The incidence, determinants and outcomes of coronary perforation during percutaneous coronary intervention in the United Kingdom between 2006–2013: an analysis of 527,121 cases from the British Cardiovascular Intervention Society database

Tim Kinnaird, MD[1], Chun Shing Kwok, MBBS MSc BSc[2], Evangelos Kontopantelis PhD[3], Nicholas Ossei-Gerning, MD[1], Peter Ludman, MD[4], Mark deBelder, MD[5], Richard Anderson MD[1,] Mamas A. Mamas, MADPhil[2,3] on behalf of the British Cardiovascular Intervention Society and the National Institute for Cardiovascular Outcomes Research.

[1]Department of Cardiology, University Hospital of Wales, Cardiff, UK; [2]Keele Cardiovascular Research Group, Institute of Science and Technology in Medicine and Primary Care and Health Sciences, University of Keele, Stoke-on-Trent and Royal Stoke Hospital, UHNM, Stoke-on-Trent, UK; [3]Farr Institute, University of Manchester, Manchester, UK, [4]Department of Cardiology, Queen Elizabeth Hospital, Edgbaston, Birmingham, UK; [5]Department of Cardiology, The James Cook University Hospital, Middlesborough, United Kingdom

Corresponding Author:
Dr Tim Kinnaird
Consultant Interventional Cardiologist
Department of Cardiology,
University Hospital of Wales,
Cardiff, UK

Email: tim.Kinnaird2@wales.nhs.uk
Phone: +44 2920 743938
Fax: +44 2920 744473

Brief title: Coronary perforation from an analysis of 527,121 cases

Conflicts of interest: No conflicts of interest for any authors, no relevant relationship with industry

Word count: 5723

Abstract

Background: As coronary perforation (CP) is a rare but serious complication of percutaneous coronary intervention (PCI) the current evidence base is limited to small series. Using a national PCI database the incidence, predictors and outcomes of CP as a complication of PCI were defined.

Methods and Results: Data were prospectively collected and retrospectively analysed from the British Cardiovascular Intervention Society dataset on all PCI procedures performed in England and Wales between 2006 and 2013. Multivariable logistic regressions and propensity scores were used to identify predictors of CP and its association with outcomes. In total 1,762 coronary perforations were recorded from 527,121 PCI procedures (incidence of 0.33%). Patients with CP were more often female or older, with a greater burden of co-morbidity and underwent more complex PCI procedures. Factors predictive of CP included age per year (odds ratio (OR) 1.03, 95% CI 1.02-1.03, p<0.001), previous CABG (OR 1.44, 1.17-1.77, p<0.001), left main (OR 1.54, 1.21-1.96, p<0.001) use of rotational atherectomy (OR 2.37, 1.80-3.11, p<0.001) and CTO intervention (OR 3.96, 3.28-4.78, p<0.001). Adjusted odds of adverse outcomes were higher for all major adverse coronary events including stroke, bleeding and mortality. Emergency surgery was required in 3% of cases. Predictors of mortality in patients with CP included age, diabetes, previous myocardial infarction, renal disease, ventilatory support, use of circulatory support, glycoprotein inhibitor use and stent type. **Conclusions:** Using a national PCI database for the first time the incidence, predictors and outcomes of coronary perforation were defined. Although CP as a complication of PCI occurred rarely, it was strongly associated with poor outcomes.

Keywords

Introduction

Coronary perforation is a rare but serious complication of percutaneous coronary intervention (PCI) with an estimated incidence of ~0.5%.[1] Entry of arterial blood into the pericardial space can lead to rapid elevation of the pericardial pressure and rapid haemodynamic compromise. Historically urgent surgical drainage was standard treatment but the development of new technologies such as covered stents and embolization coils, and new techniques such as thrombus and fat injection have allowed many perforations to be treated in the catheterisation laboratory without the need for surgical intervention.[2,3] However, despite improvements in interventional skills and equipment, percutaneous coronary interventions are increasingly complex with a higher prevalence of multi-vessel disease, worsening comorbidities (such as increasing age and renal dysfunction) and increasingly complex procedures including treatment of chronic total occlusions (CTO). In light of these temporal changes it is likely that coronary perforations will continue to occur.

Although there are several published series of coronary perforation, the rarity of the complication has limited the literature to small series derived from single centre experience. The largest published series describes 124 events and the total literature is less than 1000 cases.[4-20] Given the small numbers of events per published series it has not been possible to examine several key questions relating to the occurrence and outcomes of coronary perforation. Firstly, it is unclear from the available evidence what the true incidence of coronary perforation is and whether its incidence increasing or decreasing. Secondly, because the size of the published series it is not been possible to define exactly which demographic and procedural factors are predictive of coronary perforation. Finally, the treatment and outcomes of coronary perforation are not clearly defined.

Therefore, the objectives of the present study were to overcome these limitations and use for the first time a national PCI database to define the true incidence of coronary perforation during PCI, to describe which factors are predictive of coronary perforation, and to define the outcomes after coronary perforation.

Methods

Study design, setting and participants

We retrospectively analysed prospectively collected national data from all patients who underwent percutaneous coronary intervention (PCI) in England and Wales between January 2006 and December 2013.

Setting, data source, and study size

Data on PCI practice in the United Kingdom were obtained from the British Cardiovascular Intervention Society (BCIS) dataset that records this information prospectively and publishes this information in the public domain as part of the national transparency agenda.[21] The overall data collection process is overseen by The National Institute of Cardiovascular Outcomes Research (NICOR) (http://www.ucl.ac.uk/nicor/) and in 2013, 98.6% of all PCI procedures performed in the National Health Service (NHS) hospitals in England and Wales (www.bcis.org.uk/) were recorded on the database. The BCIS-NICOR database contains 113 clinical, procedural and outcomes variables with approximately 80,000 new records added each year.[22-23] The participants of the database are tracked by the Medical Research Information Services for subsequent mortality using the patients' NHS number (a unique identifier for any person registered within the NHS in England and Wales).

Study definitions

We analysed all recorded PCI procedures that were undertaken in the England and Wales between January 1st, 2006 and December 31st, 2013. Patients were categorised according to whether they sustained a coronary perforation during the PCI procedure or not. In the BCIS dataset the definition of coronary perforation is left to the discretion of the operators. The outcomes examined were in-hospital MACE (a composite of in-hospital mortality and in-hospital myocardial infarction or re-infarction and target vessel revascularization), 30-day mortality, 1-year mortality, 5-year mortality, in-hospital re-infarction, in-hospital emergency coronary artery bypass graft (CABG), in-hospital cardiac tamponade, in-hospital stroke and in-hospital major bleeding (defined as gastrointestinal bleed, intra-cerebral bleed, retroperitoneal hematoma, blood or platelet transfusion, or an arterial access site complication requiring surgery). Participants with missing

4

information on coronary perforation, age or sex were excluded. A detailed account of the participant inclusion process is shown in Figure 1.

Data analyses

Statistical analysis was performed using Stata v13.1 (College Station, Texas, USA). Multiple imputations using the *mi impute* command were used to reduce the potential bias from missing data, assuming missing at random mechanisms. We used chained equations to impute the data for all variables with missing information and generated 10 datasets to be used the analyses.

We examined the baseline characteristics of participants by coronary perforation status. These variables included age, sex, smoking status, body mass index (BMI), family history of coronary heart disease, hypertension, hyperlipidaemia, diabetes, previous myocardial infarction, previous stroke, peripheral vascular disease, valvular heart disease, renal disease, previous PCI, previous CABG, left ventricular function, cardiogenic shock, circulatory support, mechanical ventilation, antiplatelet therapy, warfarin use, bivalirudin use, glycoprotein IIb/IIIa inhibitors use, vessel attempted for PCI (vein graft, left main, left anterior descending (LAD), circumflex, right coronary), post-procedural TIMI flow, radial access, stent implanted, rotational atherectomy use, laser angioplasty use, cutting balloon use, presence of a chronic occlusion, surgical cover, year of PCI, and indication (stable angina, NSTEMI, STEMI). Descriptive measures for all these variables were calculated over time. We tested for associations between each categorical variable and coronary perforation using a Chi-squared test, and for continuous variables we used one-way analysis of variance. In addition, the rates of coronary perforation by year of PCI are presented. The outcomes of interest were 30-day mortality, 1-year mortality, 5-year mortality, in-hospital bleeding, re-infarction, emergency CABG, stroke, cardiac tamponade, side branch occlusion and coronary dissection for which we initially calculated the crude rates by coronary perforation status. To obtain adjusted measures of the associations between coronary perforation and the outcomes, we used logistic regressions. In the first set of models we used multiple logistic regression and included all potential predictors as covariates, to quantify the independent association between perforation and outcomes. In a second set of models we used the potential predictors to calculate a propensity score on perforation and weighted simple logistic regressions, of perforation on outcomes, on the inverse of the score (inverse probability treatment weighting). A third set of

5

simple regressions used the propensity score to perform matching with replacement to control for the effect of the covariates and estimate the average treatment effect (ATE) of coronary perforation on outcomes (teffects psmatch in Stata). The ATE is the mean difference in the outcome between patients with perforation and those without. The covariates included in the models were: age, gender, smoking status, body mass index, family history of coronary artery disease, hypercholesterolaemia, hypertension, diabetes, previous myocardial infarction, previous stroke, peripheral vascular disease, valvular heart disease, renal disease, previous PCI, previous CABG, left ventricular function, cardiogenic shock, ventilator use, circulatory support, antiplatelet therapy, warfarin, glycoprotein IIb/IIIa inhibitor, bivalirudin use, radial access, surgical cover, year, vessel of PCI, chronic occlusion, post procedure TIMI flow, stent type used, rotational atherectomy, laser angioplasty, cutting balloon, side branch occlusion, coronary dissection and diagnosis. The success of the propensity score matching was investigated by calculating descriptive statistics of the propensity score in each group and its absolute difference within each matched pair (balance diagnostics). An additional sensitivity analysis was performed by performing multiple logistic regressions with and without adjustments for centre volume.

RESULTS

Incidence and baseline demographics by perforation status

Between 2006 and 2013, 1,762 coronary perforations were recorded from 527,121 PCI procedures giving an overall incidence of 0.33%. The crude numbers of coronary perforation increased year on year (Figure 2) reflecting an increase in the total PCI volume in the United Kingdom during the study period. However, the annual incidence varied from 0.29% to 0.36% with a trend upwards that did not reach statistical significance (p=0.359). The baseline demographics for patients with and without coronary perforation are presented in Table 1. Patients with coronary perforation were more often female or older, with a greater burden of co-morbidity including hypertension, hypercholesterolemia, previous myocardial infarction, peripheral vascular disease and left ventricular dysfunction. Importantly when considering consent for procedures, coronary perforation was more likely to occur in stable angina PCI.

Procedural variables by perforation status

6

The procedural variables for patients with and without coronary perforation are presented in Table 2. Perforation was associated with use of glycoprotein IIb/IIIa inhibitor, left main disease, circumflex disease, and right coronary disease, post-procedure TIMI flow, type of stent implanted, rotational atherectomy, laser angioplasty and chronic occlusion.

Using multivariable analyses covariates found to be associated with coronary perforation were identified and are presented in Table 3. Factors associated with an increased risk of perforation were age, hypercholesterolaemia, previous CABG, left main intervention, CTO intervention, use of rotational atherectomy, procedural dissection, side-branch occlusion and NSTEMI diagnosis. Factors associated with a decreased risk of perforation were male sex, diabetes mellitus, presentation with shock and use of a cutting balloon.

Clinical outcomes by perforation status

Clinical and procedural complications and adverse outcomes recorded in the BCIS database were more frequent in patients with coronary perforation (Table 4). In-hospital MACE was significantly higher in those patients with coronary perforation compared to those without (26 vs. 2%, p<0.001), as was 30-day, 1-year and 5-year mortality. The 30-day mortality after perforation varied from 6.6% to 15.5% with a significant upward trend (P=0.049) that was also significant for 1-year mortality (p<0.001). We observed similar significant increase in mortality at both 30-days and 1-year for the group that did not sustain coronary perforation over time (Supplementary Table 1). Overall national PCI mortality with and without perforation by year is presented in Figure 3. The characteristics of ~~The temporal changes in the~~ predictive factors for perforation over time are presented in Supplementary Table 2 (means or percentages and respective confidence intervals) and indicate a significant increase in the mean complexity of the cases experiencing perforation (including patient age, presentation with shock, diabetes, history of CABG and left main PCI). Non-coronary end-points including in-hospital major bleeding and stroke were also significantly more frequent. In patients with coronary perforation, tamponade occurred in 14% of cases with 3% of patients required emergency reparative surgery. Using multiple logistic regression analyses and inverse probability-weighting propensity scoring, the adjusted odds of clinical outcomes are presented in Table 5. The predictors of 30-day mortality in patients with a coronary perforation are presented in Table 6 and included increasing age, previous diabetes, previous myocardial

7

infarction, renal disease, use of ventilatory support, use of circulatory support, glycoprotein IIb/IIIa inhibitor use and stent type. The results of the propensity score matching analysis on 10 imputed datasets using average treatment effects are demonstrated in Supplementary Table 3. There were significant increases in in-hospital MACE, 30-day mortality, 1-year mortality, in-hospital cardiac tamponade and in-hospital bleeding with coronary perforation after propensity score matching. The balance diagnostics of the propensity score matching is are shown in Supplementary Table 4. In considering the effect of centre volume on outcomes the overall median and interquartile range of centre volume was 1,295 (617 to 1,771) procedures/year. The respective centre volume results for patients who had coronary perforations was lower 1,189 (599-1,771) procedures/year. Sensitivity analysis considering the effect of an additional adjustment for centre volume did not significantly alter the results in the absence of this adjustment (Supplementary Table 5).

DISCUSSION

The current study is the first analysis of coronary perforation as a complication of percutaneous coronary intervention performed from a national angioplasty database. Although there are several previously published series, their small size has limited the robustness of any conclusions and in particular multiple logistic regression analyses of the predictors of coronary perforation and predictors of mortality in those who experience perforation have not been carried out before due to small sample sizes.

The incidence of coronary perforation during PCI in the current study is consistent with that reported in the previous smaller studies and is mid-way between the lowest reported frequency of 0.12% and the upper reported frequency of 0.82%.[10,11] Two summary studies have reported on the occurrence of coronary perforation. The 16 published coronary perforation studies involving 197,061 percutaneous coronary interventions were summarised recently. In this largely descriptive paper the perforation frequency was 0.43% although no additional analyses were presented.[1] In the second summary analysis, Patel el al reported 419 perforations from 65 studies of 18,061 patients undergoing CTO PCI.[25] In this series the reported frequency of coronary

perforation was 2.9% with a tamponade frequency of 0.2%. Although this is a large series of coronary perforation no further data was presented on the perforation subset of the main study.

In the current study, a sub-analysis of the annualised data demonstrates not only a year on year increase in the crude numbers of perforation as the number of UK PCIs increases, but also a non-significant trend for the percentage frequency to increase also. Given the independent predictors of perforation identified in this study, it is perhaps not surprising in view of the aging population with increasingly complex non-CTO and CTO procedures that the frequency of perforation is unlikely to drop.[26-28] Based on the current data it would seem reasonable to predict that the frequency of coronary perforation might actually increase in coming years.

Several previous studies have examined the baseline and procedural factors associated with perforation although none have had the sample size to perform multiple logistic regression analyses.[4-20] The findings of these smaller studies have reported somewhat divergent findings although increasing age, use of rotational atherectomy, "complex" lesions and CTO intervention all feature more commonly. The current study largely confirms the tentative findings of previous studies confirming women and the elderly to be at risk of coronary perforation as well as those cases in which atherectomy devices are utilised. Novel predictors of coronary perforation in the current study include patients with previous CABG, left main stem intervention and a reduced frequency in diabetics and in cases with cutting balloon use. The observation that both BMS and DES use were associated with a lower likelihood of perforation may be explained by several factors including guide-wire perforation, and the fact that use of covered stent is not recorded as a separate field in the database. Additionally, the occurrence of a perforation with pre-dilation may lead operators to terminate the procedure after control of the perforation, without continuing to stent implantation. The observation that use of a cutting balloon appeared to be protective against perforation is a novel finding and may support the hypothesis that careful lesion preparation thus necessitating less aggressive post-dilatation could reduce the incidence of perforation. The multi-centre nature of the database also allowed an analysis of the influence of on-site vs. off-site cardiac surgical support and no relationship was observed.

9

The incidence of major adverse events in patients with coronary perforation was high with a 13-fold increase in in-hospital MACE and a 5-fold increase in 30-day mortality. These data are a stark reminder that whilst coronary perforation during PCI is a relatively rare event, when it does occur the outcome remains extremely poor. Additionally, we observed a significant increase in mortality at 30-days and 1-year in patients who had coronary perforation as well as patients who did not have coronary perforation. This may reflect an increase in undertaking PCI on higher risk patients with time. However, the magnitude of increase in mortality was higher in the coronary perforation group compared to the non-perforation group that may also reflect the increased complexity of patients experiencing a perforation. Tamponade occurred in 14% of patients with coronary perforation, a finding that is testament to the skill of the operators necessitating rapid resuscitation, balloon occlusion and placement of a pericardial drain to avoid its occurrence. The rate of surgical repair was also extremely low (3%) in the current series and likely reflects the development of interventional tools such as covered stents and embolisation coils, as well as a wider appreciation of techniques such as distal fat and thrombus embolisation to treat distal wire tip perforations.[2,3] The size of the current analysis also enabled a multiple logistic regression analysis of the predictors of an adverse outcome in those patients who experienced a coronary perforation. The results are largely intuitive with increasing age, previous myocardial infarction and renal disease all strongly predictive of increased mortality. The observed increased mortality associated with stent use may be explained by the lack of a dedicated covered stent field in the database ie use of a covered stent may be been recorded as no stent used. This analysis also supports the anecdotal experience that if a coronary perforation does occur, concomitant peri-procedural use of a glycoprotein IIb/IIIa inhibitor is associated with worse outcomes, with an almost doubling of 30-day mortality.

This analysis has several strengths. The BCIS dataset includes >98% of all PCI procedures performed in the UK which therefore reflects a national, real-world experience that includes high-risk patients encountered in daily interventional practice (who are often excluded from randomized controlled trials). Therefore, for the first time the occurrence of perforation is reported on a national basis. Our analysis of over ½ million PCI procedures represents that largest analysis to date by several orders of magnitude, analysing temporal trends, predictors and outcomes for the first time derived from over 1700 perforations. Such large national registry data with unselected

enrolment are important for evaluation of low frequency complications such as coronary perforation, particularly given that such low event rates would mean that single centre registries/RCTs would be grossly underpowered.

LIMITATIONS

Additionally although the BCIS database does not specifically define perforation (leaving recording of this complication at the discretion of the operator), the observed incidence of perforation in our large series implies that reasonable clinical judgment was applied by UK operators. Secondly, whilst the BCIS dataset provides granular information about clinical and procedural characteristics, it does not provide information around vessel and lesion characteristics such as tortuosity, calcification, side branch proximity and lesion diameter and length. Additionally, the BCIS database does not differentiate between coronary perforations resulting from guide-wire and perforations due to vessel rupture by balloon or stent inflation. Therefore, we are unable to provide separate analyses regarding the predictors and outcomes of these sub-groups of coronary perforation. Additionally, the definition of perforation was not standardized and the database does not record the Ellis classification of coronary perforation. A sub-stratification by perforation severity is not possible within the constraints of the current dataset. The independent associations between covariates and a perforation complication that we have reported cannot infer causality, but may relate to changes in the procedure/clinical status occurring as a consequence of the perforation. For example, the use of circulatory support is associated with increased odds of perforation 4-fold, but this may not be a causal but merely reflect that post perforation, patients are more likely to require circulatory support because of significant haemodynamic compromise. Similarly side-branch occlusion may be associated with use of a covered stent. Finally, the BCIS database only records emergency CABG as an outcome after coronary perforation. As a result, we are unable to provide data on the use of covered stents, pericardial drains or embolisation coils. Finally, census data was only available at specific time points with follow-times to census weredata not available in the database extract that was used for this we obtained and hence our analysis options were limited to logistic regression models. IHowever, it has, however been shown that for relatively short follow-up times (up to 5 years) the performance of logistic regression models is not too dissimilar to survival analysis models.

Comment [EK1]: http://onlinelibrary.wiley.com/doi/10.1002/sim.4780081211/abstract

CONCLUSIONS

Using data derived from a national PCI database, coronary perforation occurred as a PCI procedural complication in 0.33% of cases. Independent predictors of coronary perforation included age, female gender, chronic total occlusion intervention and atherectomy. Coronary perforation was strongly associated with poor outcomes.

REFERENCES

1. Shimony A, Joseph L, Mottillo S, Eisenberg MJ. Coronary artery perforation during percutaneous coronary intervention: a systematic review and meta-analysis. Can J Cardiol. 2011;27:843-50.

2. Tarar MN, Christakopoulos GE, Brilakis ES. Successful management of a distal vessel perforation through a single 8-French guide catheter: Combining balloon inflation for bleeding control with coil embolization. J Invasive Cardiol. 2013;25:486-91.

3. Chen S, Lotan C, Jaffe R, Rubinshtein R, Ben-Assa E, Roguin A, Varshitzsky B, Danenberg HD. Pericardial covered stent for coronary perforations. Catheter Cardiovasc Interv. 2015;86:400-4.

4. Hendry C, Fraser D, Eichhofer J, Mamas MA, Fath-Ordoubadi F, El-Omar M, Williams P. Coronary perforation in the drug-eluting stent era: incidence, risk factors, management and outcome: the UK experience. EuroIntervention. 2012;8:79-86.

5. Al-Lamee R, Ielasi A, Latib A, Godino C, Ferraro M, Mussardo M, Arioli F, Carlino M, Montorfano M, Chieffo A, Colombo A.Incidence, predictors, management, immediate and long-term outcomes following grade III coronary perforation. JACC Cardiovasc Interv. 2011;4:87-95.

6. Romaguera R, Sardi G, Laynez-Carnicero A, Ben-Dor I, Maluenda G, Wakabayashi K, Hauville C, Torguson R, Xue Z, Kent KM, Satler LF, Suddath WO, Pichard AD, Lindsay J, Waksman R. Outcomes of coronary arterial perforations during percutaneous coronary intervention with bivalirudin anticoagulation. Am J Cardiol. 2011;108:932-5.

7. Kiernan TJ, Yan BP, Ruggiero N, Eisenberg JD, Bernal J, Cubeddu RJ, Witzke C, Don C, Cruz-Gonzalez I, Rosenfield K, Pomersantev E, Palacios I. Coronary artery perforations in the contemporary interventional era. J Interv Cardiol. 2009;22:350-3.

8. Shimony A, Zahger D, Van Straten M, Shalev A, Gilutz H, Ilia R, Cafri C. Incidence, risk factors, management and outcomes of coronary artery perforation during percutaneous coronary intervention. Am J Cardiol. 2009;104:1674-7.

9. Fasseas P, Orford JL, Panetta CJ, Bell MR, Denktas AE, Lennon RJ, Holmes DR, Berger PB. Incidence, correlates, management, and clinical outcome of coronary perforation: analysis of 16,298 procedures. Am Heart J. 2004;147:140-5.

10. Gunning MG, Williams IL, Jewitt DE, Shah AM, Wainwright RJ, Thomas MR. Coronary artery perforation during percutaneous intervention: incidence and outcome. Heart. 2002;88:495-8.

11. Fejka M, Dixon SR, Safian RD, O'Neill WW, Grines CL, Finta B, Marcovitz PA, Kahn JK. Diagnosis, management, and clinical outcome of cardiac tamponade complicating percutaneous coronary intervention. Am J Cardiol. 2002;90:1183-6.

12. Ellis SG, Ajluni S, Arnold AZ, Popma JJ, Bittl JA, Eigler NL, Cowley MJ, Raymond RE, Safian RD, Whitlow PL. Increased coronary perforation in the new device era. Incidence, classification, management, and outcome. Circulation. 1994;90:2725-30

13. Stathopoulos I1, Kossidas K, Panagopoulos G, Garratt K. Cardiac tamponade complicating coronary perforation during angioplasty: short-term outcomes and long-term survival. J Invasive Cardiol. 2013;25:486-91.

14. Ajluni SC, Glazier S, Blankenship L, et al. Perforations after percutaneous coronary interventions: clinical, angiographic, and therapeutic observations. Cathet Cardiovasc Diagn. 1994;32:206-212.

15. Dippel EJ, Kereiakes DJ, Tramuta DA, et al. Coronary perforation during percutaneous coronary intervention in the era of abciximab platelet glycoprotein IIb/IIIa blockade: an algorithm for percutaneous management. Cathet Cardiovasc Diagn. 2001;52:279-286.

16. Friedrich SP, Berman AD, Baim DS, et al. Myocardial perforation in the cardiac catheterization laboratory: incidence, presentation, diagnosis, and management. Cathet Cardiovasc Diagn. 1994;32:99-107.

17. Javaid A, Buch AN, Satler LF, et al. Management and outcomes of coronary artery perforation during percutaneous coronary intervention. Am J Cardiol. 2006;98:911-914.

18. Gruberg L, Pinnow E, Flood R, et al. Incidence, management, and outcome of coronary artery perforation during percutaneous coronary intervention. Am J Cardiol. 2000;86:680-682.

19. Ben-Gal Y, Weisz G, Collins MB, et al. Dual catheter technique for the treatment of severe coronary artery perforations. Cathet Cardiovasc Diagn. 2010;75:708-712.

20. Bauer T, Boeder N, Nef HM, et al. Fate of Patients With Coronary Perforation Complicating Percutaneous Coronary Intervention (from the Euro Heart Survey Percutaneous Coronary Intervention Registry). Am J Cardiol. 2015;116:1363-7.

21. Ludman PF, British Cardiovascular Intervention S. British Cardiovascular Intervention Society Registry for audit and quality assessment of percutaneous coronary interventions in the United Kingdom. Heart. 2011;97:1293-7.

22. Mamas MA, Anderson SG, Carr M, Ratib K, Buchan I, Sirker A, Fraser DG, Hildick-Smith D, de Belder M, Ludman PF, Nolan J; British Cardiovascular Intervention Society; National Institute for Cardiovascular Outcomes Research.. Baseline bleeding risk and arterial access site practice in relation to procedural outcomes after percutaneous coronary intervention. J Am Coll Cardiol. 2014;64:1554-64.

23. Mamas MA, Anderson SG, O'Kane PD,Keavney B, Nolan J, Oldroyd KG, Perera D, Redwood S, Zaman A, Ludman PF, de Belder MA; British Cardiovascular Intervention Society and the National Institute for Cardiovascular Outcomes Research.Impact of left ventricular function in relation to procedural outcomes following percutaneous coronary intervention: insights from the British Cardiovascular Intervention Society. Eur Heart J. 2014;35:3004-12.

24. Ratib K, Mamas MA, Routledge HC, Ludman PF, Fraser D, Nolan J. Influence of access site choice on incidence of neurologic complications after percutaneous coronary intervention. Am Heart J. 2013;165:317-24.

25. Patel VG, Brayton KM, Tamayo A, Mogabgab O, Michael TT, Lo N, Alomar M, Shorrock D, Cipher D, Abdullah S, Banerjee S, Brilakis ES. Angiographic success and procedural complications in patients undergoing percutaneous coronary chronic total occlusion interventions: a weighted meta-analysis of 18,061 patients from 65 studies. JACC Cardiovasc Interv. 2013;6:128-36.

26. Kragholm K, Halim SA, Yang Q, Schulte PJ, Hochman JS, Melloni C, Mahaffey KW, Moliterno DJ, Harrington RA, White HD, Armstrong PW, Ohman EM, Van de Werf F, Tricoci P, Alexander JH, Giugliano RP, Newby LK. Sex-Stratified Trends in Enrollment, Patient Characteristics, Treatment, and Outcomes Among Non-ST-Segment Elevation Acute Coronary Syndrome Patients: Insights From Clinical Trials Over 17 Years. Circ Cardiovasc Qual Outcomes. 2015;8:357-67.

27. Rosengren A, Wallentin L, Simoons M, Gitt AK, Behar S, Battler A, HasdaiD. Age, clinical presentation, and outcome of acute coronary syndromes in the Euroheart acute coronary syndrome survey. Eur Heart J. 2006:27:789-95.

28. George S, Cockburn J, Clayton TC, Ludman P, Cotton J, Spratt J, Redwood S, de Belder M, de Belder A, Hill J, Hoye A, Palmer N, Rathore S, Gershlick A, Di Mario C, Hildick-Smith D; British Cardiovascular Intervention Society; National Institute for Cardiovascular Outcomes

Research. Long-term follow-up of elective chronic total coronary occlusion angioplasty: analysis from the U.K. Central Cardiac Audit Database. J Am Coll Cardiol. 2014;64:235-43.