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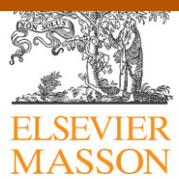

REVIEW

Intravascular ultrasound-guided percutaneous coronary interventions in contemporary practice

Angioplastie percutanée guidée par l'échographie endovasculaire en pratique

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Summary Intravascular ultrasound imaging has been pivotal in the understanding of coronary artery disease and the development of percutaneous coronary intervention. The ability to analyse vessel walls and measure atherosclerotic lesions more accurately has enabled the field of invasive cardiology to overcome the limits of angiography. In fact, intravascular ultrasound measurements correlate with functional measurement of coronary blood flow, as a result interest in their use for the diagnosis of lesion severity in ambiguous lesions and for left main trunk analysis has grown. On the interventional side, intravascular ultrasound is used to determine the major predictors of restenosis and stent thrombosis, which are the main pitfalls of percutaneous coronary intervention. In the bare-metal stent era, intravascular ultrasound-guided percutaneous coronary intervention was associated with a reduction in restenosis rates because it enabled identification and treatment of the risk factors for complications. Although drug-eluting stents have provided a great technological advance in percutaneous coronary intervention, further reducing the rate of in-stent restenosis, they have not abolished restenosis completely; intravascular ultrasound has also been used in this setting to identify the mechanisms responsible for drug-eluting stent restenosis. As in the bare-metal stent era, identification of the predictors of restenosis and stent thrombosis and their subsequent treatment may offer the promise of improved outcome in the drug-eluting stent era. This review focuses on the potential benefit of intravascular ultrasound-guided percutaneous coronary intervention with regard to restenosis and stent thrombosis in the bare-metal stent and drug-eluting stent eras.

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MOTS CLÉS
Échographie endovasculaire ;
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Endoprothèse, stent coronaire

Résumé L'imagerie par échographie endovasculaire a joué un rôle déterminant dans la compréhension de la coronaropathie et dans le développement de l'angioplastie coronaire. La possibilité d'analyser la paroi vasculaire et de mesurer de façon plus précise les lésions athéromateuses ont permis à la cardiologie interventionnelle de dépasser les limites de l'angiographie. En effet, les mesures réalisées à l'aide de l'échographie endocoronaire sont corrélées avec la mesure du flux sanguin coronaire et présente donc un intérêt particulier pour la mesure de la sévérité des lésions considérées comme angiographiquement ambiguës ou pour l'évaluation des troncs coronaire gauches. Du point de vue interventionnelle, l'échographie endocoronaire a permis d'identifier les principaux prédicteurs de resténose et de thrombose de stent qui représentent les deux principales limitations de l'angioplastie coronaire. Du fait de sa capacité à identifier les facteurs de risques de ces complications et de permettre leur traitement, l'angioplastie guidée par l'échographie endocoronaire à l'ère des stents métalliques était associée à une réduction de la fréquence de la resténose. Les stents actifs représentent une innovation technologique très importante en angioplastie, permettant de réduire de considérablement la fréquence de la resténose. Cependant ils ne l'ont pas aboli et l'échographie endocoronaire à une nouvelle fois permis d'identifier les mécanismes responsables de cette complication lors de l'utilisation de ces stents dits actifs. Tout comme dans l'ère des stents métalliques, l'identification de ces prédicteurs et leur traitement dans l'ère des stents actifs pourraient offrir une occasion d'améliorer le pronostic de l'angioplastie coronaire. Cette revue vise à résumer les données relatives au bénéfice potentiel de l'utilisation de l'échographie endocoronaire pour guider l'angioplastie coronaire sur la resténose et la thrombose de stent dans l'ère des stents métalliques et ceux des stents actifs.

Abbreviations

CAD	coronary artery disease
BMS	bare-metal stents
DES	drug-eluting stents
IVUS	intravascular ultrasound
MACE	major adverse cardiac events
MLA	minimum luminal stent area
MLD	minimum luminal diameter
PCI	percutaneous coronary intervention
PES	paclitaxel-eluting stents
SES	sirolimus-eluting stents
ST	stent thrombosis
TLR	target lesion revascularization

Introduction

IVUS has played a critical role in the development of interventional cardiology. The superior imaging capabilities of IVUS compared with angiography have increased our understanding of the pathophysiology of coronary atherosclerosis tremendously and have enabled significant refinements to be made to the diagnosis and percutaneous treatment of CAD. More than 10 years after its first use in humans, IVUS is still a key research tool in the field of medical treatment and percutaneous revascularization for CAD patients. Interest in IVUS has also grown in clinical practice, for both diagnosis and intervention. Indeed, because of its higher spatial resolution and the fact that it enables analysis of the insides of vessel walls, IVUS provides a more reproducible and accurate measurement of disease severity than angiography [1]. IVUS measurements have been correlated with functional flow data, which has allowed this anatomical device to be used to diagnose flow-limiting lesions accurately [2]. Furthermore, in the era of BMS, IVUS helped to implement stent delivery procedures and optimize implantation [3]. Studies supported a potential benefit of IVUS-guided PCI compared with angiography-guided PCI in this era, through a reduction in restenosis, although this remains controversial [4—10].

The advent of DES, which decreased the rate of in-stent restenosis dramatically, may reduce the potential impact of IVUS [11]. However, intimal hyperplasia is not abolished by the use of DES and has been linked to stent under-expansion, malapposition and incomplete lesion coverage by IVUS [12]. In addition, recent data suggest that IVUS use may prevent ST after implantation of DES [13]. Furthermore, studies have shown that in a high proportion of cases of early ST, IVUS enabled identification of a mechanical abnormality that may have been responsible for the event [14]. Whether the identification and subsequent treatment of the risk factors for in-stent restenosis and early ST make IVUS-guided PCI clinically beneficial compared with angiography-guided PCI in the DES era remains a topic for debate. We aim to review the potential clinical benefit of IVUS-guided PCI in the DES era by assessing available data.

IVUS as a diagnostic tool

Despite being the ''gold standard'' for assessing and quantifying CAD, coronary angiography only provides a luminography, with little or no data on the vessel's wall, thus limiting the ability to detect atheroma and determine lesion severity. IVUS provides information about vessel walls and the pathological process taking place in CAD. Consistently,

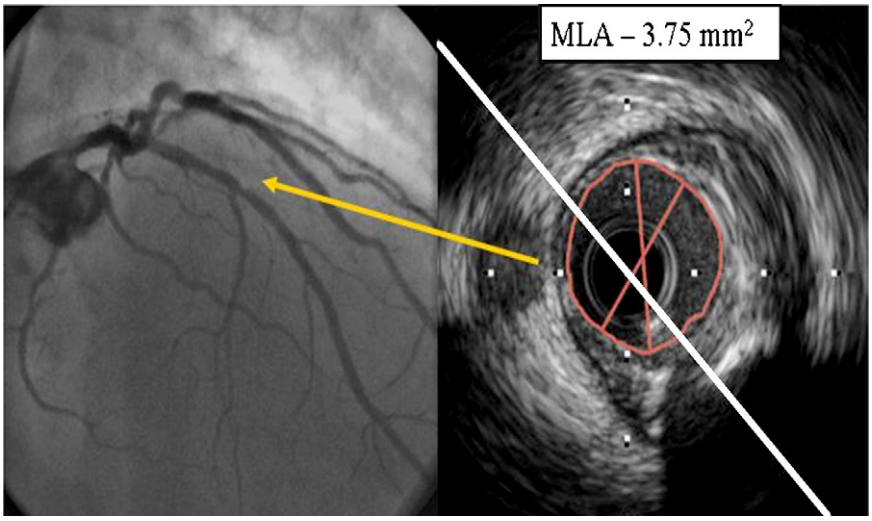


Figure 1. Illustration of the superiority of IVUS over angiography in terms of assessing the severity of coronary lesions. Left panel: an ambiguous lesion with less than 50% stenosis. Right panel: IVUS measurement of the same lesion demonstrates a flow-limiting lesion.

studies have shown large inter- and intra-observer variability in the assessment of lesion severity based on coronary angiography, even when quantitative coronary angiography measurements were used [15,16]. In contrast, IVUS imaging technology has a high spatial resolution (100—200 μm compared with 0.15—0.25 mm for angiography), which allows accurate measurement of vessel dimension and analysis of vessel walls, including plaque burden, calcifications and fibrotic tissue [17,18]. Furthermore, studies have shown a strong correlation between IVUS measurements and physiological flow assessment using fractional flow reserve evaluation [2]. IVUS can therefore be used reliably and accurately to determine lesion severity and functional significance. These properties are critical in high-risk lesions such as left main trunk lesions, where angiography has had mixed results [19,20]. It must be acknowledged, however, that this correlation is limited to large arteries (diameter > 3 mm^2). In addition, studies have shown consistently that IVUS can improve the assessment of angiography-intermediate lesions greatly, by discriminating between those that require intervention and those that do not (Fig. 1) [21].

IVUS as an interventional device

As discussed previously, IVUS has a high spatial resolution and, together with lumen imaging, facilitates the assessment of a vessel's wall. These abilities may be of great value in guiding PCI. In theory, stent implantation could be optimized with IVUS guidance to prevent the mechanical issues associated with restenosis and ST.

IVUS to reduce restenosis

Bare-metal stent era

Suboptimal stent expansion results in a reduced stent cross-sectional area on IVUS and is a stronger predictor of restenosis after implantation of BMS than any angiographic variable [22]. In light of these findings, several studies aimed to determine whether optimizing stent implantation using IVUS is clinically beneficial because of a resultant reduction in the rate of in-stent restenosis.

The first study reported was a multicentre comparison of IVUS-guided and angiography-guided PCI for matched lesions (n = 173 and 173, respectively) [4]. A benefit was seen in the ''early phase'' of the study when the IVUS group had more aggressive post-dilation with large balloons (six-month angiographic restenosis 9.2% vs 22.3%; p = 0.04). However, no difference was seen in six-month angiographic restenosis in the ''late phase'' of the study, when a less aggressive post-dilatation approach was used because of a change in the definition of optimal stent expansion (22.7% vs 23.7%; p = 1.0). Although this was a non-randomized, observational study, it provided the first evidence that IVUS-guided stent implantation may result in a different treatment strategy and improved clinical outcomes.

Thereafter, small prospective studies confirmed the superiority of IVUS guidance over angiographic guidance in PCI, with a reduced restenosis rate at six-month angiographic follow-up. The REStenosis after IVUS-guided Stenting (RESIST) study was the first randomized trial to investigate the impact of IVUS-guided PCI on outcome [10]. Although underpowered, with only 155 patients included, this study showed a trend toward less angiographic restenosis at six-month follow-up in the IVUS-guided PCI group. Moreover, IVUS use resulted in a larger stent lumen cross-sectional area, which persisted at six-month follow-up. This study supported the hypothesis that IVUS-guided PCI is potentially beneficial with regard to in-stent restenosis. These results were confirmed by Blasini et al., who showed a significant reduction in the rate of angiographic restenosis at six months with IVUS (20.9% vs 29.9%; p = 0.03); the difference was particularly evident in patients who fulfilled IVUS criteria for optimal stent placement compared with those who did not (13.5% vs 28.3%; p = 0.04) [5].

After these promising early reports, some larger studies were performed. The Can Routine Ultrasound Influence Stent Expansion (CRUISE) study was a prospective, multicentre, case-control study with 499 patients [6]. The immediate MLD and MLA obtained by quantitative coronary angiogra-

phy were significantly larger in the IVUS group. Improved stent expansion with IVUS guidance resulted in a clinical benefit at nine-month follow-up in terms of target vessel revascularization (8.5% vs 15.3%; $p < 0.05$). Despite the lack of randomization, this study was — at that time — the largest report comparing IVUS-guided stent implantation with angiography-guided stent implantation and confirmed the hypothesis that stent implantation optimization with IVUS guidance is associated with a clinical benefit in terms of reducing revascularization without impacting death or myocardial infarction. However, despite great interest in IVUS-guided PCI, these preliminary studies were either not randomized or had a small sample size.

The OPTimization with IVUS to reduce stent restenosis (OPTICUS) study was a large, randomized study that aimed to determine if IVUS guidance could reduce the rate of in-stent restenosis [7]. The primary endpoints were angiographic restenosis rate, MLD and percentage stenosis at six months, while the secondary endpoint was the rate of MACE at six and 12 months. This study failed to demonstrate a significant difference in any of the prespecified endpoints. The investigators concluded that there was no advantage to IVUS-guided BMS implantation. A lack of clinical benefit with IVUS-guided PCI was also observed in a retrospective analysis performed by the Mayo Clinic [9]. In the wake of the controversy surrounding the potential benefit of IVUS after this disappointing study, the device failed to gain wide acceptance in clinical practice.

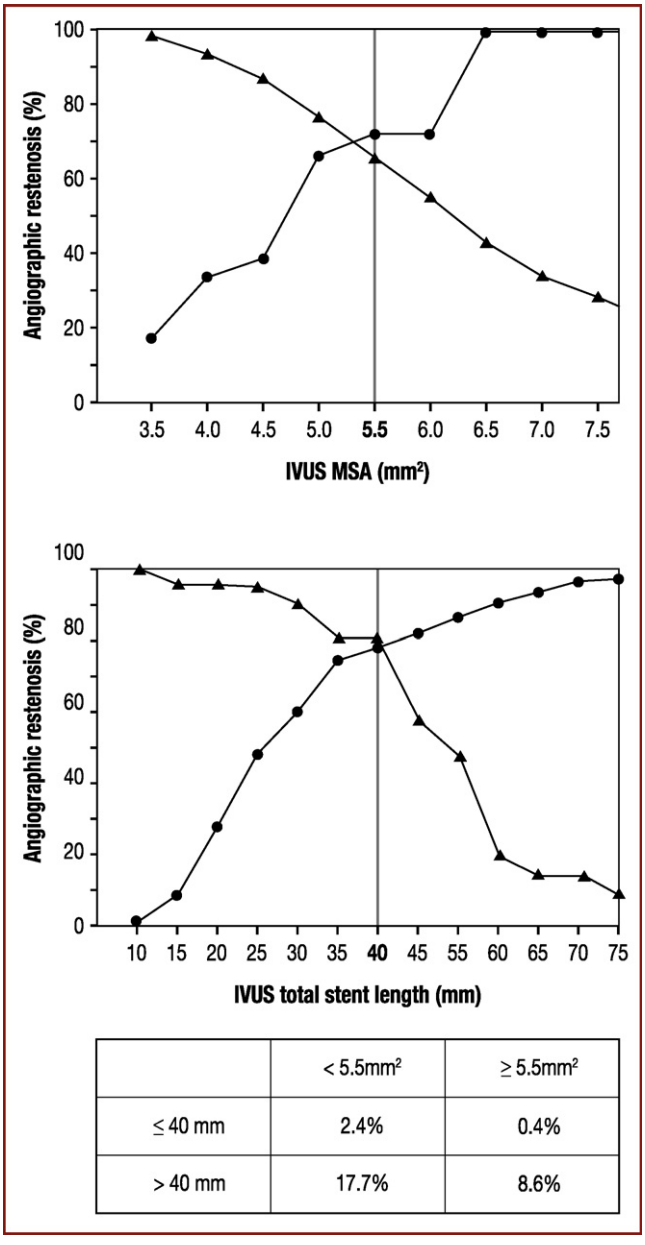
The Thrombocyte activity evaluation and effects of Ultrasound guidance in Long Intracoronary stent Placement (TULIP) study was a randomized study comparing IVUS-guided and angiography-guided stent implantation in long lesions (> 20 mm) [8]. IVUS-guided stent implantation was shown to be beneficial in patients considered to be at high risk of in-stent restenosis. Despite a small sample size, significant reductions in both TLR (10% vs 23%; $p = 0.02$) and MACE (12% vs 27%; $p = 0.03$) were seen at 12-month follow-up with IVUS-guided PCI.

Overall, these studies have failed to determine clearly whether IVUS-guided PCI can reduce in-stent restenosis effectively in the BMS era. This may be related to the fact that the findings of IVUS studies, such as the role of high-pressure inflation in preventing stent under-expansion (which plays a key role in restenosis), were integrated continuously in clinical practice, thus reducing the potential benefit of IVUS. However, despite the continuous improvements in PCI technique, IVUS-guided PCI was associated with at least a trend towards a clinical benefit in most studies and may therefore be beneficial for high-risk lesions.

Drug-eluting stent era

DES are superior to BMS in terms of rate of restenosis and subsequent repeat revascularization procedures [9,11]. Despite these major advantages, restenosis is not abolished and TLR rates reach 10% at two-year follow-up [22]. The increasing use of DES in complex patient and lesion subsets has led to significantly higher rates of DES restenosis than those seen in the randomized studies [23]. Given the encouraging results of IVUS-guided PCI in the BMS era, attempts were made to expand these findings in the DES era.

Stent under-expansion has been reported consistently as the predominant mechanism underlying DES restenosis. In fact, neointimal suppression achieved with DES has promoted stent under-expansion as the prime mechanism for restenosis [12]. In a study of 449 patients (543 lesions) who completed six-month angiographic follow-up after implantation of SES, post-procedural minimum stent area and stented length on IVUS emerged as the only predictors of DES restenosis [24]. IVUS cut-off values that predicted restenosis were a minimum stent area of 5.5 mm^2 and a stented length of 40 mm (Fig. 2). A similar finding was reported in an IVUS study of 33 lesions with DES failure (26 in-stent restenoses) [25]. Investigators found a minimum stent cross-



	< 5.5mm²	≥ 5.5mm²
≤ 40 mm	2.4%	0.4%
> 40 mm	17.7%	8.6%

Figure 2. Predictors of angiographic restenosis after implantation of SES. Sensitivity and specificity curves identify a minimum stent area of 5.5 mm^2 and a stented length of 40 mm as the cut-offs predictive of restenosis on IVUS measurement (from Hong et al. [24]).

sectional area of less than 5.0 mm^2 in 67% of restenosis cases. In an IVUS study of SES implanted for restenosis, 82% of DES failures had a post-procedural minimum stent area less than 5.0 mm^2 versus 26% in the control group ($p = 0.003$) [26]. Significant differences were also seen between groups when comparisons were made for cross-sectional areas of 3 and 4 mm^2. These studies suggest strongly that there is a relationship between smaller minimum stent cross-sectional area and DES restenosis. Conversely, the larger the post-procedural minimum stent cross-sectional area, the lower is the likelihood of restenosis. Similar findings have been reported for PES and zotarolimus-eluting stents.

Inadequate lesion coverage has also been shown to be a cause of DES restenosis. In an IVUS substudy of SIRIUS, the edges of 167 stents were studied [27]. From this cohort, 18 edge stenoses were identified at eight-month angiographic follow-up. An association was seen between edge restenosis in the SES group and both larger reference plaque area and larger stent edge area: reference minimum lumen area ratio. These findings suggest that inadequate plaque coverage led to edge stenosis, which could have been avoided by IVUS guidance. Stent fracture leading to localized drug under-dosing has been proposed as a mechanism leading to focal DES restenosis [28]. More research is required to quantify this relationship. It is unlikely that IVUS at the time of the index procedure would help to prevent this complication of DES implantation. An IVUS study has also shown non-uniform stent expansion to be associated with SES restenosis [29]. This particular study measured stent expansion by using inter-strut angles and counting stent struts. Though the measurement of such variables is not practical during routine IVUS-guided stent implantation, the findings do highlight the importance of achieving uniform stent expansion.

Few reports have been published in the DES era comparing clinical outcomes in patients undergoing IVUS-guided or angiography-guided stent implantation. In a small observational study of 58 patients undergoing elective DES implantation for unprotected left main lesions, no major difference in clinical outcomes was seen between IVUS-guided and angiography-guided PCI [30]. Another prospective study investigated the potential beneficial clinical impact of IVUS-guided PCI in high-risk lesion and patient subsets in the DES era [31]. To ensure adequate IVUS use, a target minimal stent lumen area of 5 mm^2 was to be obtained in this group. This study showed no difference between IVUS-guided PCI and angiography-guided PCI. Although the author acknowledged the small sample size, the rates of MACE at 18 months were similar. In this study, IVUS guidance was associated with higher inflation pressure (16.4 ± 1.7 vs 15.7 ± 1.5; $p < 0.001$) and balloon diameter (3.1 ± 1.1 mm vs 3.3 ± 0.4 mm; $p < 0.001$) although similar MLDs were achieved at the end of the procedure in both groups (2.87 ± 0.24 mm vs 2.94 ± 0.31 mm; p = NS). The TLR and MACE rates were identical (6% vs 6%; $p = 1.0$ and 12% vs 11%; $p = 0.7$).

IVUS to reduce acute and subacute ST

Apart from target vessel revascularization, another major drawback of PCI that could be improved by IVUS-guided PCI is ST. In fact, subacute ST was an initial major limitation of BMS implantation, with an incidence of 10—15% [32,33]. Dual antiplatelet therapy with aspirin and thienopyridine [34—36] and high-pressure stent deployment [37] have decreased the rate of post-PCI thrombotic events significantly to an incidence of 0.9% in the modern BMS era [38]. The first IVUS study reporting IVUS predictors of subacute ST observed (based on 19 patients) that smaller lumen dimension was an univariate predictor and that post-procedural dissection was a multivariable predictor [39].

Predictors and Outcomes of ST (POST) is a multicentre registry that aimed to investigate the role of IVUS in predicting ST compared with angiography [14]. The study included patients who presented with ST after IVUS-guided PCI. At least one abnormal IVUS finding (stent under-expansion, malapposition, inflow/outflow disease, dissection or thrombus) was present in 94% of the 53 patients studied. Angiographic abnormalities were detected in only 32% of patients. These results suggest that IVUS is superior to angiography during stent implantation for identifying features associated with ST. Similarly, our institution has reported the presence of abnormal post-procedural IVUS findings in 78% of 23 patients presenting with subacute ST [40]. Reduced lumen dimensions (< 80% reference), dissection, thrombus and tissue protrusion through stent struts were the major IVUS abnormalities associated with ST. These findings suggested that subacute ST after BMS implantation was associated with mechanical causes that could be identified by IVUS. Although no study has investigated whether routine use of IVUS can affect the rate of subacute ST in the BMS era, the hypothesis is that IVUS identification of abnormalities associated with ST and their subsequent treatment may result in a reduction in subacute ST. In addition to subacute ST, two other limitations of DES implantation are late and very late ST, the mechanisms of which are ill-defined and may differ from the mechanical causes of subacute ST.

Reports questioning the safety of DES compared with BMS in terms of increased rates of non-fatal myocardial infarction and death have been refuted by meta-analyses of long-term follow-ups of randomized controlled trials [41—43]. However, a recent study by Daemen et al. reported a constant ST rate of 0.6% per annum, which may be related to delayed re-endothelialization [44,45]. There are few data on IVUS findings in patients re-presenting with DES thrombosis. In a study to identify IVUS predictors of early ST, 15 patients presenting with ST after successful SES implantation were compared with 45 matched controls; stent expansion and reference segment stenosis were found to be independent predictors of thrombosis [46]. Similar findings have been reported from our institution. In a case-control study, 13 patients presenting with DES thrombosis were compared with 27 matched patients [47]. A smaller stent minimum cross-sectional area (4.6 ± 1.1 mm^2 vs 5.6 ± 1.7 mm^2, $p < 0.05$) was observed in patients with ST. In addition, these patients had a larger proximal reference plaque burden ($66 \pm 8\%$ vs $56 \pm 10\%$; $p = 0.002$).

There are few published data on IVUS findings in patients with late ST. The mechanisms of late ST are likely to be even more multifactorial than those of subacute ST, hence IVUS findings at the index procedure may not correlate with these late events. In a monocentre, case-control study, Cook et al. observed a high prevalence of stent malapposition in patients presenting with very late ST (> 12 months)

[48]. In this study, the IVUS findings of 13 patients who presented with ST were compared with a control group of 144 patients. The groups had similar reference segment cross-sectional areas but the very late ST group had a significantly larger in-stent cross-sectional area. The incidence of incomplete stent apposition was 77% in the very late ST group versus 12% in the control group ($p < 0.001$). Although it lacked IVUS data on the index procedure, this study highlighted the importance of achieving satisfactory stent apposition at baseline, irrespective of whether the cases in the study were persistent or late. A later monocentre study of 82 patients observed that stent malapposition after DES implantation occurred frequently (12%) and did not report any link between this finding and late outcomes as measured by MACE at 10-month follow-up [49]. Although the relationship between stent malapposition and late thrombosis remains controversial, IVUS guidance at the index procedure can negate malapposition at baseline, which may, in turn, have a favourable impact on late ST.

We reported recently a potential benefit of routine IVUS guidance in preventing subacute ST after implantation of DES [13]. From a registry of unselected patients undergoing DES implantation, those who had IVUS-guided PCI were identified and compared with those undergoing angiography-guided PCI ($n = 884$ in both groups). Propensity-score matching (considering patient demographics, clinical characteristics and presentation, and angiographic features) was used to compare outcomes. There were significant reductions in subacute ST (0.5% vs 1.4%; $p = 0.045$) and cumulative ST (0.7% vs 2.0%; $p = 0.014$) at 12 months in the IVUS-guided group. There were trends toward less probable ST and less TLR at 12 months in the IVUS-guided group, but there was no advantage in terms of MACE. The use of IVUS resulted in significant differences in treatment strategy (less primary stenting, greater use of rotational atherectomy, longer stent lengths and more post-dilation). These results suggest that routine IVUS guidance can detect and result in subsequent treatment of the mechanical causes responsible for subacute ST. The failure of routine IVUS guidance to impact late events is consistent with the less important role that mechanical causes play in late ST.

Potential clinical benefit of IVUS guidance in DES implantation

The important roles of stent under-expansion, malapposition and lesion coverage in DES restenosis and thrombosis, and the ability of IVUS-guided PCI to prevent these events, supports the hypothesis that IVUS is beneficial in this setting.

To quantify the degree of under-expansion seen with DES, a study comparing IVUS-determined and compliance chart-predicted minimum stent diameter and area was performed [50]. In this study, 133 patients were treated with SES and 67 patients received PES. Comparison of the individual types of DES was then made with their respective BMS platforms. DES achieved $75 \pm 10\%$ of predicted minimum stent diameter and $66 \pm 17\%$ of predicted minimum stent area. There were no significant differences in the values between DES types. Moreover, 24% of SES and 28% of PES did not achieve a minimum stent area of 5 mm^2 (the value predictive of restenosis). No difference was seen in stent expansion between the individual stent types and their respective BMS platforms. From this final observation the investigators concluded that the polymer coating does not interfere with DES expansion. A similar finding was reported with BMS, hence the disparity between IVUS measurements of stent expansion and compliance chart values is not unique to DES [51]. A study from our institution compared stent expansion between SES ($n = 46$) and PES ($n = 42$) with serial IVUS [52]. Even at high pressure inflations (20 atm), 48 and 35% of stents appeared to be under-expanded in the SES and PES groups, respectively. These studies suggest strongly that there is discordance between IVUS measurements of stent expansion and those predicted by compliance charts. Moreover, the studies highlight the need for high-pressure stent deployment and the importance of IVUS guidance in ensuring optimal stent deployment. Lesion coverage is, as described above, a strong predictor of edge restenosis. IVUS-guided PCI has the potential for accurate lesion length measurement, allowing for adequate coverage and thereby preventing edge restenosis.

Finally, it may be beneficial to ensure full stent-vessel wall apposition, although this is of less importance than stent under-expansion and lesion coverage. In fact, stent malapposition may lead to inadequate drug delivery and DES failure, and has been associated with late ST. As mentioned previously, a recent study performed in our institution has highlighted the potential benefit of IVUS-guided PCI with regard to ST. In this retrospective study, a strong trend toward less TLR was also seen with IVUS (5.1% vs 7.2%; $p = 0.07$). In another analysis from our institution, angiographic and procedural predictors of ST after DES implantation were identified [53]. This was a lesion-based analysis of 45 lesions re-presenting with ST compared with 1620 unselected lesions that were free of ST at 12 months. Lack of IVUS guidance was the only modifiable correlate of ST in this analysis (OR 0.45, 95%CI 0.24—0.84; $p = 0.013$). As in our previous analysis, IVUS guidance was associated with reductions in early ST but failed to affect late events significantly (Fig. 3).

The reductions in restenosis achieved with DES may reduce the impact of routine IVUS guidance on revascularization rates. In our propensity score-matched analysis

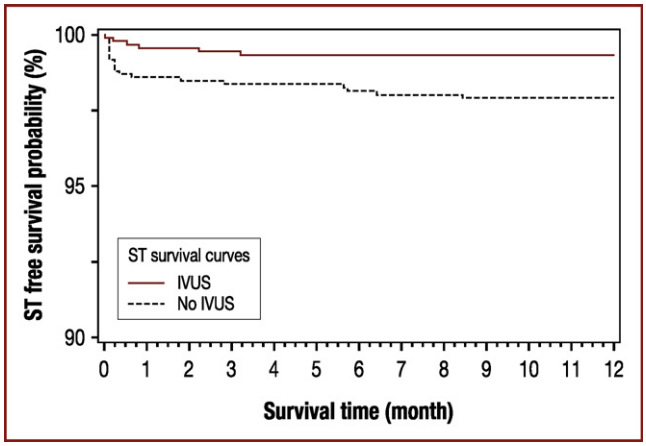


Figure 3. Kaplan-Meier curves comparing freedom from ST during one-year follow-up in patients who had IVUS-guided PCI or angiography-guided PCI (from Roy et al. [13]).

comparing patients undergoing IVUS with those undergoing angiography-guided DES implantation, there was a trend towards reduced TLR with IVUS (5.1% vs 7.2%; $p = 0.06$). In addition, we have identified lack of IVUS guidance as a predictor of clinical restenosis (OR 0.68, 95%CI 0.48—0.97; $p = 0.035$) [54]. These reduced revascularization trends are consistent with the role of stent under-expansion in DES restenosis and the potential benefit of its prevention using IVUS-guided PCI.

Specific patient and lesion subsets

Because DES are associated with low rates of events post-implantation, IVUS-guided PCI may be more relevant in high-risk patient or lesion subsets. Accordingly, diabetes mellitus and renal failure, which have been associated with increased rates of restenosis, may be interesting clinical indications. Furthermore, lesion subsets with high rates of restenosis or thrombosis (such as left main disease, bifurcations, ostial lesions, long lesions, small vessels or restenotic lesions) may benefit from the use of IVUS. Seung et al. have investigated the impact of IVUS guidance on left main trunk PCI with SES. IVUS guidance was used in 86% of the 102 patients included and the minimal stent area was $9.6 \pm 2.6\ mm^2$. The one-year TLR rate was 2%, which is well below what is usually reported for such lesions [55].

Limits to the potential benefit of IVUS-guided PCI

The lack of a proper study demonstrating the benefits of IVUS-guided PCI may be explained by the fact that angiography-guided PCI has been updated according to the knowledge gained by the use of IVUS. PCI has been optimized according to IVUS findings and may explain the difficulties in demonstrating a clinical benefit of IVUS-guided PCI. This explains why IVUS-guided PCI is under-used despite the fact that the technology has been available for more than 10 years. Other limits are the cost associated with the device, although if it is clinically beneficial, then it may actually be cost-effective. Thus, IVUS may be best-suited for use with intermediate- or high-risk lesions where it can be used for both diagnosis and intervention.

Conclusion

IVUS is superior to angiography for determining lesion severity and is thus warranted in left main, ostial and intermediate lesion assessment to better quantify lesion severity. During intervention, IVUS has several potential advantages, enabling accurate choice of stent diameter and length or the need for rotational atherectomy. However, despite these advantages and although a trend toward improved prognosis with IVUS-guided PCI was found in the BMS era, the results are less convincing in the DES era. Although the role of routine IVUS guidance in DES implantation remains uncertain, given the advantages mentioned previously, its use could lead to clinical benefit in high-risk patients.

Conflicts of interests

No conflict of interest exists.

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