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Optical coherence tomography to guide percutaneous coronary intervention of the left main coronary artery: the LEMON study

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KEYWORDS

- drug-eluting stents
- left main artery
- optical coherence tomography

Abstract

Background: Intravascular ultrasound (IVUS)-guided PCI improves the prognosis of left main stem (LMS) PCI and is currently recommended by international guidelines. Although OCT resolution is greater than that of IVUS, this tool is not yet recommended in LMS angioplasty due to the absence of data.

Aims: This pilot study aimed to analyse the feasibility, safety and impact of OCT-guided LMS PCI.

Methods: This prospective, multicentre trial investigated whether patients might benefit from OCT-guided PCI for mid/distal LMS according to a pre-specified protocol. The primary endpoint was procedural success defined as follows: residual angiographic stenosis <50% + TIMI 3 flow in all branches + adequate OCT stent expansion (LEMON criteria).

Results: Seventy patients were included in the final analysis (median age: 72 [64-81] years, 73% male). The OCT pre-specified protocol was applied in all patients. The primary endpoint was achieved in 86% of subjects. Adequate stent expansion was observed in 86%, significant edge dissection in 30% and residual significant strut malapposition in 24% of the cases. OCT guidance modified the operators' strategy in 26% of the patients. The rate of one-year survival free from major adverse clinical events was 98.6% (97.2-100).

Conclusions: This pilot study is the first to report the feasibility and performance of OCT-guided LMS PCI according to a pre-specified protocol.

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Abbreviations

Cx	circumflex artery
DMB	distal main branch
ICI	intracoronary imaging
IVUS	intravascular ultrasound
LAD	left anterior descending artery
LMS	left main stem artery
OCT	optical coherence tomography
PCI	percutaneous coronary intervention
PMB	proximal main branch
POT	proximal optimisation technique
SB	side branch

Introduction

Percutaneous coronary intervention (PCI) represents a valid alternative for the treatment of left main stem (LMS) lesions in selected patients[1] and is currently considered by the European guidelines in patients with low or intermediate SYNTAX score[2]. These interventions require accurate analysis of lesion anatomy, adequate stenting strategy and optimal assessment of the results[3].

The guidance and optimisation of LMS PCI by intravascular ultrasound (IVUS) can improve the overall procedure quality by allowing more precise device selection and identification of early stenting pitfalls that favour adverse clinical events[4-7]. Optical coherence tomography (OCT) is considered as non-applicable for coronary artery ostia and might be limited in case of a large vessel; however, the technique outmatches IVUS in identification of thrombus, coronary dissection and incomplete stent apposition due to its better spatial resolution[5]. Hence, mid and distal LMS can be adequately studied by this imaging modality with comparable, if not superior, results to IVUS[8,9]. Moreover, online three-dimensional (3D) reconstruction of OCT images clarifies the device configuration within coronary bifurcations and precisely identifies the guidewire recrossing point into the stent-jailed side branch (SB)[10]. However, there is a lack of available data and consensus regarding the use of OCT guidance for LMS PCI[9,11].

In the current study, we aimed to assess the feasibility, performance and safety of a standardised OCT-guided protocol for completion and optimisation of LMS PCI.

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Material and methods

STUDY DESIGN AND INCLUSION/EXCLUSION CRITERIA

The LEMON study (LEft Main Oct-guided iNterventions) was a prospective, multicentre, open-label, interventional, non-randomised trial that investigated OCT guidance for LMS PCI in 10 French interventional cardiology centres. The aim of the study was to assess the applicability of a predefined standardised protocol. Inclusion criteria were: 1) age >18 years and informed consent; 2) stable or non-stable mid/distal LMS lesion (Medina classification: 1,0,0, 1,1,0 or 1,0,1) requiring PCI with a one- or two-stent strategy or stable or non-stable ostial left anterior descending artery (LAD) and/or circumflex artery (Cx) lesion (Medina classification 0,1,0 or 0,0,1) requiring PCI with involvement of the distal LMS; and 3) a SYNTAX angiographic score <23.

The exclusion criteria included any of the following: ostial LMS lesion; acute ST-elevation myocardial infarction (STEMI); cardiogenic shock; severe chronic renal failure (Cr Cl <30 ml/min/m²); anticipated technical contraindication to OCT (highly calcified lesions, severe proximal tortuosity); contraindication to drug-eluting stent implantation.

The research protocol was approved by the CHU Kremlin-Bicêtre ethics committee and the participants gave written informed consent. The study is registered at ClinicalTrials.gov (identifier: NCT04248777).

THE LEMON STANDARDISED PCI PROTOCOL

The LMS PCI strategy was guided by three pre-specified OCT runs **(Figure 1, Figure 2A)**.

– Run #1 was performed from the main vessel towards the LMS before any stent implantation to analyse plaque characteristics, identify proximal and distal landing zones (LZ), measure lesion length, reference segment dimensions and determine stent dimensions and the proximal optimisation technique (POT) balloon diameter[12]. SB OCT analysis was left to the discretion of the operator.

– Run #2 was performed after the stent was implanted, POT was applied and the SB was rewired. It aimed to assess an adequate guidewire recrossing point into the stent-jailed SB.

– Run #3 was performed after PCI optimisation to analyse stent expansion and identify significant strut malapposition and edge dissection. In case of additional stent optimisation, a supplementary OCT run was acquired to assess the final result. The detailed protocol is provided in **Supplementary Appendix 1**.

ANGIOGRAPHIC ANALYSIS

The LMS bifurcation was analysed according to the latest European Bifurcation Club (EBC) consensus document, including grading using the Medina classification and segmentation in the proximal main branch (PMB/LMS), SB and distal main branch (DMB)[3]. The PCI strategy (one or two stents) was left to the operators' discretion and involved implantation of XIENCE Sierra™ everolimus-eluting stents (Abbott Vascular, Santa Clara, CA, USA).

The angiography data were centrally reviewed by two independent operators. The stenosis degree was calculated by a dedicated quantitative coronary angiography (QCA) software (Centricity CA1000; GE Healthcare, Buc, France).

OCT ACQUISITION AND ANALYSIS

The OCT analysis methodology is provided in **Supplementary Appendix 2**.

STENT EXPANSION

Minimal stent area (MSA) was assessed in the different stent sections (MB and DMB) and stent expansion was analysed by three different methods: LEMON, DOCTORS and ILUMIEN III[12,13].

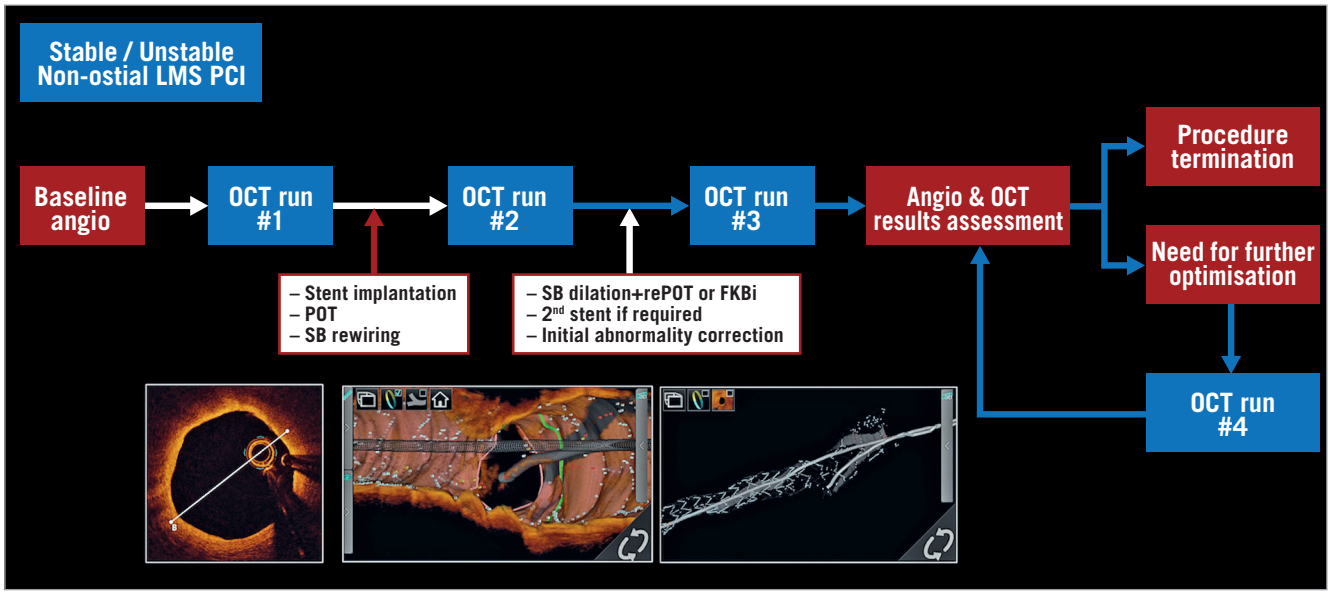

Figure 1. *Global overview of the LEMON protocol.*

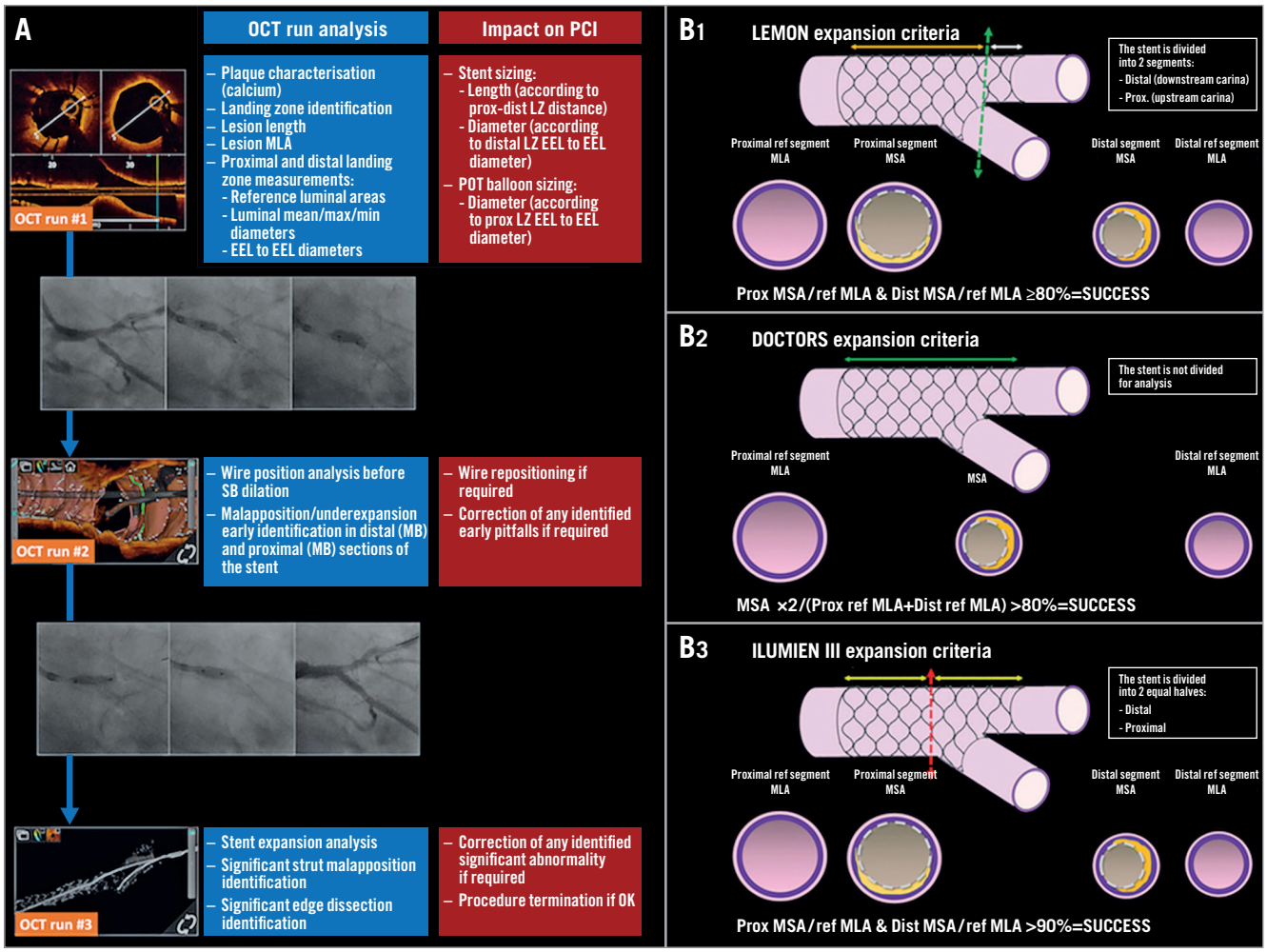

Figure 2. *OCT guidance in LMS PCI in the LEMON trial. A) Roles of the pre-specified OCT runs on the decision-making process during LMS PCI. B1) - B3) Comparison of the calculation of the LEMON, DOCTORS and ILUMIEN III criteria for stent expansion evaluation in bifurcated lesions.*

The LEMON criteria have been proposed to overcome the inherent difficulties in stent expansion assessment within bifurcated lesions (where proximal and distal reference segments display discrepant areas)[14]. The stent was split into two sections, using the carina as the cut-off point. The MSA was then measured in the proximal (upstream carina) and distal (downstream carina) sections. The ratio between MSA and reference minimum luminal area (RefMLA) was calculated for both sections. The expansion was considered successful if the MSA/RefMLA was ≥80% in both proximal and distal stent sections **(Figure 2B)**.

ENDPOINTS

The clinical and procedural characteristics were entered into a predefined standardised case report form. Clinical follow-up was obtained by clinic visits and/or by telephone contact.

The primary endpoint was procedural success, defined as follows: Thrombolysis In Myocardial Infarction (TIMI) 3 flow in all vessels + residual stenosis <50% by QCA + adequate stent expansion according to LEMON criteria.

Secondary endpoints included: 30-day and one-year incidence of major adverse cardiovascular events (MACE: a composite of cardiovascular death/stent thrombosis/target vessel revascularisation), percentage of appropriate wire position on run #2, stent expansion according to DOCTORS and ILUMIEN III criteria, contrast agent volume and radiation dose (safety endpoints).

STATISTICAL ANALYSIS

Statistical analysis was performed with SPSS, Version 21.0 software (IBM Corp., Armonk, NY, USA). Continuous numerical data are expressed as median±interquartile range and qualitative data as percent. Normal distribution of continuous variables was tested by the Kolmogorov-Smirnov test. The differences between the variables were compared by the chi-square or Fisher's test for qualitative variables and by the Mann-Whitney U, Kruskal-Wallis, Student's t-test or Student's paired t-test for quantitative variables. The agreement between local operator and core lab for the wire recrossing point into the jailed SB was evaluated by the kappa coefficient. Binary logistic regression analysis was used to test the relationships between inadequate stent deployment incidence and clinically relevant variables. Univariable regression analyses were performed first to test the relationship between outcome and selected parameters, then all covariates with a p-value of <0.10 were included in the multivariable backward stepwise elimination regression model. A value of p<0.05 indicated a statistically significant difference.

Results

BASELINE CHARACTERISTICS

Between May 2018 and January 2019, a total of 117 patients were screened for inclusion; the final analysis included 70 patients. The flow chart of the study is given in **Supplementary Figure 1**. The distal LMS was stenosed in 93% of patients; the remaining 7% of patients presented a Medina 0,1,1 lesion. The population baseline characteristics are given in **Table 1**.

Table 1. Baseline characteristics.

		N=70
Male gender, n (%)		51 (73)
Age, years		72 (64-81)
Cardiovascular risk factors, n (%)	HTN	49 (70)
	Active smoking	13 (19)
	Former smoking	23 (33)
	Dyslipidaemia	39 (56)
	Diabetes mellitus	19 (27)
	Body mass index >30 kg/m^2	32 (46)
Previous myocardial infarction, n (%)		13 (19)
Previous PCI, n (%)		27 (39)
Previous CABG, n (%)		3 (4)
Clinical presentation, n (%)	Stable CAD	54 (77)
	Unstable CAD (UA & NSTEMI)	16 (23)
Creatinine clearance, ml/min/m^2		76 (65-88)
LVEF, %		53 (45-61)
Vessel, n (%)	LMS	65 (93)
	LAD	30 (43)
	Cx	9 (13)
Bifurcation, n (%)		58 (83)
Trifurcation, n (%)		12 (17)
LMS lesion QCA pre, %		59 (56-61)
PCI technique, n (%)	Balloon predilation	48 (69)
	1-stent technique	58 (83)
	2-stent technique	12 (17)

There was no predilation before OCT run #1. OCT analyses revealed that the culprit lesion was most frequently a mixed plaque. The stenosis length was 19 mm (14-27 mm) and the maximal LMS luminal and EEL/EEL diameters were 4.5 mm (4.1-4.9 mm) and 4.9 mm (4.5-5.5 mm), respectively. The MB and SB were both imaged before PCI in two patients.

The provisional one-stent strategy was the preferred operator strategy. When a two-stent strategy was decided on, the T-stenting and TAP techniques were applied in all patients **(Supplementary Table 1)**. POT/Side/rePOT sequence was performed in 37 patients and POT/final kissing balloon inflation (FKBi) in 33 patients (12 patients with a two-stent technique and 21 patients with a one-stent technique). The median main stent diameter and length were 3.5 mm (3.0-3.5 mm) and 23 mm (18-28 mm), respectively **(Supplementary Table 1)**.

PRIMARY ENDPOINT AND IMPACT OF OCT ON OPERATOR STRATEGY

The pre-specified protocol was respected in all the patients. Further PCI optimisation was provided in 26% of the cases following OCT run #2 or run #3, suggesting that OCT guidance modified the operators' strategy in more than one patient out of four.

The primary endpoint was achieved in 86% of the cases. This percentage was driven by the achievement of optimal stent

expansion: the expansion was considered appropriate according to the LEMON criteria in 86% of the cases, but this percentage decreased to 40% and 37% when analysed with the DOCTORS and ILUMIEN III criteria, respectively. Angiographic residual LM stenosis <50% and final TIMI 3 flow were achieved in all patients. The stenosis percentage decreased from 61% (53-76%) to 16% (0-21%) by QCA and from 76% (63-84%) to 6% (0-17%) by OCT (p<0.0001). Multivariable analysis revealed that larger proximal reference EEL/EEL diameter was a predictor of inadequate stent expansion **(Supplementary Table 2)**. We also observed that proximal reference segment MLA was larger and LM stent MSA smaller in patients with suboptimal LM stent expansion compared to others **(Supplementary Table 3)**. However, a large MSA was observed in the vast majority of patients **(Supplementary Table 4)**.

MALAPPOSITION AND EDGE DISSECTION

The stent proximal edge was visualised in all cases. The final OCT analysis findings (after corrective actions) are presented in **Table 2**. Edge dissection was present in 30% of the cases, mostly on the distal part of the stent. However, the incidence of significant dissection was lower - 1% on the proximal edge and 9% on the distal edge. Residual significant strut malapposition was observed in 17 patients (24%), 9 (13%) in the proximal part, 4 (6%) in the distal part and 4 (6%) in both sections of the stent. However, when comparing post-POT OCT analysis (OCT run #2) with the final OCT run, all malapposition parameters were significantly reduced **(Supplementary Table 5, Supplementary Figure 2)**. Finally, there was no influence of FKBi or POT/Side/rePOT strategies on post-PCI OCT parameters **(Supplementary Table 6)**.

Table 2. OCT characteristics.

Lesion characteristics		N=70	
Lipid plaque, n (%)		2 (3)	
Calcified plaque, n (%)		4 (6)	
Fibrous plaque, n (%)		12 (17)	
Mixed plaque, n (%)		52 (74)	
Thrombus, n (%)		4 (6)	
Minimal lumen area, mm²		3.1 (1.9-4.3)	
Lesion length, mm		19 (14-27)	
Area stenosis, %		76 (63-84)	
Pre-PCI analysis	**Prox. ref. segment**	**Dist. ref. segment**	***p*-value**
Mean luminal diameter, mm	4.0 (3.7-4.3)	3.0 (2.5-3.3)	<0.001
Max luminal diameter, mm	4.5 (4.1-4.9)	3.2 (2.9-3.7)	<0.001
Min luminal diameter, mm	3.5 (3.2-3.9)	2.8 (2.3-3.0)	<0.001
Luminal area, mm²	12.5 (10.7-14.2)	6.9 (5.1-8.7)	<0.001
EEL/EEL diameter, mm	4.9 (4.5-5.5)	3.7 (3.4-4.2)	<0.001
Final post-PCI analysis	**Prox. stent segment**	**Dist. stent segment**	***p*-value**
Minimal stent area, mm²	11.6 (9.6-14.3)	6.7 (5.7-8.3)	<0.001
Expansion, %	94 (83-113)	101 (87-119)	0.61
Significant malapposition, n (%)	13 (18)	8 (11)	0.24
Significant plaque protrusion, n (%)	38 (54)	47 (68)	0.12
Any edge dissection, n (%)	5 (7)	21 (30)	<0.001
Significant edge dissection, n (%)	1 (1)	6 (9)	0.05
Thrombus, n (%)	1 (2)	1 (2)	1

SECONDARY ENDPOINTS

The wire position could be analysed in 68 patients (97% of the cohort) on run #2. The core lab analysis showed that the wire was in an appropriate position towards the SB in 81% of the cases and inappropriate in 19%. The local operators reported wire position analysis in 60 patients **(Supplementary Table 7)**. In this subset, there was an agreement on wire position in 44 patients and the k coefficient was 0.3. The operators proceeded to a wire repositioning in 15% of the cases on the basis of the OCT analysis.

The median contrast agent volume, procedure duration and radiation dose were 220 ml (180-260 ml), 65 mins (54-82 mins) and 4,374 cGy/cm² (2,200-7,868 cGy/cm²), respectively.

Follow-up was achieved in all patients. No MACE were recorded at 30 days following PCI. One patient died from a non-cardiovascular cause (fatal traumatic subdural haematoma at day #98). One patient suffered from a target vessel revascularisation (related to LMS intra-stent restenosis). Thus, the one-year MACE rate was 1.4% and the 12-month actuarial survival free from MACE was 98.6% (97.2-100%) **(Figure 3)**.

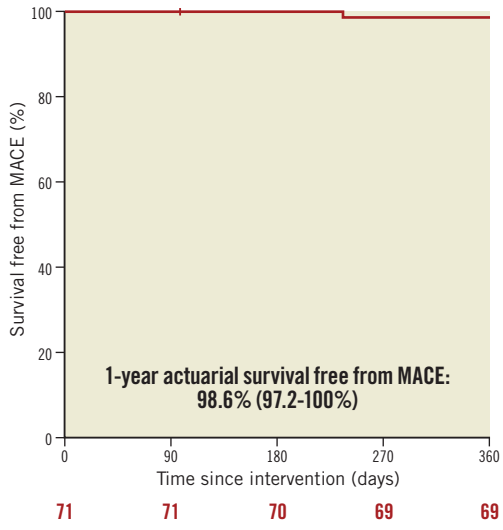

Figure 3. *One-year incidence of MACE (cardiovascular death/target vessel revascularisation/stent thrombosis) in the LEMON cohort.*

Discussion

The pilot LEMON study was conducted to assess the possible applicability of a pre-specified standardised OCT protocol for LMS PCI in a multicentre cohort. The main results of the study

can be summarised as follows: 1) OCT guidance for LMS PCI was feasible and safe, and was successful in 86% of patients; 2) an optimal guidewire recrossing point into the stent-jailed side branch was observed in 81% of the cases at the first attempt following POT, but modest agreement was observed between the core lab and local operators; 3) OCT guidance impacted on operator strategy in one patient out of four despite adequate/acceptable angiographic results and the operators being experienced.

Intracoronary imaging (ICI) guidance (either by OCT or by IVUS) improves the quality of PCI[7]. The potential benefits of ICI-guided PCI are more pronounced in case of complex/high-risk lesions, which includes bifurcated and LMS lesions. LMS lesions display specific features (diameter discrepancies, tapered anatomy, plaque eccentricity and a higher probability of calcifications) that are difficult to analyse correctly by angiography alone[15]. Hence, the use of IVUS to guide LMS stent implantation provides a significant clinical advantage according to the multiple studies conducted so far[6,7,16] and is currently recommended by international guidelines[2]. The higher resolution of OCT compared to IVUS confers greater sensitivity for detection of thrombus, stent underexpansion, strut malapposition and edge dissection, suggesting that it might be a valuable option for LMS PCI guidance. LMS OCT analysis is feasible in its mid/distal, but not ostial portions[8,17,18] and is more accurate than IVUS for post-stenting assessment[9]. Recently, Cortese et al observed in the ROCK-1 retrospective series of non-standardised OCT-guided distal LMS PCI[11] that the procedure detected a substantial number of cases of acute strut malappositon and device underexpansion and led to lower lumen late loss at follow-up[11]. To the best of our knowledge, the LEMON trial is the first study to have prospectively evaluated a specific OCT protocol with pre-specified optimisation criteria. It thus reinforces the interest of standardised protocols for ICI guidance in LMS PCI[15].

Our current results confirm, on a large scale, the feasibility, safety and efficacy of the procedure. The success rate of the procedure was very encouraging, as the primary endpoint was achieved in 86% of the cases. Interestingly, the failures were related to non-achievement of the pre-specified device expansion criteria. Hence, optimal stent expansion was observed in 86% of the cases, according to the LEMON criteria, but in only 40% and 37% with the DOCTORS and ILUMIEN III criteria, respectively. These results are explained by the differences in the calculation of these indices: the LEMON criteria were conceived for bifurcated lesions, whereas the DOCTORS and ILUMIEN III criteria were not. Hence, these discrepancies highlight the difficulty in assessing optimal expansion by ICI within the LMS. Although the LEMON criteria were conceived to integrate some of the geometrical features of bifurcated lesions, they might not be completely adapted to the LMS as they do not take into account the anatomy and shape of the vessel and do not include specific analysis of the polygon of confluence (POC). Hence, tapered or funnel shapes display luminal area variations along the LMS that might influence the calculation of the degree of expansion[14]. However, the percentage of optimal expansion achieved in LEMON remains higher than in other "simpler" lesion series such as ILUMIEN III or DOCTORS[12,19], and is in line with the most recently observed results in LMS ICI-guided PCI[7]. Altogether, these data advocate for the need of further improvement in our understanding of LMS anatomy and design of more adapted stent expansion criteria. Hence, ongoing trials will integrate a dedicated bifurcation expansion algorithm that will specifically analyse (ILUMIEN IV) or not (OCTOBER) the POC[20].

The operators reported that post-PCI OCT analysis influenced their strategy and led to further optimisation despite satisfactory angiographic results in 26% of the cases. These results are in line with the ILUMIEN I trial data, in which post-PCI OCT analysis prompted PCI optimisation in 27% of the patients[21]. However, in LEMON, we cannot assess the influence of pre-PCI OCT analysis on the stenting strategy (especially in terms of device sizing) as this was not a pre-specified endpoint. Nevertheless, our study confirms the impact of periprocedural OCT on physician decision making, which is more pronounced for complex lesions[21]. OCT guidance is currently proposed by the EBC to support bifurcation lesion PCI and this might be expanded to distal LMS lesions[14]. In addition to its higher resolution, OCT analysis can also provide 3D online reconstructions to assess the distal recrossing point into a stent-jailed side branch. In this series, the core lab analysis identified an appropriate wire position after POT in 81% of the cases, hence validating the AptiVue™ E5 software. Once again, these results are in line with previous reports[10] and might be related to the stent design as well as the systematic use of POT before SB rewiring[3]. However, we also recognise the modest agreement between core lab and local operators, suggesting that continuous physician education, better experience in handling these new tools and potential upgrades in online software are required to improve the results.

Limitations

Several limitations of this study deserve consideration. First, this pilot study was not randomised and did not include a control angiography guidance group, as our main task was to evaluate the feasibility of standardised OCT-guided LMS PCI. Future studies in the field will integrate control groups and longer follow-up. Moreover, the strict inclusion criteria might have induced a degree of patient selection. However, although we did not include STEMI, extremely tight and unstable lesions requiring predilation, high SYNTAX score, severe renal failure patients, extremely complex lesions or other bifurcation PCI techniques (such as DK crush or culotte) in LEMON, we believe that the spectrum of patients we analysed covers a large proportion of the individuals treated in our cath labs. Finally, our study only included mid and distal LMS lesions. Although this situation might evolve in the future, ostial LMS lesion PCI should only be performed under IVUS guidance.

Conclusions

The prospective multicentre LEMON study is the first to report the feasibility and performance of OCT-guided LMS PCI according to

a predefined standardised protocol. The impact of this strategy on clinical outcome compared to conventional angiography-guided or IVUS-guided LMS PCI has to be evaluated in future, larger randomised trials.

Impact on daily practice

Although OCT is accurate to guide PCI, there is a lack of available data regarding its use in the LMS. The LEMON study demonstrates for the first time the possible use of OCT for guidance of LMS PCI according to a pre-specified standardised protocol. This procedure was feasible and safe but its impact on clinical outcome has to be investigated in future, larger randomised trials.

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Conflict of interest statement

N. Amabile reports consulting/lecturing fees (modest) from Abbott Vascular and Boston Scientific, and a research grant from Abbott Vascular. G. Souteyrand reports consulting/lecturing fees (modest) from Terumo, Abbott Vascular and Boston Scientific. N. Meneveau reports consulting fees (modest) from Abbott Vascular. P. Motreff reports consulting fees (modest) from Abbott Vascular and Terumo. G. Cayla reports lectures fees (modest) from Abbott. T. Lefèvre reports honoraria/consultation, personal fees (modest) from Terumo and Boston Scientific. C. Caussin reports consulting/lecturing fees (modest) from Abbott and Boston Scientific. The other authors have no conflicts of interest to declare.

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Supplementary data

Supplementary Appendix 1. Methods

The LEMON standardised PCI protocol

All procedures were conducted under efficient anticoagulation by unfractionated heparin and all patients received preprocedural dual antiplatelet therapy (aspirin + $P2Y_{12}$ inhibitors) that was continued following PCI. The LMS PCI strategy was guided by three pre-specified and standardised OCT runs.

- OCT run #1 was performed before any stent implantation to analyse plaque characteristics, identify the proximal and distal landing zones (LZ), and measure lesion length and reference segment dimensions. Reference segments were determined as the most "normal-appearing" segments 5 mm proximal and distal to the lesion shoulders. The stent diameter was chosen according to the distal LZ external elastic lamina (EEL) to EEL diameter when applicable or lumen diameter as reported by the ILUMIEN III investigators, the stent length according to the distance between landing zones and the proximal optimisation technique (POT) balloon diameter according to the proximal LZ EEL to EEL diameter. EEL to EEL diameters were rounded down to the nearest 0.25 mm to determine device diameters.

- OCT run #2 was performed after the stent was implanted, POT was applied and the side branch was rewired. It aimed to assess an adequate guidewire recrossing point into the stent-jailed side branch (through a cell connecting to the carina) and identify early stent mechanical non-optimal results.

- OCT run #3 was performed after PCI optimisation to analyse final stent expansion and identify major strut malapposition and edge dissection. In case of additional stent optimisation, a supplementary OCT run was applied to assess the final result.

In case of identified significant malapposition or underexpansion (definition below), correction was proposed by using a larger diameter non-compliant balloon. To avoid perforation, in all cases, the non-compliant balloon diameter could be no larger than the nearest reference vessel EEL, or up to 0.5 mm larger than the post-PCI mean reference lumen diameter (if the EEL was not visible). Additional stenting for management of significant dissections was proposed in case of dissection with a length >3 mm and radial extension >60°.

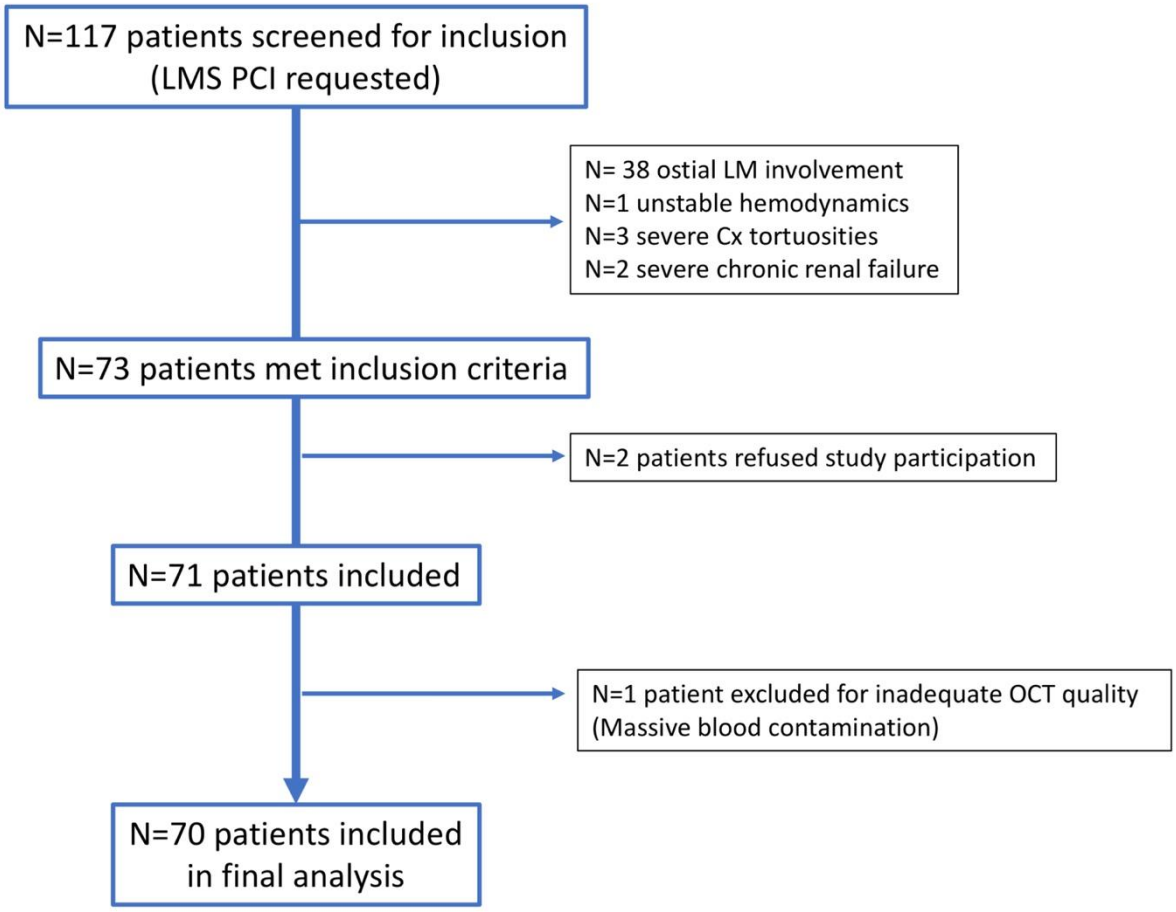
An adequate guidewire recrossing point into the stent-jailed side branch was defined as the most distal cell of the MB stent facing the SB ostium (cell connecting to carina) in case of POT/Side/rePOT or culotte/T stenting/TAP stenting strategy. The adequate recrossing point was defined as the most proximal cell of the crushed SB stent in case of a DK crush strategy.

Supplementary Appendix 2. OCT acquisition and analysis

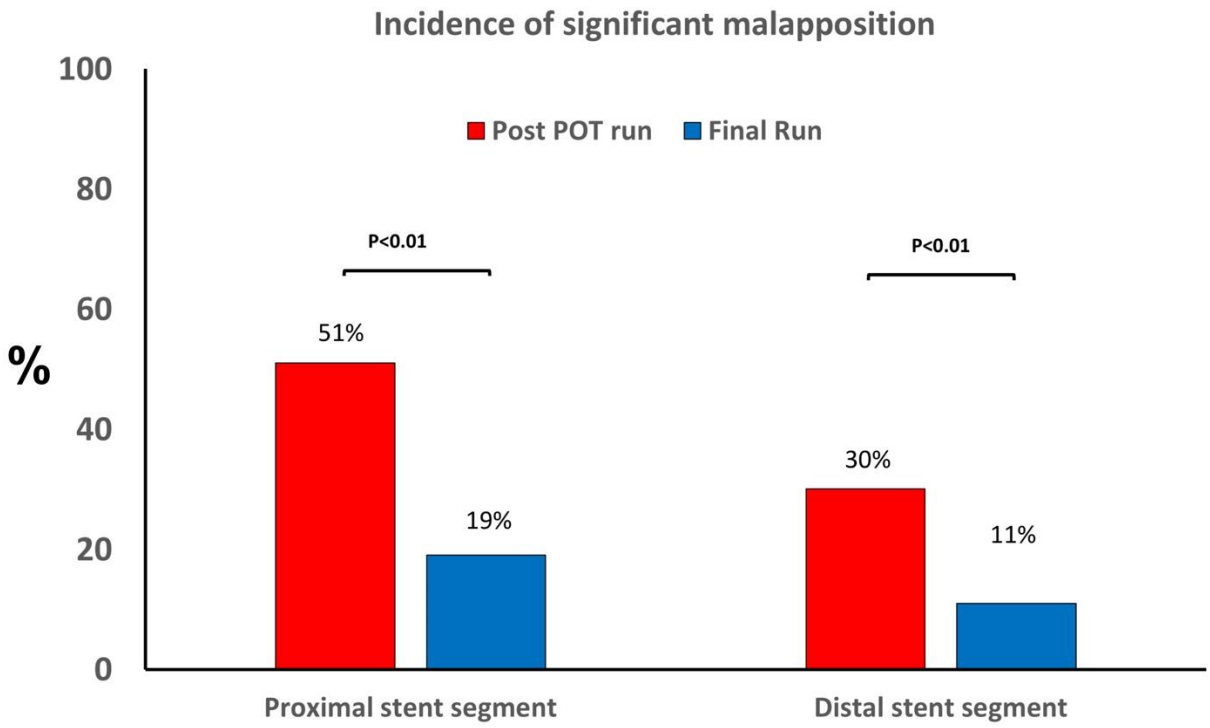
OCT images were acquired using the FD-OCT OPTIS™ system (Abbott Vascular, Santa Clara, CA, USA) and 6 Fr guide catheter compatible Dragonfly™ Duo and Dragonfly™ OPTIS™ catheter (Abbott Vascular).

OCT images were analysed offline using the dedicated manufacturer software for 2D and 3D analyses (AptiVue™ E5 software; Abbott Vascular) in a centralised core laboratory (Institut Mutualiste Montsouris OCT lab) by two independent operators. The cross-section images were sequentially analysed at 1 mm intervals and discordances were resolved by consensus. Lesion length, minimal lesion area, percentage of area stenosis, plaque composition, and presence of thrombus were determined according to the EAPCI consensus documents. EEL was identified on proximal and distal reference segments according to the ILUMIEN III methodology. EEL to EEL diameters on proximal and distal LZ were used for stent and POT balloon sizing. The position of the SB wire into an appropriate stent cell (connecting to the carina) was assessed by 3D analysis according to previously published methods. The configuration of the overhanging struts on the SB ostium and the recrossing position were visualised on a "cut-away" view and a "fly-through" view, respectively, of the 3D-OCT. The jailing configurations at the SB orifice and the rewiring position were classified according to previous reports. Briefly, in the link-connecting type, there was a link connecting to the carina and, in the link-free type, there was no link at the carina. The larger area enclosed by both the carina and the stent strut, with at least one distal top of the stent hoop located on the SB ostium, was defined as the distal cell.

Strut apposition, edge dissections and residual material protrusion were analysed and graded (significant versus non-significant) according to the latest EAPCI consensus document. Significant malappositon was defined as acute strut malapposition with maximal distance ≥0.4 mm and longitudinal extension ≥1 mm. Significant dissection was defined as dissection with one or more of the following criteria : arc extension ≥60°, length ≥2 mm and/or medial extension. Significant material protrusion was defined as tissue extrusion from inside the stent area with an extent >500 µm into the lumen. The crude minimal stent area (MSA) in the different stent sections (LM, polygon of confluence and main branch) was compared to cut-off values previously proposed by the consensus documents and IVUS studies: 8.2 mm^2 (LM), 7.2 mm^2 (POC), 6.3 and 4.5 mm^2 (LAD), 5 and 4.5 mm^2 (Cx).



Supplementary Figure 1. Flow chart of the study.



Supplementary Figure 2. Evolution of significant strut malapposition among patients between post-POT and final OCT analysis.

Supplementary Table 1. Angiographic and procedural characteristics.

	N=70
Lesion type	
Medina 1,1,1	11 (16)
Medina 1,1,0	39 (56)
Medina 1,0,1	4 (6)
Medina 0,1,1	5 (7)
Medina 1,0,0	11 (16)
PCI technique	
1-stent technique	**58 (83)**
POT/Side/rePOT	37 (64)
POT/Kissing	21 (36)
2-stent technique (including final kissing)	**12 (17)**
T-stenting	6 (50)
TAP	6 (50)
Main stent	
Diameter, mm	3.5 (3.0-3.5)
Length, mm	23 (18-28)
Maximal inflation pressure, atm	12 (10-14)
POT balloon	
Diameter, mm	4.5 (4.0-5.0)
Length, mm	12 (8-12)
Max inflation pressure, atm	16 (14-18)
2nd stent (for 2-stent technique)	
Diameter, mm	3.0 (2.5-3.5)

Length, mm	15 (12-20)
If POT/Side/rePOT: SB balloon	
Diameter, mm	3.0 (3.0-3.5)
Length, mm	12 (12-15)
Maximal inflation pressure, atm	14 (12-16)
If final kissing balloon inflation	
Balloon MB diameter, mm	3.5 (3.0-3.5)
Balloon MB length, mm	15 (12-15)
Maximal inflation pressure, atm	13 (10-16)
Balloon SB diameter, mm	3.0 (3.0-3.0)
Balloon SB length, mm	15 (12-15)
Maximal inflation pressure, atm	14 (12-16)

Supplementary Table 2. Predictors of adequate stent deployment according to the LEMON criteria.

	Univariable analysis		**Multivariable analysis**	
	OR [95% CI]	***p*-value**	**OR [95% CI]**	***p*-value**
Male gender	0.26 [0.03-2.2]	0.21		
Age (per year)	1.05 [0.99-1.11]	0.08	1.05 [0.99-1.11]	0.09
Hypertension	1.7 [0.42-6.73]	0.46		
Diabetes mellitus	3.86 [0.45-32.7]	0.22		
Presentation: chronic coronary syndrome	1.55 [0.35-6.84]	0.56		
Lesion length by OCT, per mm	1.02 [0.94-1.11]	0.64		
POT balloon diameter, per mm	0.45 [0.13-1.48]	0.19		
POT balloon/proximal LZ EEL diameter ratio	9.31 [0.1-917.9]	0.34		
Final kissing balloon inflation	1.4 [0.36-5.48]	0.63		
Plaque calcifications identified by OCT	2.7 [0.65-10.97]	0.17		
Proximal LZ EEL/EEL diameter, per mm	**0.37 [0.14-0.96]**	**0.04**	**0.36 [0.14-0.96]**	**0.04**
Distal LZ EEL/EEL diameter, per mm	0.4 [0.1-1.4]	0.15		

LZ: landing zone

Supplementary Table 3. Stent MSA and reference segment dimensions in patients with optimal and suboptimal LM final stent expansion.

	Suboptimal LM stent expansion (n=7)	**Optimal LM stent expansion (n=63)**	***p*-value**
Proximal reference segment EEL/EEL diameter, mm	5.2 (5.0-5.6)	4.9 (4.4-5.4)	0.16
Proximal reference segment mean luminal diameter, mm	4.3 (4.2-4.9)	4.0 (3.7-4.3)	0.014
Proximal reference segment max. luminal diameter, mm	4.7 (4.5-5.3)	4.4 (4.0-4.9)	0.10
Proximal reference segment MLA, mm^2	14.2 (13.9-14.9)	12.0 (10.4-13.9)	0.016
Post-PCI MSA, mm^2	9.4 (8.5-10.7)	11.9 (9.8-14.6)	0.008

All statistical comparisons by the Kruskal-Wallis test.

Supplementary Table 4. Achievement of different MSA cut-off values among the bifurcation segments according to the stenting direction.

Main vessel to main branch stent direction	Target value	N (%)
LM to LAD (N=62)	LM MSA ≥8.2 mm^2	61 (98)
	POC MSA ≥7.2 mm^2	62 (100)
	LAD MSA ≥6.3 mm^2	39 (63)
	LAD MSA ≥4.5 mm^2	57 (92)
LM to Cx (N=8)	LM MSA ≥8.2 mm^2	8 (100)
	POC MSA ≥7.2 mm^2	8 (100)
	Cx MSA ≥5 mm^2	6 (75)
	Cx MSA ≥4.5 mm^2	7 (88)

Cx: circumflex artery; LAD: left anterior descending; LM: left main artery; MSA: minimal stent area; POC: polygon of confluence

Supplementary Table 5. Evolution of malapposed strut parameters between post-POT OCT run and final OCT analysis.

Malappositon	Post-POT OCT run (run #2)		Final OCT run (run #3)	
	Prox. stent section	**Dist. stent section**	**Prox. stent section**	**Dist. stent section**
Significant malapposition (%)	51%	30%	19% *	11% #
All patients				
Radial extension (°)	108 (122)	57 (83)	47 (75) *	33 (52) #
Length (mm)	2.33 (2.87)	1.98 (2.86)	0.90 (1.58) *	0.80 (1.4) #
Maximal distance (mm)	0.49 (0.49)	0.25 (0.33)	0.21 (0.34) *	0.15 (0.24) #
Significant malapposition patients after run #2				
Radial extension (°)	199 (103)	112 (143)	75 (86) *	54 (58) #
Length (mm)	4.43 (2.6)	2.4 (3.3)	1.47 (1.9) *	1.6 (1.8) #
Maximal distance (mm)	0.89 (0.32)	0.40 (0,5)	0.33 (0.37) *	0.28 (0.27) #
Significant malapposition patients after run #3				
Radial extension (°)	155 (114)	116 (87)	150 (75)	99 (37)
Length (mm)	3.4 (2.3)	4.6 (3.6)	3.3 (1.9)	3.1 (1.4)
Maximal distance (mm)	0.75 (0.48)	0.55 (0.32)	0.78 (0.29)	0.63 (0.12)
Nominal stent diameter, mm			3.5 (0.3)	3.4 (0.2)
Stent average diameter, mm			4.2 (0.7)	3.0 (0.4)
Stent maximum diameter, mm			4.6 (0.9)	3.4 (0.4)
Stent minimum diameter, mm			3.9 (0.7)	2.7 (0.5)
Vessel average diameter, mm			4.7 (0.9)	3.3 (0.3)

Vessel maximum diameter, mm		5.4 (1.2)	3.8 (0.4)
Vessel minimum diameter, mm		4.1 (0.8)	2.8 (0.3)

* *p*-value <0.001 for proximal stent section comparison between run #3 and run #2.

p-value<0.001 for distal stent section comparison between run #3 and run #2.

Variables are expressed as mean (SD).

Supplementary Table 6. Comparison between final kissing inflation and POT/Side/rePOT strategies on final OCT parameters in LMS stent segment.

	Final kissing (n=33)	**POT/Side/ rePOT (n=37)**	***p*-value**
Pre PCI			
Prox. reference segment MLA (mm²)	12.5 (10.4-14.3)	12.5 (10.8-14.2)	0.86
Prox. reference segment EEL/EEL diameter	4.9 (4.5-5.5)	4.9 (4.4-5.5)	0.69
Prox. reference segment luminal max diameter (mm)	4.3 (4.1-5.0)	4.5 (4.1-4.8)	0.97
Prox. reference segment luminal min diameter (mm)	3.5 (3.2-4.0)	3.6 (3.2-3.9)	0.95
Prox. reference segment eccentricity	1.25 (1.15-1.37)	1.21 (1.11-1.41)	0.59
Stent diameter (mm)	3.5 (3.0-4.0)	3.5 (3.0-3.5)	0.72
Post PCI			
MSA (mm²)	11.4 (9.1-14.8)	11.7 (9.8-14.0)	0.61
Expansion (%)	93 (82-113)	99 (85-115)	0.75
Significant malapposition	6 (18)	7 (19)	0.94
Significant edge dissection	3 (9)	1 (3)	0.27

Eccentricity was calculated as the ratio between maximal and minimal luminal diameters in reference segment.

Supplementary Table 7. Correlation between local operators and core lab analysis for wire position assessment.

	Inadequate wire position (core lab)	**Adequate wire position (core lab)**	**Total**
Inadequate wire position (operator)	**7 (12%)**	**11 (18%)**	**18**
Adequate wire position (operator)	5 (8%)	37 (62%)	42
Total	12	48	60

Inter-observer K coefficient: 0.3.