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Systematic Review/Meta-analysis

Coronary Artery Perforation During Percutaneous Coronary Intervention: A Systematic Review and Meta-analysis

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ABSTRACT

Numerous studies have examined the incidence, predictors, outcomes, and management strategies of coronary artery perforation (CAP). Individually, these studies have been inconclusive because of their limited sample sizes and/or single-centre designs. We conducted a systematic review and meta-analysis of studies pertaining to CAP in order to estimate its incidence and outcomes and to critically review its risk factors and treatment. We systematically searched the literature to identify all registry studies investigating CAP. Data were pooled by means of the random-effects model. In 16 studies involving 197,061 percutaneous coronary interventions, the pooled incidence of CAP was 0.43% (95% confidence interval, 0.35%-0.52%). The most reproducible risk factors were treatment of complex lesions and use of atheroablative devices. A variety of major management strategies for CAP were used, in particular, observation, heparin reversal, prolonged balloon inflation, covered stent implantation, pericardiocentesis, and surgery. In a hierarchical Bayesian random-effects model, the pooled tamponade rates were 0.4% (95% credible interval [CrI], 0.0%-5.7%), 3.3% (95% CrI, 0.0%-11.4%), and 45.7% (95% CrI, 34.9%-57.5%) for patients with Ellis class I, II, and III CAP, respectively. Pooled mortality rates were 0.3% (95% CrI, 0.0%-4.4%), 0.4% (95% CrI, 0.0%-2.8%), and 21.2% (95% CrI, 12.0%-31.4%) for patients with Ellis class I, II, and

RÉSUMÉ

De nombreuses études ont examiné l'incidence, les prédicteurs, les résultats et les stratégies de gestion de la perforation coronaire (PC). Séparément, ces études ont été peu concluantes en raison de leurs tailles d'échantillon limitées ou de leurs conceptions unicentriques, ou les deux. Nous avons mené une revue systématique et une méta-analyse d'études se rapportant à la PC dans le but d'évaluer son incidence et ses résultats, et de revoir de manière critique ses facteurs de risque et son traitement. Nous avons systématiquement cherché dans la littérature pour trouver toutes les études enregistrées examinant la PC. Les données étaient regroupées au moyen du modèle d'effets aléatoires. Dans 16 études impliquant 197 061 interventions coronariennes percutanées, l'incidence groupée de la PC a été de 0,43 % (intervalle de confiance de 95 %, 0,35 %-0,52 %). Les facteurs de risque les plus fréquents ont été le traitement de lésions complexes et l'utilisation de dispositifs athéroablatifs. Une variété de stratégies de gestion majeures pour la PC ont été utilisées, en particulier, l'observation, le renversement de l'héparine, le gonflement prolongé du ballonnet, l'implantation d'une endoprothèse vasculaire couverte, la péricardiocentèse et la chirurgie. Dans un modèle bayésien hiérarchique d'effets aléatoires, les taux de tamponnade groupés ont été de 0,4 % (intervalle de crédibilité à 95 % [ICr], 0,0 %-5,7 %), 3,3 % (ICr à

Percutaneous treatment of coronary artery disease has become a mainstay of cardiology practice. In 2006, more than 1 million percutaneous coronary intervention (PCI) procedures were performed in the United States alone.[1] As medical technology advances, interventionalists are treating patients with increasingly complex coronary anatomy. Consequently, these physicians face the infrequent, yet potentially lethal, complication of coronary artery perforation (CAP).[2-17] Our understanding of CAP has advanced significantly, and diagnostic classifications, as well as therapeutic and pharmacologic interventions, have been developed. Numerous studies have addressed the incidence, risk factors, diagnosis, and management of CAP. However, CAP is a rare complication, and the literature contains only small studies with limited power to draw meaningful conclusions. Narrative reviews have provided some guidance in the management of CAP but have not systematically reviewed the literature in order to provide critical ap-

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III CAP respectively. CAP complicating percutaneous coronary intervention is rare, and its morbidity and mortality vary directly with Ellis classification. Management discrepancies highlight the need to establish a uniform treatment paradigm for CAP.

95 %, 0,0 %-11,4 %), et 45,7 % (ICr à 95 %, 34,9 %-57,5 %) pour les patients avec une PC de classe Ellis I, II et III, respectivement. Les taux de mortalité groupés ont été de 0,3 % (ICr à 95 %, 0,0 %-4,4 %), 0,4 % (ICr à 95 %, 0,0 %-2,8 %), et 21,2 % (ICr à 95 %, 12,0 %-31,4 %) pour les patients avec une PC de classe Ellis I, II et III, respectivement. La PC qui se complique par une intervention coronaire percutanée est rare; sa morbidité et sa mortalité varient selon la classification Ellis. Les différences de gestion mettent en évidence le besoin d'établir un paradigme de traitement uniforme pour la PC.

praisal of the individual studies. Therefore, we conducted a systematic review and meta-analysis of the literature pertaining to CAP in order to examine its classification, incidence, risk determinants, and factors that predict outcomes and management. Based on our analysis, we offer a paradigm for management.

Methods

Search strategy

We systematically searched EMBASE and MEDLINE (January 1990-September 2010) to identify all observational registry studies investigating CAP. The MESH search string was ("coronary vessels"[MeSH Terms] or ("coronary"[All Fields] and "vessels"[All Fields]) or "coronary vessels"[All Fields] or ("coronary"[All Fields] and "artery"[All Fields]) or "coronary artery"[All Fields]) and perforation [All Fields]. We limited our search to studies conducted in humans and published in peer-reviewed journals and in the English language. The retrieved studies were examined to eliminate potential duplicates or overlapping data. Editorial comments, reviews, and reference lists of retrieved articles were hand-searched for further data.

The selected studies in our systematic review, along with additional studies, reviews, and case reports,[18-39] formed the basis of a narrative appraisal for the following topics: (1) definition and classification; (2) incidence; (3) patients and angiographic characteristics; (4) atheroablative devices; (5) hydrophilic wires; (6) balloon angioplasty and stents; (7) adjunctive antithrombotic therapy; (8) coronary perforation complications; and (9) treatment.

Inclusion criteria

We included a study in our systematic review if: (1) it reported CAP according to the Ellis classification scheme;[16] (2) CAP was identified by a coronary angiography; and (3) at least 1 of the following major adverse cardiac events was reported: death, myocardial infarction, and tamponade. As we wished to generalize our results, we excluded case reports and studies investigating CAP as a result of a solitary interventional device. In addition, we excluded studies investigating CAP only in selected subjects with a unique coronary characteristic, such as chronic total occluded arteries.

Data extraction

Data extracted from each study included first author, year of publication, study period, total number of PCIs, and number of PCIs complicated by CAP. We extracted CAP population characteristics, including sex, mean age with standard deviation, and baseline cardiovascular risk factors. Additionally, we extracted data concerning major adverse cardiac event outcomes stratified by the Ellis classification scheme.[16]

Statistical analysis

We examined the incidence of CAP for each individual study and then pooled data across all studies using the DerSimonian and Laird random-effects models. Statistical heterogeneity was assessed using I^2 statistics with a 95% confidence interval (CI). Major adverse cardiac event estimates across studies were summarized and pooled with a 2-level Bayesian hierarchical random-effects model. At the first level of our model, we assumed that events observed within each study followed a binomial distribution, with each study having its own event rate. At the second level, we assumed that the logit-transformed event rates from each study followed a normal distribution, with the mean representing the overall mean rate across studies on the logit scale and the standard deviation representing between-study variability in these rates, again on the logit scale. We report the results transformed back to the probability scale via inverse logit transform, with 95% credible intervals (CrIs), which are the Bayesian analogue to CIs, including both within- and between-study variances. We used Stata (version 9.0, StataCorp, Collage Station, TX) and WinBUGS (version 1.4; MRC Biostatistics Unit, Cambridge, UK) software for statistical analyses.

Results

In total, 605 citations were identified from database searches, of which 76 were duplicates. After excluding case reports, editorial comments, nonrelevant articles, and reviews, 16 studies[2-17] met our inclusion criteria for a systematic review and meta-analysis (Fig. 1). An additional 22 publications were identified as relevant for a narrative supplementary review.[18-39]

Definition and classification of CAP

Classification methods for CAP are summarized in Table 1. CAP is most commonly classified according to the Ellis classification scheme.[16] Type I CAP is defined by the development of an extraluminal crater without extravasation. Type II CAP is defined by the development of a pericardial or myocardial blush without contrast jet extravasation. Type III CAP is defined by the development of an extravasation jet through a frank ($\geq$ 1 mm) perforation or cavity spilling into an anatomic cavity chamber (ventricles, pericardial space, etc). Several studies divide Ellis type III into type III and type IV (with or without cavity spilling, respectively) as patients with type III cavity spilling typically fare better than patients with frank type III CAP.[6,11-12]

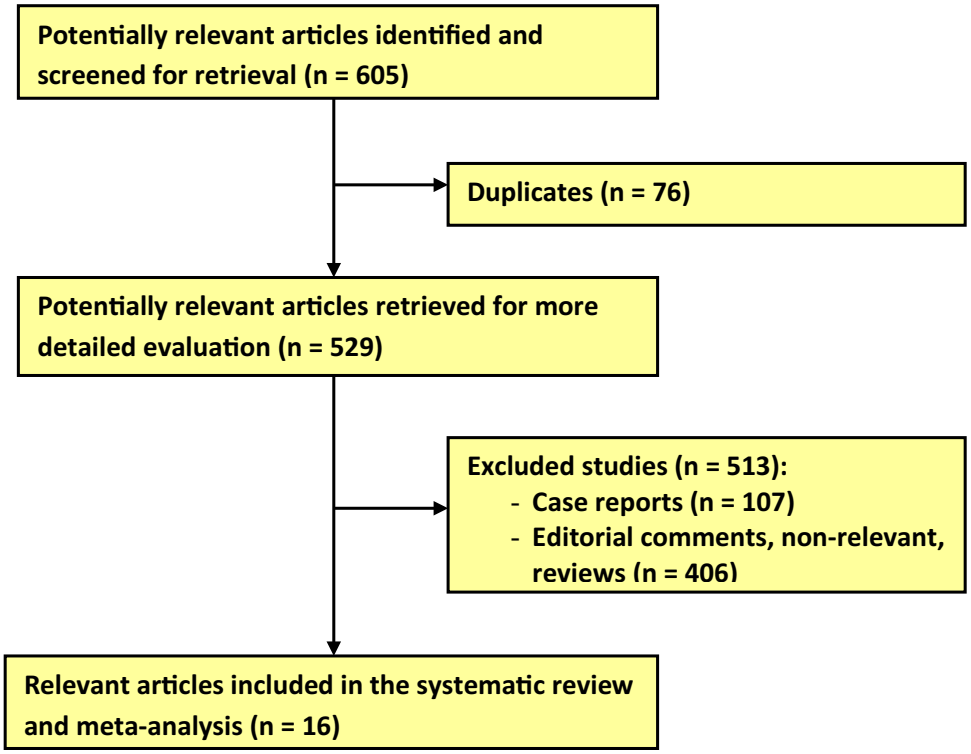

Figure 1. Flow diagram of studies included in the systematic review.

Less commonly used classification schemes exist and separate CAP into 2 types. Fukutomi et al. classified CAP as type I when there is an epicardial staining without a jet contrast extravasation, and type II when there is an epicardial staining with a visible jet of contrast extravasation.[18] Kini et al. classified CAP as type I when there is a myocardial staining without contrast extravasation, and type II when there is a frank extravasation into pericardium, coronary sinus, or cardiac chambers.[19] To date, no prospective study has validated the different classification schemes through a core laboratory analysis. However, the Ellis classification scheme is the most widely used classification for risk stratification and prognostication.

Pooled incidence of CAP

Sixteen studies exploring CAP in unselected populations contributed to the calculation of the pooled incidence. The reported incidence of CAP ranged from 0.1% to 0.84% (Table 2). The cumulative incidence of CAP in these studies, encompassing 197,061 PCIs, was 0.43% (95% CI, 0.35%-0.52%; $I^2 = 89.8\%$). When CAP has been investigated in studies with selected populations, however, higher estimates have been reported. In a study of 764 consecutive patients treated with excimer laser coronary angioplasty, CAP occurred in 3.0%.[20] Of the 2759 consecutive patients in the Excimer Laser Coronary Angioplasty Registry, 1.3% had CAP.[21] In addition, higher estimates have been reported in the treatment of chronic total occlusions. Of the 498 patients treated for chronic total occlusions in the Japan registry of chronic total occlusions, CAP was documented in up to 13.6%.[22]

Table 1. Classification methods for coronary artery perforation

Classification	Description
Ellis[16]	Type I: Extraluminal crater without extravasation
	Type II: Pericardial or myocardial blush without contrast jet extravasation
	Type III: Extravasation jet through a frank (≥ 1 mm) perforation or cavity spilling into an anatomic cavity chamber (ventricles, pericardial space, etc)
Fukutomi[18]	Type I: Epicardial staining without a contrast extravasation
	Type II: Epicardial staining with a visible jet of contrast extravasation
Kini[19]	Type I: Myocardial staining without contrast extravasation
	Type II: Contrast extravasation into pericardium, coronary sinus, or cardiac chambers

Patients and angiographic characteristics

Several patient-related risk factors were associated with the development of CAP. These included older age,[3,5,16] hypertension,[5] previous coronary artery bypass graft operation,[5,11] history of congestive heart failure,[14] PCI for non-ST elevation myocardial infarction or unstable angina,[5] prior clopidogrel use,[3] and lower creatinine clearance.[3] Two studies found that women appear to be at higher risk of CAP; however, other studies have found no association between sex and CAP.[5,9,11,16]

Angiographic risk factors included type B or C lesions,[5,9,11] chronic total occluded arteries,[5,9] small vessels,[9] culprit lesion in the right coronary or circumflex arteries,[5,9] calcified lesions,[5,9] tortuous and angulated vessels,[9] and the presence of multivessel coronary disease.[9] Shimony et al.[5] found that the femoral approach for PCI was independently associated with a higher risk for CAP. However, they could not exclude the possibility of selection bias since the femoral approach was used

Table 2. Baseline characteristics of patients with coronary artery perforation complication

First author	Publication year	Study period	No. of PCI	No. of PCI complicated by CAP (%)	Mean age ± SD	% Men	% HTN	% DM	% Previous MI	% Previous CABG	% Previous PCI
Kiernan[2]	2009	2000–2008	14,281	68 (0.48)	71 ± 11	61.7	83.8	16.1	NA	NA	NA
Jacob[3]	2009	2001–2007	12,921	35 (0.27)	67.5 ± 9.2	68.5	65.7	22.8	42.8	14.3	34.2
Panagiota[4]	2009	2002–2007	2991	5 (0.17)	65 ± 12	80	60	NA	NA	NA	NA
Shimony[5]	2009	2001–2008	9568	57 (0.59)	67.9 ± 11.7	68.4	82.4	31.5	NA	21	43.8
Shirakabe[6]	2007	1991–2005	3415	12 (0.35)	70.1 ± 9.6	58.3	75	50	NA	NA	NA
Javaid[7]	2006	1996–2005	38,559	72 (0.19)	68.5 ± 11.2	62.5	73.6	30.5	NA	36.1	36.1
Ramana[8]	2005	2001–2004	4886	25 (0.50)	67	84	76	28	NA	NA	NA
Stankovic[9]	2004	1993–2001	10,014	84 (0.84)	60 ± 10	80.9	55.9	16.6	55.9	13	NA
Witzke[10]	2004	1995–2003	12,658	39 (0.30)	69 ± 10	74.3	71.8	23	46.1	15.4	30.7
Fasseas[11]	2004	1990–2001	16,298	95 (0.58)	67.7 ± 11	56.8	64.2	21	61	38.9	NA
Eggebrecht[12]	2004	1998–2003	6433	19 (0.30)	66.3 ± 7.7	68.4	94.7	31.5	NA	36.8	47.3
Gunning[13]	2002	1995–2001	6245	52 (0.80)	NA	51.9	48	7.6	NA	5.7	NA
Dippel[14]	2001	1995–1999	6214	36 (0.58)	NA	NA	NA	NA	NA	NA	NA
Gruberg[15]	2000	1990–1999	30,746	84 (0.27)	64 ± 13	57.1	57.1	20.2	44	20.2	NA
Ellis[16]	1994	1990–1991	12,900	62 (0.50)	67 ± 10	53.2	NA	NA	NA	NA	NA
Ajluni[17]	1994	1988–1992	8932	35 (0.40)	66 ± 9	NA	NA	NA	NA	NA	NA

CABG, coronary artery bypass graft; CAP, coronary artery perforation; DM, diabetes mellitus; HTN, hypertension; MI, myocardial infarction; NA, not available; PCI, percutaneous coronary intervention; SD, standard deviation.

more frequently for higher-risk populations, such as hemodynamically unstable patients, or for patients who had previously undergone coronary artery bypass graft surgery.

Atheroablative devices (excimer laser angioplasty, Rotablators)

PCI registries originating in the early 1990s and early 2000s reported up to 30% of CAPs to be associated with atheroablative devices. Laser angioplasty evolved in the 1980s as a new technique as concern grew about the restenosis phenomenon in patients who had undergone balloon angioplasty. Directional coronary atherectomy and Rotablators were also used routinely in the 1980s and 1990s in order to deal with complex lesions in target vessels. On the basis of data from PCI registries, concerns mounted regarding vessel perforation. Bittl et al. reported an incidence of CAP of 3% among 764 patients treated specifically with excimer laser coronary angioplasty.[20] Ajluni et al. reported a CAP in 35 of 8932 patients.[17] CAP rates were 0.14% post balloon angioplasty, 1.3% after transluminal extraction coronary atherectomy, and 2% after laser coronary angioplasty. Ellis et al. found that the incidence of CAP had ranged from 0.1% to 2.1% and was greater with devices that removed rather than displaced tissue.[16] Dippel et al. reported an incidence of 0.58% CAP;[14] however, after the incidence by specified interventional modality was evaluated, the incidence ranged from 0.05% when done by stents to 3.3% when done by Rotablators and to 11.1% when done by extraction coronary atherectomy. They concluded that the likelihood of developing a class III CAP was much greater in the atheroablative devices group (odds ratio [OR], 28.9; 95% CI, 7.5-112.2). In keeping with these reports, higher incidence of CAP may have been related to a learning curve associated with use of atheroablative devices, or to an interventional practice in selected centres. However, this may not be applicable to contemporary PCIs. Atheroablative devices are rarely used nowadays, following the introduction of bare metal stents and particularly with the introduction of drug-eluting stents.

Hydrophilic wires

The innovation of hydrophilic guidewires has provided cardiologists with a vital instrument to successfully treat chronic total occluded arteries and other complex coronary lesions.[23] Javaid et al. found that 13 out of 15 CAPs occurred with the use of hydrophilic wires.[7] In addition, Kiernan et al. reported that 90% of CAPs occurred with the use of hydrophilic guidewires.[2] In contrast, others did not find an association between hydrophilic guidewires and CAP.[1] Thus, it is unclear whether hydrophilic guidewires are associated with CAP or whether their widespread use provides an erroneous impression of higher CAP incidence.

Balloon angioplasty and stents

Off-label stent use, stenting in complex lesions, inflation with high pressure, oversized balloons, and noncompliant balloons are potentially prone to CAP. The reported incidence of CAP caused by balloons and stents during PCI procedures ranges from 0.05% to 0.15%. Importantly, most CAPs are caused by wires and are less frequently caused by balloons or stents.[2-17] A balloon-to-artery ratio > 1.1 has been associated with a 2- to 3-fold increase in CAP.[17] Doll et al.[3] found that

stents were less frequently used in patients who had CAP than in controls with no CAP (OR, 0.29; 95% CI, 0.14-0.63). Conversely, no differences were demonstrated regarding balloon use during PCI between patients who had CAP and controls (OR, 1.39; 95% CI, 0.57-3.36). Shimony et al. reported that there were no differences in CAP severity classification for each interventional tool, whether it was a wire, a balloon, or a stent.[5] Fasseas et al. noted that the incidence of CAP was lowest with stenting; however, Ellis class II CAP was most commonly associated with stent implantation.[11]

Notably, most CAPs are found before balloon inflation or stent implantation, resulting in the immediate discontinuation of the PCI procedure. Therefore, it is unclear to what extent wires are more prone to CAP than are balloons and stents. On a similar note, there is uncertainty as to whether CAP is associated more with drug-eluting stents or bare metal stents. Drug-eluting stents are preferably used when the likelihood of restenosis is high. Therefore, it may be expected that there will be an increased incidence of CAP with drug-eluting stents in such procedures.

Adjunctive antithrombotic therapy

There are conflicting results regarding a possible association between the use of specific antithrombotic therapy, such as IIb/IIIa inhibitors, with the incidence, severity, or outcomes of CAP.[3,8,9-11,13,14] In a pooled analysis from the Acute Catheterization and Urgent Intervention Triage Strategy (ACUITY), Randomized Evaluation of PCI Linking Angiomax to Reduced Clinical Events (REPLACE-2), and Harmonizing Outcomes With Revascularization and Stents in Acute Myocardial Infarction (HORIZON AMI) trials, treatment of patients experiencing CAP with adjunctive antithrombotic therapy of bivalirudin was not associated with worse outcomes compared with treatment with heparin plus IIb/IIIa inhibitors.[3] Ramana et al. found that the use of various IIb/IIIa inhibitors did not worsen the hemodynamic state of patients who had CAP.[8] Witzke et al. found that in a series of 39 CAPs, the outcome was not affected by the use of IIb/IIIa inhibitors.[10] In a study of 6214 patients, of whom 36 experienced CAP, it was found that adjunctive abciximab therapy did not increase the risk of CAP, nor did it adversely affect clinical outcomes for patients in whom CAP had occurred.[14]

Alternatively, Gunning et al. reported that 9 out of 10 CAPs related to IIb/IIIa inhibitors required pericardial drainage, and 4 of these CAPs resulted in signs of tamponade over 2 hours post PCI.[13] They postulated that the mechanism of the tamponade was considered to be a coronary puncture by a guidewire and that the extent of bleeding was amplified by the use of IIb/IIIa inhibitors. Stankovic et al.[9] found a trend for a higher rate of CAP with the use of IIb/IIIa inhibitors (OR, 1.86; 95% CI, 0.95-3.63). Fasseas et al. found that among patients who had CAP, 33.3% of those receiving IIb/IIIa inhibitors required placement of covered stent or emergency cardiac surgery, compared with 3.2% of patients who did not receive IIb/IIIa inhibitors. At the same time, perforation class and clinical outcomes such as tamponade, myocardial infarction, and death were similar between the 2 groups.[11] Kini et al. found that cardiac tamponade from wire-associated CAP was less frequent with bivalirudin use than with heparin use. They postulated that the short half-life and reversible thrombin inhibition property of bivalirudin were responsible for its beneficial effect.[19]

Table 3. Clinical outcomes following coronary artery perforation

	No. of CAP				No. (%) of tamponade				No. (%) of myocardial infarction				No. (%) of death			
First author	Overall	Ellis I	Ellis II	Ellis III	Overall	Ellis I	Ellis II	Ellis III	Overall	Ellis I	Ellis II	Ellis III	Overall	Ellis I	Ellis II	Ellis III
Kiernan[2]	68	30	25	13	12 (17.6)	NA	NA	NA	5 (7.3)	NA	NA	NA	4 (5.9)	NA	NA	NA
Jacob[3]	35	NA	NA	NA	8 (22.9)	NA	NA	NA	NA	NA	NA	NA	4 (11.4)	NA	NA	NA
Panagiota[4]	5	1	1	3	2 (40.0)	0	0	2 (67.0)	NA	NA	NA	NA	1 (20.0)	0	0	1 (33.0)
Shimony[5]	57	7	30	20	9 (15.8)	0	0	9 (45.0)	NA	NA	NA	NA	4 (7.0)	0	0	4 (20.0)
Shirakabe[6]	12	3	2	7	3 (25.0)	NA	NA	NA	NA	NA	NA	NA	1 (8.3)	NA	NA	NA
Javaid[7]	72	14	33	25	14 (20.0)	0	4 (12.1)	10 (40.0)	NA	NA	NA	NA	12 (16.7)	0	1 (3)	11 (44.0)
Ramana[8]	25	6	10	9	1 (4)	NA	NA	NA	8 (32.0)	1 (16.7)	2 (20.0)	5 (55.6)	2 (8.0)	0	0	2 (22.2)
Stankovic[9]	84	0	56	28	NA	NA	NA	NA	15 (17.8)	NA	NA	NA	7 (8.0)	0	0	7 (25.0)
Witzke[10]	39	8	15	16	7 (18.0)	0	0	7 (44.0)	7 (18.0)	0	0	7 (44.0)	1 (2.5)	0	0	1 (6.3)
Fasseas[11]	95	17	58	20	11 (11.6)	0	1 (1.8)	10 (50.0)	12 (12.6)	2 (11.7)	8 (13.8)	2 (10)	7 (7.4)	1 (5.8)	3 (5.2)	3 (15)
Eggebrecht[12]	19	2	7	10	4 (21.0)	NA	NA	NA	NA	NA	NA	NA	2 (10.5)	NA	NA	NA
Gunning[13]	52	NA	NA	NA	24 (46.0)	NA	NA	NA	NA	NA	NA	NA	6 (11.5)	NA	NA	NA
Dippel[14]	36	0	19	16	8 (22.0)	NA	1 (5.3)	6 (37.5)	NA	NA	NA	NA	4 (11.1)	0	0	3 (18.8)
Gruberg[15]	84	NA	NA	NA	26 (31.0)	NA	NA	NA	28 (34.0)	NA	NA	NA	8 (10.0)	NA	NA	NA
Ellis[16]	62	13	31	18	15 (24.1)	1 (7.7)	4 (13.0)	10 (55.6)	13	0	4 (13.0)	9 (50.0)	3 (4.8)	0	0	3 (16.6)
Ajluni[17]	35	NA	NA	NA	6 (17.0)	NA	NA	NA	9 (25.7)	NA	NA	NA	3 (9.0)	NA	NA	NA
Overall (%; 95 CrI)	780				20.8 (15.5-26.9)	0.4 (0.0-5.7)	3.3 (0.0-11.4)	45.7 (34.9-57.5)	19.3 (11.9-28.9)	3.8 (0.0-25.4)	10.4 (1.1-32.6)	36.3 (7.6-78.9)	8.6 (6.5-11.2)	0.3 (0.0-4.4)	0.4 (0.0-2.8)	21.2 (12.0-31.4)

CAP, coronary artery perforation; CrI, credible interval, the Bayesian analogue to standard confidence intervals; NA, not available.

Complications secondary to CAP

There are limited data concerning the risk factors for morbidity and mortality in patients with CAP. Nevertheless, the single most important predictor of morbidity and mortality was found to be the severity of CAP by Ellis classification. Other risk factors include older age,[15] need for emergent surgery,[15] development of tamponade,[6,7,13,15] and the presence of chronic renal insufficiency.[7]

The reported incidence of complications varied significantly among studies. This could have been due to differences in the design of the studies, population heterogeneity, and interventional techniques applied in each centre (Table 3). When data were pooled across studies, patients with Ellis II CAP had higher rates of tamponade and myocardial infarction compared with patients with Ellis I CAP; however, mortality rates were similar between the 2 groups. Patients with Ellis III CAP had the highest rate of adverse events, with a more than 10-fold increase in tamponade and death compared with patients with Ellis II CAP. Myocardial infarction rates increased by more than 3-fold compared with patients with Ellis II CAP.

Treatment

Because of the lack of prospective studies and guidelines, there are a wide variety of potential approaches to the manage-

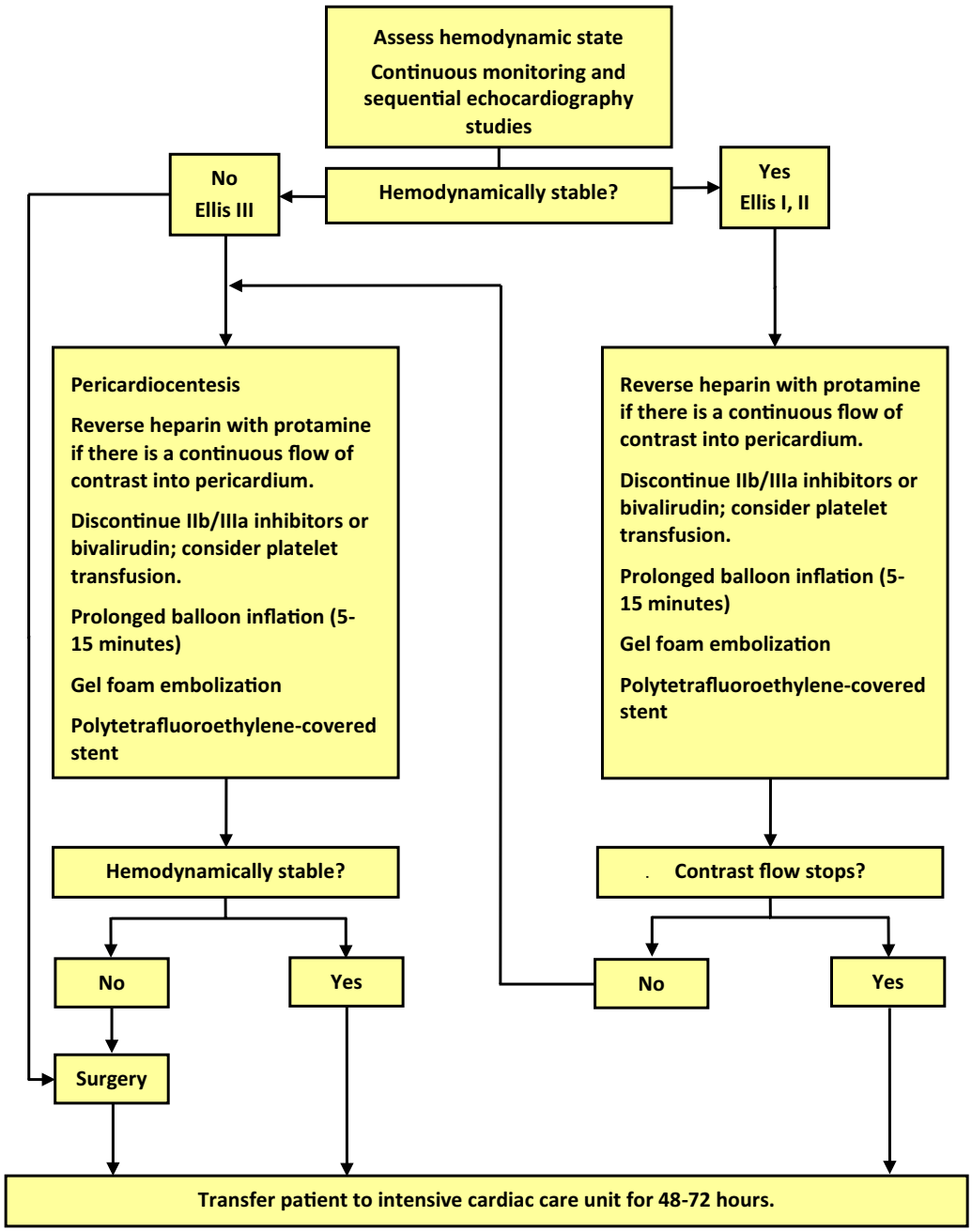

Figure 2. Algorithm of coronary artery perforation management.

ment of CAP. Strategies range from patient observation to urgent operation. Many factors should be considered, particularly the severity of CAP, patient hemodynamic status, interventional practice and equipment applied in each centre, and the operators' skills on-site. Subsequently, the estimated risk of morbidity and mortality should be weighed against the risk of invasive management. Since CAP is an uncommon complication, its treatment protocols should be reviewed periodically by the catheterization team, and appropriate equipment should be easily available in the laboratory.

A long-established modality is the quick conversion of heparin with protamine-sulfate. Protamine-sulfate is a polypeptide that is used to reverse heparin anticoagulation and to delay the absorption of insulin. Some still fear the consequences of this treatment as it can cause platelet aggregation, stent thrombosis, anaphylactic reaction, cardiac arrest, myocardial depression, or other adverse effects.[24-27] Patients who receive protamine-containing insulin, including NPH insulin, seem to be at greater risk for these adverse effects. However, these adverse effects are rare, and other studies have publicized the safety of protamine.[28,29] The introduction of new antithrombotic products such as IIb/IIIa inhibitors and bivalirudin requires discontinuation of such therapy or platelet transfusion.

Prolonged balloon dilatation blocks the blood flow distal to the inflation site, can be quickly applied, and is widely used for CAP treatment. However, prolonged balloon dilatation can cause distal ischemia, especially in the absence of downstream collaterals. In contrast, perfusion balloons seal the perforation while allowing distal vessel perfusion. They gained popularity before the stent era; however, as their main purpose was for coronary dissection handling, they are now rarely used since coronary dissections are treated regularly with stents.

Polytetrafluoroethylene is composed of carbon chains saturated with fluorine.[30] Polytetrafluoroethylene-covered stents prevent blood leakage between stent struts. A high rate of success has been reported with polytetrafluoroethylene-covered stents.[31-33] However, they lack elasticity, and rapid deployment in calcified arteries can be difficult. Covered stents are frequently not suitable for end artery distal perforation made by wires, which cause most of the CAPs. Treating CAP with 2 catheters through dual access may enable a rapid delivery of the covered stents without losing control of the perforation site.[34]

Pericardiocentesis is often needed for hemodynamically unstable patients. It can be done in the catheterization lab or the intensive cardiac care unit assisted by echo or fluoroscopy visualization. It can be a definitive treatment or a bridging treatment before coronary artery bypass graft surgery. In a series of 31 tamponade cases complicating CAP, 61% were treated with aspiration alone, yet 39% required further emergency surgical intervention.[35]

Several case reports describe potential treatment techniques such as transcatheter delivery of subcutaneous tissue, balloon catheter delivery of intracoronary thrombin, transcatheter injection of polyvinyl alcohol form, or collagen embolization.[36-39] It remains to be shown whether these treatment modalities will gain much wider success and popularity.

Conclusion

CAP remains a rare, potentially fatal complication of PCI. The poor prognosis associated with severe CAP emphasizes the importance of taking measures to prevent this complication. Awareness of risk factors, careful guidewire selection, and avoidance of balloon overexpansion remain the mainstays of CAP prevention. Importantly, advances in interventional techniques and devices have improved the success rate of PCI for chronic totally occluded arteries. During these procedures, aggressive stiff guidewires are advanced into a coronary lumen that is inadequately visualized. Heightened awareness and careful guidewire positioning are required to avoid vessel perforation and inadvertent migration into small collaterals.[40]

If CAP occurs, various management strategies could be considered, although there are few evidence-based data in this regard. Continuous monitoring in the catheterization lab and subsequently in the intensive cardiac care unit is of paramount importance since deterioration can occur up to 24 to 48 hours afterwards (Fig. 2). Echocardiography studies should be performed serially. Conservative treatment modalities are simple follow-up, heparin reversal, platelet transfusion, covered stents, prolonged balloon inflation, and distal embolization. Pericardiocentesis should be strongly considered for pericardial effusion with tamponade physiology. Urgent surgery is required for CAP leading to severe hemodynamic deterioration that cannot be treated by conservative means or pericardial drainage.

This review highlights the need for the creation of multicentre CAP registries that could be used to establish a standardized treatment paradigm based on experience for this rare clinical event. With further prospective studies, additional information could be obtained to assist the release of guidelines.

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