**Left Main Stem Percutaneous Coronary Intervention: does onsite surgical cover make a difference?**

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**ABSTRACT**

**Background**

Non-surgical centers (NSC) contribute significantly to the capacity of overall PCI in the UK. Whilst previous studies have demonstrated similar PCI outcomes in surgical centers (SC) vs. NSC, it is unknown whether this applies to more complex procedures such as left main stem (LMS) PCI. We compared patient characteristics and outcomes of LMS PCI performed across SC and NSC in England and Wales.

**Methods**

A retrospective analysis of procedures between January 2006-March 2020 was performed using the British Cardiovascular Intervention Society database and stratified according to the surgical status of the center. The primary outcomes assessed were in-hospital major adverse cardiovascular and cerebrovascular events (MACCE), all-cause mortality and bleeding academic research consortium (BARC) stage 3-5 bleeding.

**Results**

40,744 patients underwent LMS PCI during the period, of which 13922 (34.2%) had their procedure performed at a NSC. The proportion of LMS PCI performed in NSC increased more than two-fold (15.9% in 2006 to 36.7% in 2020). There was no association between surgical cover location and in-hospital mortality (odds ratio [OR] 0.92 95%CI 0.69-1.22), in-hospital MACCE (OR 1.00 95%CI 0.79- 1.25) or emergency CABG (OR 1.00 95%CI 0.95-1.06). NSC had lower BARC 3-5 bleeding complications (OR 0.53 95%CI 0.34-0.82).

**Conclusions**

There has been an increase in LMS PCI volumes at NSC, particularly elective LMS PCI. LMS PCI performed at NSC was not associated with increased mortality, in-hospital MACCE or emergency CABG, despite higher disease complexity.

Key words:

Left main stem disease, Percutaneous coronary intervention, surgical centers, revascularization

**NON-STANDARD ABBREVIATIONS AND ACRONYMS**

| | |
|---|---|
| ACS | Acute coronary syndromes |
| AMI | Acute myocardial infarction |
| BARC | Bleeding academic research consortium |
| BCIS | British Cardiovascular Intervention Society |
| CABG | Coronary artery bypass graft |
| CI | Confidence interval |
| CVA | Cerebrovascular accident |
| DES | Drug eluting stent |
| FFR | Fractional flow reserve |
| GP-2b3a | Glycoprotein IIb/IIIa inhibitor |
| HQIP | Healthcare Quality Improvement Partnership |
| IHD | Ischemic heart disease |
| IVUS | Intravascular ultrasound |
| LMS | Left main stem |
| LV | Left ventricle |
| MACCE | Major adverse cardiovascular and cerebrovascular events |
| NHS | National Health Service |
| NSC | Non-surgical centres |
| OCT | Optical coherence tomography |
| PCI | Percutaneous coronary intervention |
| PVD | Peripheral vascular disease |
| OR | Odds ratio |
| SC | Surgical centres |
| SD | Standard deviation |

**WHAT IS KNOWN?**

- Previous studies have demonstrated similar PCI outcomes at surgical vs. non-surgical centers, although it is unknown whether these findings can be extrapolated to LMS PCI with only a few small reports demonstrating efficacy at non-surgical centers.

**WHAT THE STUDY ADDS?**

- This national analysis highlights a significant change in practice over the last decade with a significant increase of LMS PCI occurring in non-surgical centers.
- There was no association with increased mortality, in-hospital MACCE or emergency CABG despite increased disease complexity thereby demonstrating in-hospital outcomes are not compromised by absence of onsite surgical backup.

## INTRODUCTION

Traditionally, the gold standard treatment for patients with significant left main stem (LMS) disease has been coronary artery bypass graft surgery (CABG). However, with advancements in stent technology, percutaneous coronary intervention (PCI) techniques and imaging, as well as a growing evidence base, the treatment of LMS disease with PCI has evolved from salvage scenarios to include intermediate-low risk patient categories[1-5].

LMS PCI is a relatively high-risk procedure due to the large proportion of myocardium subtended, which may be associated with ventricular dysfunction, arrhythmias, or hemodynamic instability. Approximately 5% of patients undergoing coronary angiography have significant LMS disease[6]. They may present in elective and acute settings, often posing complex decision making regarding the optimal revascularization strategy, which can be logistically challenging in non-surgical centers (NSC). In the UK, following the publication of the coronary heart disease national framework standard in 2000, there was a considerable expansion of PCI facilities in NSC to accommodate an increasing clinical demand, especially for acute coronary syndromes (ACS)[6-8]. Following on, the number and proportion of centers performing PCI in NSC have increased, so that since 2011 they represent 64% of centers[9].

Previous studies undertaken both in North America and the UK have demonstrated no significant difference in outcomes of PCI performed at surgical centers (SC) vs. NSC[10-14]. However, it is unknown whether this can be extrapolated to LMS PCI, especially since LMS patients are frequently excluded from larger studies. Single center reports from individual NSC in the UK have demonstrated the safety and efficacy of LMS PCI with modest patient numbers, although they have not been compared to outcomes in SC[10, 11, 13, 15].

Our aim was to study the clinical and angiographic profile of patients undergoing unprotected LMS PCI in SC vs. NSC across the UK over a 15 year period. We also sought to investigate associations between the surgical status of centers and clinical outcomes (in-hospital all-cause mortality, MACCE and major bleeding).

## METHODS

*Study Setting and population*

In this retrospective population cohort study, we interrogated the British Cardiovascular Intervention Society (BCIS) registry to include all patients age >18 years undergoing PCI for unprotected LMS disease between 1st January 2006 to 31st March 2020 (figure S1). BCIS PCI registry collects information about clinical characteristics, angiographic profile, procedural pharmacology, and in-hospital outcomes of all patients undergoing PCI in any National Health Service (NHS) acute hospitals[9]. The encrypted and pseudonymized data are used for audit, research and public reporting without formal individual patient consent under section 251 of NHS act 2006. Data are processed by the Healthcare Quality Improvement Partnership in a collaboration with the National Institute of Cardiovascular Outcomes Research host. This study did not require institutional ethical approval because we processed the data without patient identifiable information[16-18]. Requests to access the dataset from qualified researchers may be sent to the BCIS-NICOR group, but we do not have permission to share the data.

Patients with missing information about important study demographics such as age, in-hospital death and LMS PCI variable were excluded from the study (table S1). The proportion of unavailable information for each variable was reported for the overall cohort as well as the NSC and SC cohorts separately. The final study cohort contained patients from 119

centers which were grouped into onsite SC vs. NSC based on the presence or absence of on-site cardiothoracic surgical support.

The primary outcome was all-cause in-hospital mortality. Secondary outcomes included major adverse cardiovascular and cerebrovascular events (MACCE; composite of death, acute stroke/transient ischemic attack and reinfarction), emergency CABG, and bleeding academic research consortium (BARC) stage 3-5 bleeding, as per the standard definition[19].

*Statistical Analysis*

Patient demographics and procedural characteristics of the SC were compared with the NSC group. Continuous variables were presented as mean values with standard deviation (SD) after checking the data distribution and compared using the t-test. Categorical variables are summarized as percentages and analyzed using the chi-squared test. Cochrane Armitage test was used to study statistically significant differences in the temporal trends of LMS PCI stratified by PCI indication. The missing data were assumed to be missing at random and were imputed using multiple imputations with chained equations (table S1). The levels of unavailable data are high for certain variables, although it has been shown that multiple imputation frameworks are robust even when levels of missingness are extremely high. Although, some protection is offered when data is not missing at random. Ten imputed datasets were generated, and all subsequent analyses were performed on the imputed datasets. Final model estimates were pooled using Rubin's rule[20, 21]. Multi-level multivariable logistic regression models were used, with random intercepts for centers to account for the nested structure of the data, in order to 1) assess the association between surgical cover status and in-hospital adverse outcomes, namely mortality, MACCE, BARC 3-5 bleeding and emergency CABG, and 2) examine predictors of in-hospital mortality among patients undergoing PCI for LMS

disease. To assess the results from multiple imputation analyses, we also performed a complete case analysis by excluding missing variable information as a sensitivity analysis. All associations are reported as odds ratios (OR) with corresponding 95% confidence intervals (CI).

Variables adjusted for in the models included: age, sex, race, year of procedure, clinical syndrome, previous acute myocardial infarction (AMI), previous PCI, prior coronary artery bypass graft surgery (CABG), diabetes mellitus, renal failure (Creatinine ≥200 $\mu$mol/l and/or dialysis), family history of ischaemic heart disease (IHD), left ventricular (LV) function, hypercholesterolaemia, peripheral vascular disease (PVD), previous cerebrovascular accident (CVA), hypertension, smoking status, cardiogenic shock, mechanical ventilation, circulatory support (intra-aortic balloon pump or LV assist device), vascular access, number of vessels and lesions attempted, number of drug-eluting stents (DES), use of fractional flow reserve (FFR), intravascular imaging (intravascular ultrasound (IVUS) or optical coherence tomography (OCT)) or calcium modification (rotablation, laser angioplasty), and in-hospital pharmacotherapy (clopidogrel, ticagrelor, prasugrel, warfarin, glycoprotein IIb/IIIa inhibitor (GP-2b3a)). All statistical analyses were performed using Stata 16 MP (College Station, TX).

## RESULTS

A total of 40,744 patients underwent unprotected LMS PCI during the study period, of which 13,922 (34.2%) had LMS PCI at NSC. The percentage of LMS PCI undertaken at NSC steadily increased from 15.9% in 2006 to 36.7% in 2020 (Ptrend <0.001) (Figure 1).

Patients in the NSC group were older (mean age 70.9 years vs. 70.4 years, p<0.001) and less likely to be females (26.4% vs. 28.4%, p<0.001) compared to the SCs. Patients in the SC group had higher prevalence of cardiovascular comorbidities such as hypertension (64.1%

vs. 62.1%, p<0.001), hypercholesterolemia (58.8% vs. 60.4%, p<0.001) and poor LV systolic function (19.2% vs. 17.1%, p<0.001). The NSC group were more likely to be treated with clopidogrel (72.2% vs. 61.7%, p<0.001) as a choice of second antiplatelet following PCI.

There were changes in PCI practice when stratified by the indication. Elective LMS PCI increased from 34.4% in 2006 to 42.8% in 2020 (Ptrend <0.001), which was mirrored with the decrease in the LMS PCI for ACS indication in the NSC from 53.3% to 46.0%, respectively (Ptrend <0.001) (Figure 2). In contrast, the STEMI indication for LMS PCI remained stable in both NSCs and SCs. (Ptrend 0.81) (Figure 3). There were significant center variations in the proportions of LMS PCI, however higher proportions of LMS PCI were undertaken at NSC and the majority of SC performed lower volumes of LMS PCI during the study period (Figure 4).

There were important differences in the angiographic profile of the NSC group compared to the SC group, as reported in Table 1. The NSC group displayed higher disease complexity with an increased number of lesions (≥3) treated (30.3% vs. 28.8%, p<0.001), the number of vessels (≥3) treated (31.7% vs. 27.9%, p<0.001), and more than three stents used (28.6% vs. 26.8%, p<0.001) compared to the SC group. Intracoronary imaging in the form of IVUS or OCT (43.8% vs. 53.5%, p<0.001) was significantly lower in the SC than in the NSC. Similarly, radial access was less commonly used in the SC (56.9% vs. 63.2%, p<0.001) compared to the NSC. However, atherectomy was less commonly used in the NSC (9.4% vs.11.7%, p<0.001) compared to SC.

The crude in-hospital mortality (7.0% vs. 5.7%, p<0.001), in-hospital MACCE (8.5% vs. 7.6%, p 0.002) and emergency CABG (0.2% vs. 0.1%, p 0.005) were significantly higher in the SCs compared to NSCs. However, after the adjustment of case-mix differences, there was no association between surgical cover status and in-hospital mortality (OR 0.92 95%CI 0.69-1.22), in-hospital MACCE (OR 1.00 95%CI 0.79-1.25) and emergency CABG (OR 1.00

95%CI 0.95-1.06). NSC had significantly lower odds of BARC 3-5 bleeding complications (OR 0.53 95%CI 0.34-0.82) compared to the SCs. Similar outcomes were observed when NSCs were stratified according to PCI indication compared to the SCs (Table 2). The results of complete case analysis showed similar results to the imputated dataset (see table S2).

Finally, the independent predictors of in-hospital mortality are reported in Table 3. Use of IVUS (OR 0.44 95%CI 0.38-0.51), OCT (OR 0.43 95%CI 0.27-0.69) and radial access (0.63 95%CI 0.56-0.71) were strongly associated with lower odds of in-hospital mortality. STEMI presentation (OR 8.17 95%CI 6.46-10.35), cardiogenic shock (OR 6.66 95%CI 5.85-7.59) and female sex (OR 1.24 95%CI 1.11-1.31) were associated with increased in-hospital mortality.

## DISCUSSION

This is the first national report comparing the clinical characteristics and outcomes of LMS PCI in SCs vs. NSC. We observed an over two-fold increase in PCI for LMS disease at NSC, although there was significant variation in LMS PCI volumes between centers. The proportion of LMS PCI for STEMI has remained stable, but elective LMS PCI activity has increased significantly with an almost 8.4% temporal increase at NSC. There was a higher use of intracoronary imaging and transradial access at the NSC compared to the SC. Finally, despite the higher lesion and case complexity of PCI undertaken at NSC, there was no association between surgical cover status and in-hospital mortality, MACCE and emergency CABG.

The original expansion of NSC in the UK was driven by high rates of cardiovascular disease and a national directive to improve revascularization rates after a prolonged period of inequitable service distribution[14]. It was not primarily intended to facilitate high-risk elective

PCI, and yet we observed a significant increase in elective LMS PCI at NSC. There is no formal criteria in the UK regarding which patients can or cannot be treated at a NSC providing the appropriate expertise and equipment is available[14, 22]. It is plausible that recent trial data, coupled with increased local availability of adjunctive technology such as IVUS/OCT, rotational atherectomy, and circulatory support may have encouraged NSC operators to undertake more complex procedures such as LMS PCI[1-3, 5, 23]. Data from previous studies have shown that routine PCI can be safely performed without onsite surgical backup[10, 13-15]. However, our study shows that these practices can safely be extrapolated to high-risk LMS PCI without an increase in in-hospital adverse outcomes.

Patients in the SC group had a higher clinical risk profile with increased prevalence of cardiovascular comorbidities, including hypertension, hypercholesterolemia, LV impairment and renal disease. Some of these patients might have been specifically selected for referral to SC following heart team discussion due to perceived increased risk, given the readily available access to facilities such as mechanical support devices, calcium modification adjuncts, renal dialysis capacity and emergency cardiac surgery. Indeed, we observed increased use of IABP and rotational atherectomy at SC which most likely reflects this increased comorbidity burden.

NSC had a lower incidence of BARC 3-5 bleeding complications than SC which is likely to be driven by the increased use of trans-radial access at NSC, since this is known to be associated with lower access site related bleeding complications[24–27]. There was a significantly higher use of intravascular imaging (50.6% vs. 39.9%) at the NSC compared to SC. Furthermore, intravascular imaging use was a strong independent predictor of reduced in-hospital mortality. IVUS-guided PCI is associated with lower long-term risks of mortality and MACCE compared with angiography-guided PCI in patients undergoing PCI for unprotected left main coronary artery disease[1, 28, 29]. In Excel IVUS substudy, use of IVUS influenced stent

strategy and equipment size, including larger balloon utilization, high-pressure inflation, identification, and optimization of stent under expansion[3]. The increased use of radial access and intravascular imaging at NSCs may potentially have resulted in superior medium-long term outcomes given the benefits of less early bleeding combined with the advantages of optimal stent sizing and apposition conferred by intravascular imaging, however this is beyond the remit of our study.

Finally, the requirement for onsite surgery originated from the days of early angioplasty, where emergency CABG occurred in more than 5% of cases but advances in technology have significantly reduced the need for it[30]. Our cohort demonstrated this, with only 0.2% and 0.1% of patients in the SC and NSC groups respectively required emergency cardiac surgery for LMS PCI.

Given this is an observational study, we could not adjust for variables not collected in the original database. In addition, the study does not report on outcome measures such as repeat revascularization, recurrent MI or MACCE beyond the index hospital admission. Syntax scoring and anatomic information such as the location/type of disease within the LMS were not available. Finally, we are not able to ascertain information about the decision-making processes or use of MDT discussions in these cases.

PCI in the LMS is regarded as a relatively challenging procedure. Decision-making regarding revascularization in LMS disease is often complex and influenced by several factors that should be discussed at multidisciplinary meetings. The use of intracoronary imaging should be considered in every case as it has been shown to impact strategy and outcomes favorably. Our findings suggest that performing this procedure is safe and feasible in NSC[31, 32].

## CONCLUSION

There has been a significant increase in LMS PCI volumes at NSC, particularly elective LMS PCI. Disease complexity was significantly higher in the NSC cohort, and despite this LMS PCI performed at NSCs was not associated with increased mortality, in-hospital MACCE or emergency CABG compared to SC. These findings suggest that the performance of LMS PCI in hospitals without onsite cardiac surgery does not compromise in-hospital outcomes and is a potential safe and feasible option.

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**DISCLOSURES**

All authors declare no relevant conflicts in relation to the content of this paper.

**SUPPLEMENTAL MATERIAL**

Tables S1-2

Figure S1

**REFERENCES**

1. Ladwiniec A, Walsh SJ, Holm NR, Hanratty CG, Makikallio T, Kellerth T, Hildick-Smith D, Mogensen LJH, Hartikainen J, Menown IBA et al. Intravascular ultrasound to guide left main stem intervention: a NOBLE trial substudy. EuroIntervention. 2020;16:201-209.

2. Makikallio T, Holm NR, Lindsay M, Spence MS, Erglis A, Menown IBA, Trovik T, Eskola M, Romppanen H, Kellerth T et al. Percutaneous coronary angioplasty versus coronary artery bypass grafting in treatment of unprotected left main stenosis (NOBLE): a prospective, randomised, open-label, non-inferiority trial. Lancet. 2016;388:2743-52.

3. Maehara A, Mintz G, Serruys P, Kappetein A, Kandzari D, Schampaert E, Van Boven A, Horkay F, Ungi I, Mansour S, et al. Impact of final minimal stent area by IVUS on 3-year outcome after PCI of left main coronary artery disease: the EXCEL trial. **J Am Coll Cardiol**. 2017;69:963.

4. Cavalcante R, Sotomi Y, Lee CW, Ahn JM, Farooq V, Tateishi H, Tenekecioglu E, Zeng Y, Suwannasom P, Collet C et al. Outcomes after percutaneous coronary intervention or bypass surgery in patients with unprotected left main disease. J Am Coll Cardiol. 2016;68:999-1009.

5. Mohr FW, Morice M, Kappetein AP, Feldman T, Stahle E, Colombo A, Mack M, Holmes DR, Morel M, Dyck NV, Houle VM et al. Coronary artery bypass graft surgery versus percutaneous coronary intervention in patients with three-vessel disease and left main coronary disease: 5-year follow-up of the randomised, clinical SYNTAX trial. Lancet. 2013;381:629-38.

6. DeMots H, Rosch J, McAnulty JH, Rahimtoola SH. Left main coronary artery disease. Cardiovasc Clin. 1977;8:201-11.

7. Dawkins KD, Gershlick T, De Belder M, Chauhan A, Venn G, Schofield P, Smith D, Watkins K, Gray HH. Percutaneous coronary intervention: recommendations for good practice and training. Heart. 2005;91:vi1-vi27.

8. Boyle R. DoH explains thinking behind national service framework for coronary heart disease. BMJ. 2000;321:1083.

9. Rashid M, Ludman PF, Mamas MA. British Cardiovascular Intervention Society registry framework: a quality improvement initiative on behalf of the National Institute of Cardiovascular Outcomes Research (NICOR). Eur Heart J Qual Care Clin Outcomes. 2019;5:292-7.

10. Adamson P, Ayling J, Gillespie J, Walker J, Hamer A, Fisher N. The first New Zealand experience of Percutaneous Coronary Intervention without onsite cardiac surgery. Heart, Lung and Circulation. 2009;18:S2.

11. Stub D, Hanson L, Vogrin S, Noaman S, Goh CY, Dinh D, Lefkovits J, Reid CM, Brennan A, Zheng W et al. Clinical Outcomes of Unprotected Left Main Coronary Artery Percutaneous Coronary Intervention in Australian Non-Surgical Centres. Heart, Lung and Circulation. 2021;30:S296.

12. Coughlan JJ, Blake N, Chongprasertpon N, Ibrahim M, Arnous S, Kiernan TJ. Revascularisation of left main stem disease: a prospective analysis of modern practice and outcomes in a non-surgical centre. Open Heart. 2018;5:e000804.

13. Alaour B, Onwordi E, Khan A, Menexi C, Carta S, Strike P, Griffiths H, Anantharam B, Hobson A, Dana A. Outcome of left main stem percutaneous coronary intervention in a UK nonsurgical center: A 5-year clinical experience. Catheter Cardiovasc Interv. 2021;99:601–606.

14. Garg S, Anderson SG, Oldroyd K, Berry C, Emdin C, Peters SAE, West NEJ, Kelly D, Balachandran K, Mcdonald J et al. Outcomes of percutaneous coronary intervention performed at offsite versus onsite surgical centers in the United Kingdom. J Am Coll Cardiol. 2015;66:363-72.

15. Rao U, Eccleshall S, Sarev T, Hughes L, Ryding A, Wistow T, Gilbert T. 27 Clinical outcomes of unprotected left main stem percutaneous coronary intervention in a non-surgical centre. Heart. 2016;102:A12-A13.

16. Taxiarchi P, Kontopantelis E, Kinnaird T, Curzen N, Banning A, Ludman P, Shoaib A, Rashid M, Martin GP, Mamas MA. Adoption of same day discharge following elective left main stem percutaneous coronary intervention. Int J Cardiol. 2020;321:38-47.

17. Rashid M, Wu J, Timmis A, Curzen N, Clarke S, Zaman A, Nolan J, Shoaib A, Mohamed MO, Belder MA et al. Outcomes of COVID-19 Positive Acute Coronary Syndrome Patients; a multisource Electronic Healthcare Records Study from England. J Intern Med. 2021;290:88-100.

18. Shoaib A, Van Spall HGC, Wu J, Cleland JGF, McDonagh TA, Rashid M, Mohamed MO, Ahmed FZ, Deanfield J, Belder MA et al. Substantial decline in hospital admissions for heart failure accompanied by increased community mortality during COVID-19 pandemic. Eur Heart J Qual Care Clin Outcomes. 2021;7:378-87.

19. Rashid M, Rushton CA, Kwok CS, Kinnaird T, Kontopantelis E, Olier I, Ludman P, Belder MA, Nolan J, Mamas MA. Impact of Access Site Practice on Clinical Outcomes in Patients Undergoing Percutaneous Coronary Intervention Following Thrombolysis for ST-Segment Elevation Myocardial Infarction in the United Kingdom: An Insight From the British Cardiovascular Intervention Society Dataset. JACC Cardiovasc Interv. 2017;10:2258-65.

20. Rubin DB. Multiple Imputation for Nonresponse in Surveys 1987 Wiley New York. 1987.

21. Rubin DB. Multiple imputation after 18 years. Journal of the American statistical Association. 1996;91:473-89.

22. Banning AP, Baumbach A, Blackman D, Curzen N, Devadathan S, Fraser D, Ludman P, Norell M, Muir D, Nolan J et al. Percutaneous coronary intervention in the UK: recommendations for good practice 2015. Heart. 2015;101:1-13.

23. Morice M, Serruys PW, Kappetein AP, Feldman TE, Stahle E, Colombo A, Mack MJ, Holmes DR, Torracca L, Gerrit-Anne VE et al. Outcomes in patients with de novo left main disease treated with either percutaneous coronary intervention using paclitaxel-eluting stents or coronary artery bypass graft treatment in the Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery (SYNTAX) trial. Circulation. 2010;121:2645-53.

24. Rao SV, Hess CN, Barham B, Aberle LH, Anstrom KJ, Patel TB, Jorgensen JP, Mazzaferri EL Jr, Jolly SS, Jacobs A et al. A registry-based randomized trial comparing radial and femoral approaches in women undergoing percutaneous coronary intervention: the SAFE-PCI for Women (Study of Access Site for Enhancement of PCI for Women) trial. JACC Cardiovasc Interv. 2014;7:857-67.

25. Jolly SS, Yusuf S, Cairns J, Niemela K, Xavier D, Widimsky P, Budaj A, Niemela M, Valentin V, Lewis BS et al. Radial versus femoral access for coronary angiography and intervention in patients with acute coronary syndromes (RIVAL): a randomised, parallel group, multicentre trial. Lancet. 2011;377:1409-20.

26. Romagnoli E, Biondi-Zoccai G, Sciahbasi A, Politi L, Rigattieri S, Pendenza G, Summaria F, Patrizi R, Borghi A, Russo CD et al. Radial versus femoral randomized investigation in ST-segment elevation acute coronary syndrome: the RIFLE-STEACS (Radial Versus

Femoral Randomized Investigation in ST-Elevation Acute Coronary Syndrome) study. J Am Coll Cardiol. 2012;60:2481-9.

27. Ando G, Capodanno D. Radial Access Reduces Mortality in Patients With Acute Coronary Syndromes: Results From an Updated Trial Sequential Analysis of Randomized Trials. JACC Cardiovasc Interv. 2016;9:660-70.

28. Kang D, Ahn J, Yun S, Park H, Cho SC, Kim TO, Park S, Lee PH, Lee SW, Park SW et al. Long-term clinical impact of intravascular ultrasound guidance in stenting for left main coronary artery disease. Circulation: Cardiovascular Interventions 2021;14:e011011.

29. Maehara A, Mintz G, Serruys P, Kappatein A, Kandzari D, Schampaert E, Boven AV, Horkay F, Ungi I, Mansour S et al. Impact of final minimal stent area by IVUS on 3-year outcome after PCI of left main coronary artery disease: the EXCEL trial. J Am Coll Cardiol. 2017;69:963.

30. de Belder MA. On-site surgical standby for percutaneous coronary intervention: a thing of the past? Heart. 2007;93:281.

31. Neumann F, Sousa-Uva M, Ahlsson A, Alfonso F, Banning AP, Benedetto U, Byrne RA, Collet JP, Falk V, Head SJ et al. 2018 ESC/EACTS Guidelines on myocardial revascularization. Eur Heart J. 2019;40:87-165.

32. Lawton JS, Tamis-Holland JE, Bangalore S, Bates ER, Beckie TM, Bischoff JM, Bittl JA, Cohen MG, DiMaio JM, Don CW et al. 2021 ACC/AHA/SCAI Guideline for Coronary Artery Revascularization: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2022;145:e4–e17.

## TABLES

**Table 1:** Baseline characteristics and angiographic profile of patients undergoing LMS PCI

| Variable | Surgical onsite | Surgical offsite | |
|---|---|---|---|
| Number of patients | 26822 (65.8%) | 13922 (34.2%) | |
| Age, mean ± SD | 70.4 (11.8) | 70.9 (11.4) | <0.001 |
| Females | 7618 (28.4%) | 3663 (26.4%) | <0.001 |
| BMI | 27.9 (5.5) | 27.9 (5.3) | 0.91 |
| Indication | | | |
| Stable | 10449 (39.0%) | 5587 (40.1%) | <0.001 |
| NSTEMI | 11787 (44.0%) | 6249 (44.9%) | |
| STEMI | 4582 (17.1%) | 2086 (15.0%) | |
| Smoking status | | | |
| Non-smoker | 9503 (40.8%) | 4673 (38.3%) | <0.001 |
| Current smoker | 3843 (16.5%) | 1847 (15.1%) | |
| Ex-smoker | 9932 (42.7%) | 5684 (46.6%) | |
| Comorbidities | | | |
| Prior PCI (%) | 6901 (26.7%) | 4354 (32.1%) | <0.001 |
| Prior MI (%) | 9024 (36.4%) | 4790 (36.0%) | 0.39 |
| Diabetes (%) | 6755 (26.3%) | 3438 (25.7%) | 0.25 |
| Hypertension (%) | 16146 (64.1%) | 8155 (62.1%) | <0.001 |
| Hypercholesterolemia | 15220 (60.4%) | 7724 (58.8%) | <0.001 |
| Family history of heart disease (%) | 8727 (38.8%) | 5178 (43.8%) | <0.001 |
| Renal disease (%) | 2985 (11.3%) | 1243 (9.0%) | <0.001 |
| Peripheral vascular disease | 2618 (10.4%) | 1353 (10.3%) | 0.80 |
| Prior cerebrovascular accident | 1791 (7.1%) | 997 (7.6%) | 0.08 |
| Left Ventricular Ejection Fraction | | | |

| | | | |
|---|---|---|---|
| Good (LVEF >=50%) | 8212 (59.4%) | 5186 (66.0%) | <0.001 |
| Fair (LVEF 30%-49%) | 2954 (21.4%) | 1326 (16.9%) | |
| Poor (LVEF <= 29%) | 2650 (19.2%) | 1341 (17.1%) | |
| Pharmacology | | | |
| GPIIb/IIIa inhibitor | 4998 (20.4%) | 2544 (19.7%) | 0.12 |
| Clopidogrel | 14446 (61.7%) | 8992 (72.2%) | <0.001 |
| Prasugrel | 735 (3.1%) | 328 (2.6%) | 0.007 |
| Ticagrelor | 4178 (17.8%) | 1942 (15.6%) | <0.001 |
| Warfarin | 357 (1.5%) | 173 (1.4%) | 0.31 |
| Procedural characteristics | | | |
| Pressure Wire | 1877 (8.0%) | 1542 (12.2%) | <0.001 |
| Intravascular ultrasound | 9296 (39.9%) | 6404 (50.6%) | <0.001 |
| Optical coherence tomography | 901 (3.9%) | 368 (2.9%) | <0.001 |
| IABP use | 2252 (9.0%) | 904 (6.8%) | <0.001 |
| Cardiogenic shock on admission | 2737 (12.3%) | 1273 (11.4%) | 0.02 |
| Number of drug eluting stents | | | |
| 0 | 3915 (19.2%) | 1882 (18.2%) | <0.001 |
| 1 | 5704 (28.0%) | 2702 (26.1%) | |
| 2 | 5285 (26.0%) | 2801 (27.1%) | |
| ≥3 | 5457 (26.8%) | 2962 (28.6%) | |
| Number of lesions treated | | | <0.001 |
| 1 | 5285 (28.5%) | 2563 (26.0%) | |
| 2 | 6630 (35.8%) | 3455 (35.1%) | |
| ≥3 | 5344 (28.8%) | 2984 (30.3%) | |
| Number of vessels treated | | | <0.001 |
| Single vessel PCI | 7694 (28.7%) | 2870 (20.6%) | |
| 2 Vessel PCI | 11638 (43.4%) | 6636 (47.7%) | |
| 3 vessel PCI | 7490 (27.9%) | 4416 (31.7%) | |
| Directional/rotational atherectomy | 2403 (11.7%) | 1071 (9.4%) | <0.001 |

| | | | |
|---|---|---|---|
| Radial access | 14826 (56.9%) | 8543 (63.2%) | <0.001 |
| Stent Length | 27.6 (16.5) | 32.7 (20.5) | <0.001 |
| Stent Diameter | 4.0 (0.6) | 4.1 (0.6) | <0.001 |
| Outcomes | | | |
| In-hospital MACCE | 2242 (8.5%) | 1047 (7.6%) | 0.002 |
| In-hospital mortality | 1802 (7.0%) | 773 (5.7%) | <0.001 |
| Bleeding complications | 347 (1.3%) | 89 (0.6%) | <0.001 |
| Emergency CABG | 54 (0.2%) | 12 (0.1%) | 0.005 |

BMI: Body Mass Index, CABG: Coronary artery bypass graft, GPIIb/IIIa: Glycoprotein IIb/IIIa, IABP: Intra-aortic balloon pump, LVEF: Left Ventricular Ejection Fraction, MACCE: Major adverse cardiovascular and cerebrovascular events, MI: Myocardial Infarction, NSTEMI: Non-ST Elevation Myocardial Infarction, PCI: Percutaneous Coronary Intervention, SD: Standard deviation, STEMI: ST Elevation Myocardial Infarction.

**Table 2**: Adjusted odds of in-hospital outcomes in the imputated dataset

| Outcomes | Reference | Odds Ratio (95% CI) |
|---|---|---|
| In-hospital mortality | On-site surgical | 0.92 (0.69-1.22) |
| In-hospital MACCE | On-site surgical | 1.00 (0.79-1.25) |
| In-hospital bleeding | On-site surgical | 0.53 (0.34-0.82) |
| Emergency CABG | On-site surgical | 1.00 (0.95-1.06) |
| **Elective PCI** | | |
| In-hospital mortality | On-site surgical | 0.87 (0.53-1.43) |
| In-hospital MACCE | On-site surgical | 0.96 (0.69-1.33) |
| In-hospital bleeding | Onsite surgical | 0.59 (0.37-0.94) |
| Emergency CABG | Onsite surgical | 0.93 (0.74-1.51) |
| **ACS PCI** | | |
| In-hospital mortality | On-site surgical | 1.05 (0.78-1.41) |
| In-hospital MACCE | On-site surgical | 0.96 (0.77-1.19) |
| In-hospital bleeding | On-site surgical | 0.46 (0.33-0.63) |
| Emergency CABG | On-site surgical | 0.94 (0.66-1.17) |
| **STEMI PCI** | | |
| In-hospital mortality | On-site surgical | 1.04 (0.74-1.45) |
| In-hospital MACCE | On-site surgical | 1.00 (0.72-1.40) |
| In-hospital bleeding | On-site surgical | 0.48 (0.30-0.78) |
| Emergency CABG | On-site surgical | 0.99 (0.87-1.30) |

ACS: Acute coronary syndrome, CABG: Coronary artery bypass graft, CI: Confidence Interval, MACCE: Major adverse cardiovascular and cerebrovascular events, NSTEMI: Non-ST Elevation Myocardial Infarction, PCI: Percutaneous Coronary Intervention, STEMI: ST Elevation Myocardial Infarction.

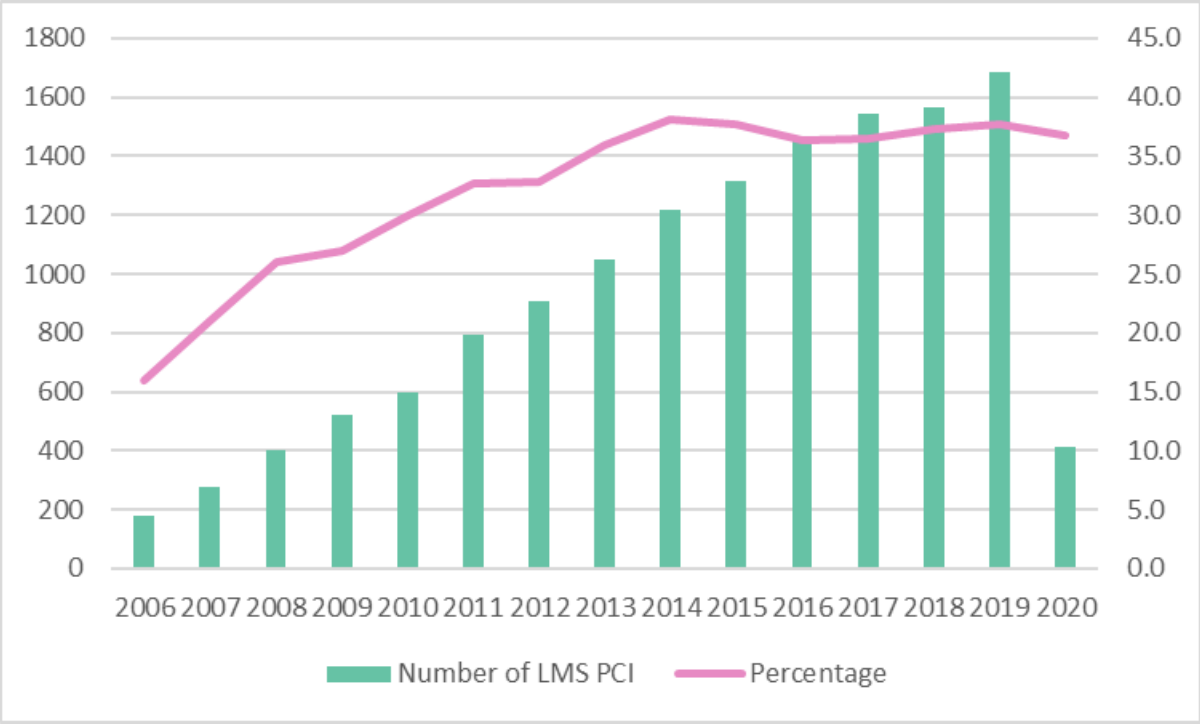
**Table 3:** Independent predictors of mortality in patients undergoing LMS PCI

| Variable | Odds ratio (95% confidence interval) |
|---|---|
| Indication for PCI | |
| NSTEMI/ACS | 3.15 (2.54-3.91) |
| STEMI | 8.17 (6.46-10.35) |
| Hypertension | 1.00 (0.89-1.13) |
| Hypercholesteremia | 0.80 (0.71-0.89) |
| Peripheral vascular disease | 1.66 (1.41-1.95) |
| Previous PCI | 0.82 (0.70-0.95) |
| Previous AMI | 1.05 (0.92-1.20) |
| Diabetes mellitus | 1.21 (1.07-1.37) |
| Smoking status | |
| Current smoker | 1.15 (0.97-1.36) |
| Ex-smoker | 1.02 (0.90-1.17) |
| Clopidogrel use | 0.78 (0.68-0.90) |
| Prasugrel use | 0.60 (0.45-0.81) |
| Ticagrelor | 0.72 (0.62-0.88) |
| IVUS use | 0.44 (0.38-0.51) |
| OCT use | 0.43 (0.27-0.69) |
| Cardiogenic shock | 6.66 (5.85-7.59) |
| Age (per year) | 1.01 (1.00-1.01) |
| Female sex | 1.24 (1.11-1.31) |
| Radial access | 0.63 (0.56-0.71) |

ACS: Acute coronary syndrome, AMI: Acute myocardial infarction, CI: Confidence Interval, IVUS: Intravascular ultrasound, NSTEMI: Non-ST Elevation Myocardial Infarction, OCT: Optical coherence tomography, PCI: Percutaneous Coronary Intervention, STEMI: ST Elevation Myocardial Infarction.

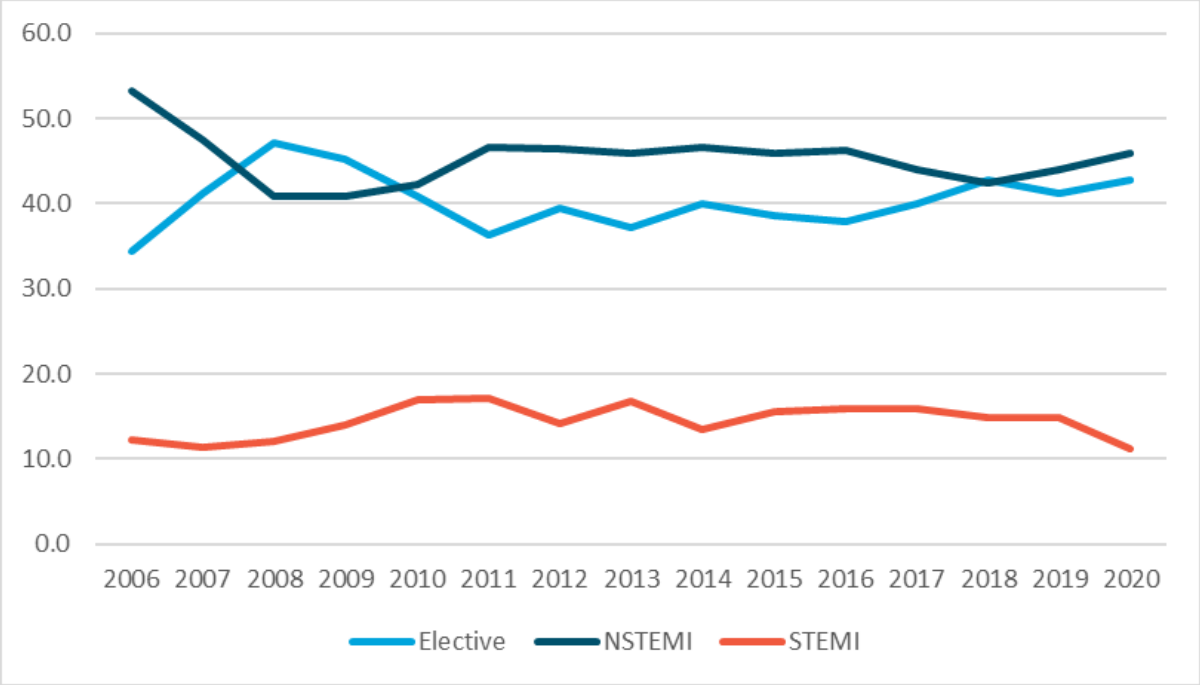
**FIGURES**

**Figure 1**: Temporal trends in LMS PCI volumes performed in non-surgical centers



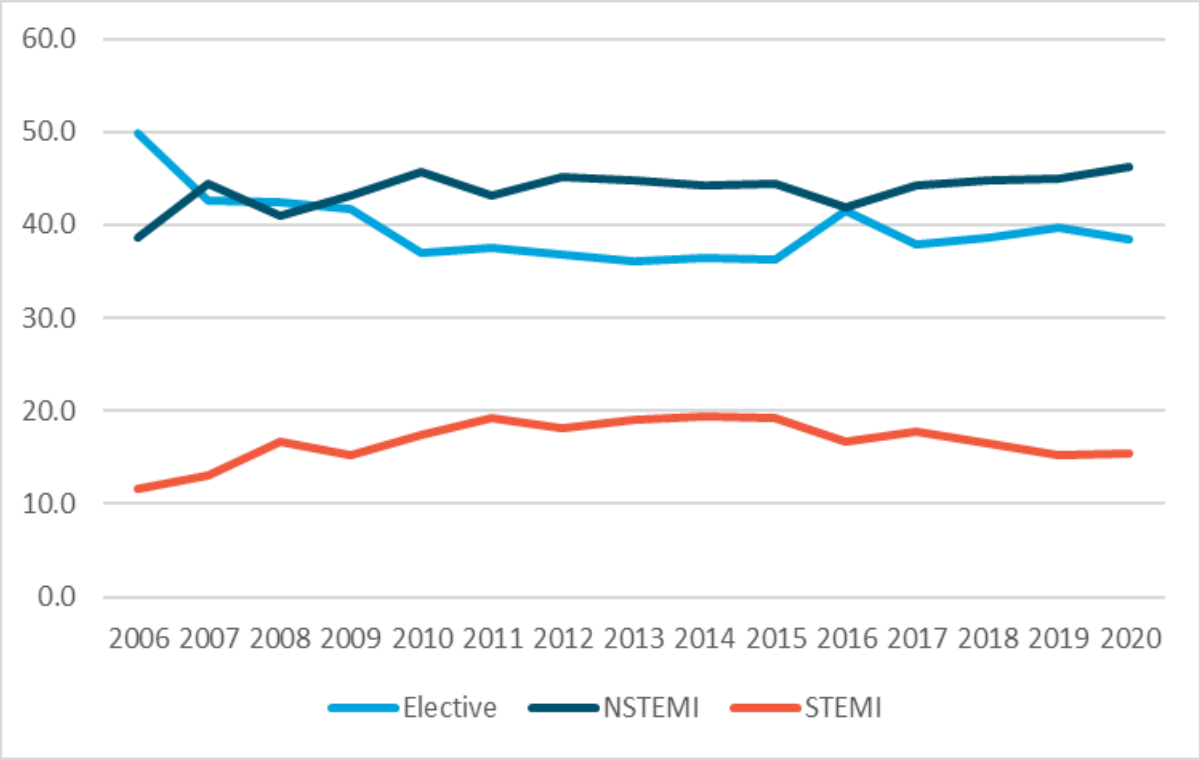

LMS: Left main stem, PCI: Percutaneous coronary intervention

**Figure 2**: Temporal trends in LMS PCI in non-surgical centers by indication



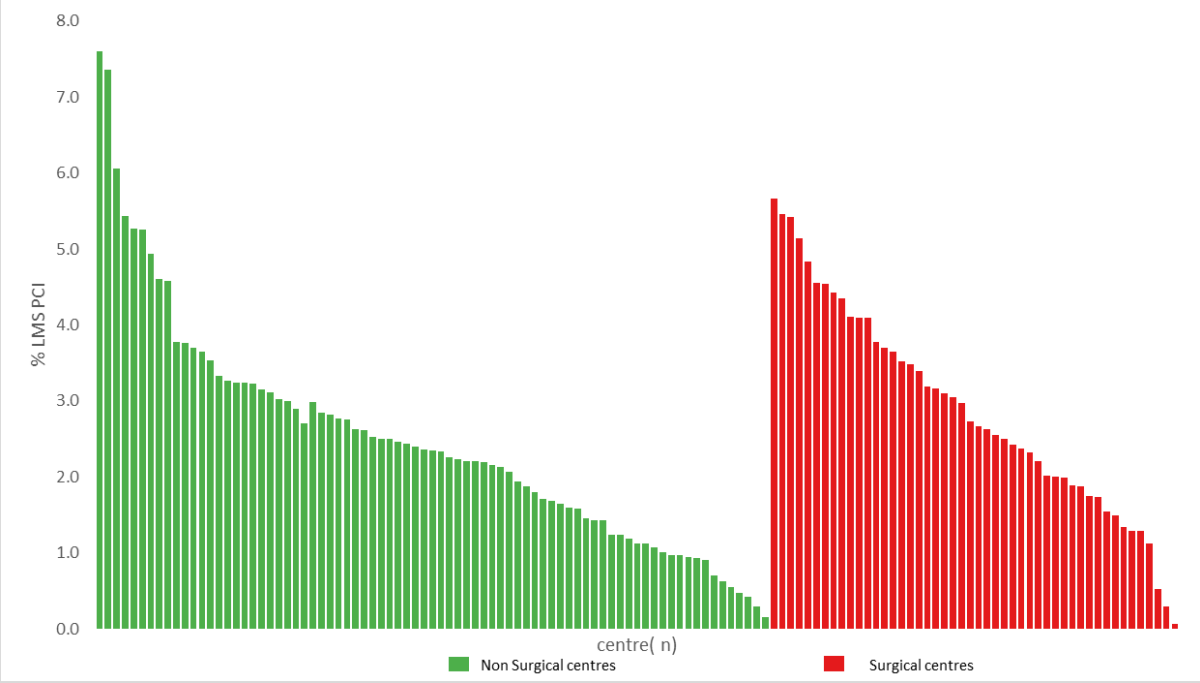

NSTEMI: Non-ST Elevation Myocardial Infarction, STEMI: ST Elevation Myocardial Infarction.

**Figure 3**: Temporal trends in LMS PCI in surgical centers by indication




NSTEMI: Non-ST Elevation Myocardial Infarction, STEMI: ST Elevation Myocardial Infarction.

**Figure 4:** Proportions of LMS PCI per center during the study period




LMS: Left main STEM, PCI: Percutaneous coronary intervention

## GRAPHIC ABSTRACT