<td>8.35% (445)</td>
<td>14.41% (10)</td>
<td>1.679 (0.897–3.142)</td>
<td>0.105</td>
</tr>
<tr>
<td>Target lesion revascularization</td>
<td>2.66% (139)</td>
<td>4.00% (2)</td>
<td>1.041 (0.258–4.205)</td>
<td>0.955</td>
</tr>
<tr>
<td>Target vessel revascularization</td>
<td>3.34% (178)</td>
<td>4.05% (2)</td>
<td>0.815 (0.202–3.285)</td>
<td>0.774</td>
</tr>
<tr>
<td>Definite or probable ST</td>
<td>0.42% (22)</td>
<td>0.00% (0)</td>
<td>0.619 (0.035–10.87)</td>
<td>0.743</td>
</tr>
<tr>
<td>Target lesion failure</td>
<td>5.88% (310)</td>
<td>8.97% (6)</td>
<td>1.415 (0.631–3.175)</td>
<td>0.399</td>
</tr>
<tr>
<td>Patient-oriented composite outcomes</td>
<td>13.50% (728)</td>
<td>20.15% (15)</td>
<td>1.533 (0.920–2.557)</td>
<td>0.101</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; LSD, longitudinal stent deformation; MI, myocardial infarction; QCA, quantitative coronary angiography; and ST, stent thrombosis.

### Figure 6. Comparative incidence of quantitative coronary angiography (QCA)-based vs angiographically overt longitudinal stent deformation (LSD) by stent platforms. Proportions of QCA-based and angiographically overt LSD are presented.
calcification and the different visibility among various stent types. However, we carefully selected lesions which were appropriate to be analyzed and excluded cases with unreliable angiographic images including foreshortening. We also used specialized QCA technicians who were blinded to the purpose of the study, and all suspected LSD cases were reviewed by an independent group of physicians. Moreover, we think that any potential errors in measurement because of these issues would have been evenly distributed considering large number of lesions analyzed from a large cohort.

Conclusions
Although uncommon, LSD occurs in the currently used second-generation DES, regardless of the type of stent platform. Additional downstream imaging and procedures were strongly related with the LSD, independent with lesion factors or stent types. Careful manipulation of secondary imaging or procedure devices, as well as adequate stent apposition, may decrease the incidence of LSD.

Sources of Funding
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Disclosures
None.

References

### Table 5. Summary of Clinical and Procedural Characteristics of 9 Cases of Angiographically Overt LSD

<table>
<thead>
<tr>
<th>Patent No.</th>
<th>Age/Sex</th>
<th>Lesion Location</th>
<th>Stent Size, mm</th>
<th>SB Stenting</th>
<th>SB POBA</th>
<th>IVUS use</th>
<th>Additional Downstream PCI</th>
<th>Any Secondary Device Use</th>
<th>Additional Stenting Required</th>
<th>Future Clinical Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>59/M</td>
<td>LM</td>
<td>P-E 3.0×28</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case 2</td>
<td>81/F</td>
<td>mLAD</td>
<td>P-E 3.0×24</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Case 3</td>
<td>61/M</td>
<td>LM</td>
<td>P-E 3.0×28</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case 4</td>
<td>72/M</td>
<td>pRCA</td>
<td>P-E 3.0×28</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case 5</td>
<td>50/F</td>
<td>mLAD</td>
<td>P-E 4.0×28</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case 6</td>
<td>68/M</td>
<td>mLAD</td>
<td>P-E 3.0×28</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case 7</td>
<td>39/M</td>
<td>pLAD</td>
<td>P-E 4.0×28</td>
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<td>No</td>
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</tr>
<tr>
<td>Case 8</td>
<td>73/M</td>
<td>pLAD</td>
<td>X-V 4.0×28</td>
<td>No</td>
<td>No</td>
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<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case 9</td>
<td>63/F</td>
<td>mLAD</td>
<td>X-V 3.0×15</td>
<td>No</td>
<td>No</td>
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<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

IVUS indicates intravascular ultrasound; LAD, left anterior descending artery; LM, left main; LSD, longitudinal stent deformation; mLAD, mid left anterior descending artery; PCI, percutaneous coronary intervention; pLAD, proximal left anterior descending artery; POBA, plain old balloon angioplasty; pRCA, proximal right coronary artery; RCA, right coronary artery; and SB, stent thrombosis.

Risk Factors of Longitudinal Stent Deformation


Predictors and Long-Term Clinical Outcome of Longitudinal Stent Deformation: Insights From Pooled Analysis of Korean Multicenter Drug-Eluting Stent Cohort


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Supplemental Material

Predictors and Long-Term Clinical Outcome of Longitudinal Stent Deformation: Insights from Pooled Analysis of Korean Multicenter Drug-Eluting Stent Cohort

Supplementary Figure Legends

Supplementary Figure 1. A Representative Case of Longitudinal Stent Deformation with Shortening in Promus Element Stent

(A-C) A Promus Element stent (red dotted lines, 3.5 × 14 mm) was implanted in the diffuse lesion of middle portion of LAD. (D) An angiographically-overt LSD occurred (white arrowhead) after the IVUS catheter which got stuck during withdrawal. (E) Additional post-dilation was done, and (F) final angiographic image showed patent stent with TIMI grade 3 flow. The patient underwent 3-year follow-up without any clinical event.

Abbreviations: IVUS, intravascular ultrasound; LAD, left anterior descending artery; LSD, longitudinal stent deformation; TIMI, Thrombolysis in Myocardial Infarction.

Supplementary Figure 2. A Representative Case of Longitudinal Stent Deformation with Shortening in Xience V Stent

(A-C) A Xience V stent (red dotted lines, 3.0 × 15 mm) was deployed in the diffuse lesion of
middle portion of LAD. (D) Additional side branch balloon angioplasty with kissing ballooning for the bifurcation lesion was followed. (E) A QCA-based LSD was retrospectively detected, which occurred after the procedure (white arrow, absolute decrease of 3.36 mm and relative decrease of 25.5%). (F) The final angiographic image showed patent stent with TIMI grade 3 flow. The patient underwent 3-year follow-up without any clinical event.

Abbreviations: QCA, quantitative coronary angiography, otherwise as in Supplementary Figure 1.

Supplementary Figure 3. A Representative Case of Longitudinal Stent Deformation with Shortening in Endeavor Resolute Stent

(A and B) An Endeavor Resolute stent (red dotted lines, 3.5 × 38 mm) was deployed in the diffuse lesion of proximal LAD. (C) Additional post-dilation and (D) IVUS evaluation was subsequently followed. (E) An eccentric LSD with shortening of proximal edge occurred after the procedure (white arrow, absolute decrease of 5.11 mm and relative decrease of 16.7%). (F) The final angiographic image showed patent stent with TIMI grade 3 flow. The patient underwent 3-year follow-up without any clinical event.

Abbreviations: QCA, quantitative coronary angiography, otherwise as in Supplementary Figure 1.

Supplementary Figure 4. Cumulative Incidence of TLF and POCO According to
Occurrence of LSD

Kaplan-Meier curves are shown to compare (A) target lesion failure and (B) patient-oriented composite outcomes between LSD and non-LSD group. Hazard ratios with 95% confidence intervals are presented.

Abbreviations: CI, confidence interval; HR, hazard ratio; LSD, longitudinal stent deformation; POCO, patient-oriented composite outcomes; TLF, target lesion failure.
Supplementary Figure 1. A Representative Case of Longitudinal Stent Deformation with Shortening in Promus Element Stent
Supplementary Figure 2. A Representative Case of Longitudinal Stent Deformation with Shortening in Xience V Stent
Supplementary Figure 3. A Representative Case of Longitudinal Stent Deformation with Shortening in Endeavor Resolute Stent
### A. Target Lesion Failure

HR 1.42 (95% CI 0.63 - 3.18), \( p = 0.399 \)

Log rank \( p = 0.397 \), Breslow \( p = 0.361 \)

### B. Patient-Oriented Composite Outcomes

HR 1.53 (95% CI 0.92 - 2.56), \( p = 0.101 \)

Log rank \( p = 0.099 \), Breslow \( p = 0.084 \)