Index of Microcirculatory Resistance at the Time of Primary Percutaneous Coronary Intervention Predicts Early Cardiac Complications: Insights From the OxAMI (Oxford Study in Acute Myocardial Infarction) Cohort

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Background—Early risk stratification after primary percutaneous coronary intervention (PPCI) for ST-segment–elevation myocardial infarction is currently challenging. Identification of a low-risk group may improve triage of patients to alternative clinical pathways and support early hospital discharge. Our aim was to assess whether the index of microcirculatory resistance (IMR) at the time of PPCI can identify patients at low risk of early major cardiac complications and to compare its performance against guideline-recommended risk scores.

Methods and Results—IMR was measured using a pressure–temperature sensor wire. Cardiac complications were defined as the composite of cardiac death, cardiogenic shock, pulmonary edema, malignant arrhythmias, cardiac rupture, and presence of left ventricular thrombus either before hospital discharge or within 30-day follow-up. In total, 261 patients undergoing PPCI who were eligible for coronary physiology assessment were prospectively enrolled. Twenty-two major cardiac complications were reported. Receiver operating characteristic curve analysis confirmed the utility of IMR in predicting complications and showed significantly better performance than coronary flow reserve, the Primary Angioplasty in Myocardial Infarction II (PAMI-II), and Zwolle score (P≤0.006). Low microvascular resistance (IMR ≤40) was measured in 159 patients (61%) of the study population and identified all patients who were free of major cardiac complications (sensitivity: 100%; 95% CI, 80.5–100%).

Conclusions—IMR immediately at the end of PPCI for ST-segment–elevation myocardial infarction reliably predicts early major cardiac complications and performed significantly better than recommended risk scores. These novel data have implications for early risk stratification after PPCI. (J Am Heart Assoc. 2017;6:e005409. DOI: 10.1161/JAHA.116.005409.)

Key Words: clinical outcome • microcirculation • myocardial infarction

The incidence of major in-hospital complications following ST-segment–elevation myocardial infarction (STEMI) after primary percutaneous coronary intervention (PPCI) has decreased dramatically but remains at ≈10%.1,2 Following PPCI, patients are routinely admitted to coronary intensive care units (ICUs) for close monitoring and usually remain in the hospital for up to 72 hours, independent of their progress and clinical status, because few validated early risk-stratification tools exist to risk-stratify these patients.

Improved methods of identifying risk may have important implications for clinical management, for example, in terms of intensity of monitoring and duration of admission.3,4 The American College of Cardiology/American Heart Association and European Society of Cardiology guidelines suggest that...
PPCI patients with a “low risk of complications” might be candidates for non-ICU admission and early discharge. They recommend the Primary Angioplasty in Myocardial Infarction II (PAMI-II) and Zwolle PPCI score as tools to potentially identify low-risk patients.

Guidewire-based measurement of coronary flow and pressure is safe and easily conducted at the time of PPCI. The thermodilution-derived index of microcirculatory resistance (IMR) is a specific, quantitative, and reproducible measure of microvascular function, which predicts infarct size and left ventricular ejection fraction after an acute myocardial infarction. Moreover, an IMR value >40, measured at the time of PPCI, is associated with adverse long-term outcomes in terms of death and rehospitalization for heart failure. It is unknown whether IMR allows identification of in-hospital cardiac complications such as cardiac death, cardiogenic shock, pulmonary edema, malignant arrhythmias, or cardiac rupture and thus can be used as a tool to identify those at high risk early after PPCI.

The aims of this study were to assess the relationship between IMR measured immediately after PPCI and incidence of early cardiac complications and to compare the diagnostic performance of IMR against the guideline-recommended PAMI-II and Zwolle scores.

Methods

Patient Population and Acute Management

Patients presenting with an acute STEMI and referred for PPCI to the Oxford Heart Centre were prospectively assessed for enrollment in the study (Figure 1). STEMI was defined as ongoing chest pain and ST-segment elevation on the ECG. Exclusion criteria were safety or clinical concerns based on the operator’s judgment, including PCI-related complications.
hyperemic transit time, and fractional flow reserve was defined as the mean distal pressure divided by the mean proximal pressure during maximal hyperemia.

**Clinical End Point and Follow-up**

Major cardiac complications were defined as the following events after completion of the PPCI and at any time within 30 days: cardiac death (including sudden death), cardiogenic shock (prolonged hypotension with systolic blood pressure <90 mm Hg and signs of organ hypoperfusion requiring treatment), documented pulmonary edema (evidence of pulmonary congestion on chest radiographs, requirement for administration of intravenous diuretics, and impaired left ventricular function with ejection fraction ≤45% on transthoracic echocardiography), malignant ventricular tachycardia (ventricular fibrillation or sustained ventricular tachycardia requiring immediate defibrillation or cardioversion, respectively), malignant bradyarrhythmia (requiring administration of atropine or isoprenaline, and/or pacing), cardiac wall rupture, and intraventricular thrombus (revealed by echocardiography and/or cardiac magnetic resonance scan).

Data from 30-day clinical follow-up were collected by either telephone interview or office visit. All staff collating the outcome data was blinded to the coronary physiology data. One patient was lost to 30-day follow-up after an uneventful hospital discharge on day 3 and emigration at 10 days after PPCI, resulting in a total follow-up rate of 99.6%.

**Figure 1.** Study flowchart. IMR indicates index of microcirculatory resistance; OxAMI, Oxford Study in Acute Myocardial Infarction; PCI, percutaneous coronary intervention; PPCI, primary percutaneous coronary intervention; STEMI, ST-segment–elevation myocardial infarction.
Guideline-Recommended Risk Scores

According to the PAMI-II criteria, low-risk patients are aged <70 years with a left ventricular ejection fraction >45%, 1- or 2-vessel disease, successful PCI (<50% residual stenosis and TIMI [Thrombolysis in Myocardial Infarction] flow grade ≥2 or 3), and no persistent arrhythmias. The Zwolle score defines STEMI patients as low risk if they have ≤3 of 16 points based on Killip class, postprocedural TIMI flow, age <60 years, ischemic time <4 hours, and absence of 3-vessel disease or anterior myocardial infarction.

In the present study, experienced operators assessed pre- and postprocedural TIMI flow at angiography. Transthoracic echocardiography to obtain left ventricular function was performed before discharge by operators who were blinded to the coronary physiology indices.

Angiographic area at risk was assessed by the BARI (Bypass Angioplasty Revascularization Investigation) jeopardy score, as described previously.

Statistical Analysis

Continuous variables are reported as mean±SD or median and interquartile range, as appropriate. Frequencies are given as absolute values and percentages. Normally distributed continuous variables (age, creatinine, heart rate, stent diameter) were compared using the unpaired t test. The Mann–Whitney U test was used to compare continuous variables that were not normally distributed. Comparisons between frequencies were performed using χ² statistics or the Fisher exact test. Kaplan–Meier methodology and the associated log-rank test. Discriminative ability against major cardiac complications are reported in Figure S1.

Diagnostic Performance of IMR, CFR, and Risk Scores to Predict Clinical Outcome

According to the receiver operating characteristic curve analysis, IMR showed excellent performance to predict major cardiac complications, with an area under the curve (AUC) of 0.90 (95% confidence interval [CI], 0.85–0.93) and performed significantly better than CFR (AUC: 0.75; 95% CI, 0.69–0.80; P=0.006), the PAMI-II score (AUC: 0.71; 95% CI, 0.66–0.77; P=0.001), and the Zwolle score (AUC: 0.72; 95% CI, 0.66–0.77; P=0.004), as shown in Figure 2. Discriminative ability according to the AUC was similar for CFR and the PAMI-II and Zwolle scores.

According to the established cutoff values, IMR >40 was measured in 102 of 261 patients (39.1%) and was able to identify all 17 patients (sensitivity: 100%) with early major cardiac complications following an acute myocardial infarction, with a specificity of 65.2% (Figure 2). The individual complications are shown in Table 2. In patients with an adverse event, the IMR value was between 65 and 171 (median: 98.2; interquartile range: 87.2–114.8). As visualized on the receiver operating characteristic curve in Figure 2, an IMR cutoff value of 40 provides a sufficient safety margin before losing sensitivity of 100%. CFR stratified by a value of 2 and PAMI-II >0 achieved lower sensitivity (94.1% and 88.2%, respectively) and specificity (26.6% and 45.5%, respectively) compared with IMR >40 to identify patients developing an early complication (Figure 2). The sensitivity of the Zwolle score stratified by a value of 3 to predict a composite end point was lowest at 26.5%. The plots of continuous IMR, CFR, and PAMI-II and Zwolle scores against major cardiac complications are reported in Figure S1.
### Table 1. Clinical Characteristics on Admission Stratified by IMR

|                          | Whole Cohort (N=261) | IMR ≤40 (n=159) | IMR >40 (n=102) | P Value |
|--------------------------|----------------------|-----------------|-----------------|---------|
| **Male sex, n**          | 209 (80.0)           | 130 (81.7)      | 79 (77.5)       | 0.40    |
| **Age, y, mean**         | 61.4±12.0            | 59.4±11.8       | 64.5±11.6       | 0.001   |
| **Comorbidities, n**     |                      |                 |                 |         |
| Hypertension             | 100 (38.3)           | 54 (34.0)       | 46 (45.1)       | 0.07    |
| Hypercholesterolemia     | 98 (37.5)            | 59 (37.1)       | 39 (38.2)       | 0.90    |
| Diabetes mellitus        | 27 (10.3)            | 18 (11.3)       | 9 (8.8)         | 0.52    |
| History of smoking       | 166 (63.6)           | 110 (69.2)      | 56 (54.9)       | 0.02    |
| Family history of IHD    | 102 (39.1)           | 67 (42.1)       | 35 (34.3)       | 0.23    |
| Creatinine, µmol/L, mean | 81.2±25.7            | 80.3±25.6       | 81.8±26.2       | 0.74    |
| Previous myocardial infarction | 22 (8.5)  | 12 (7.6)       | 10 (10.0)       | 0.50    |
| **Periprocedural medications, n** |          |                 |                 |         |
| Aspirin                  | 257 (98.5)           | 156 (98.1)      | 101 (99.0)      | 1.00    |
| Clopidogrel              | 239 (91.6)           | 148 (93.1)      | 91 (89.2)       | 0.27    |
| Ticagrelor/prasugrel      | 10 (3.8)             | 6 (3.8)         | 4 (3.9)         | 1.00    |
| Thrombus aspiration      | 219 (83.9)           | 131 (82.4)      | 88 (86.3)       | 0.41    |
| Beta blocker             | 36 (13.8)            | 19 (11.9)       | 17 (16.7)       | 0.28    |
| ACE inhibitor             | 63 (24.1)            | 33 (20.8)       | 30 (29.4)       | 0.11    |
| **Clinical presentation, n** |                        |                 |                 |         |
| Systolic blood pressure <90 mm Hg | 17 (7.0)  | 11 (7.5)       | 6 (6.2)         | 0.70    |
| Heart rate before PCI, beats/min, mean | 79.5±17.0 | 79.6±17.1 | 79.3±17.0 | 0.89 |
| Killip class >1          | 24 (9.2)             | 13 (8.2)        | 11 (10.8)       | 0.20    |
| **Pain-to-wire time, n** |                        |                 |                 |         |
| <4 h                     | 169 (64.8)           | 109 (68.6)      | 60 (58.8)       | 0.28    |
| ≥4 and <12 h             | 79 (30.3)            | 43 (27.0)       | 36 (35.3)       | 0.55    |
| ≥12 h                    | 13 (5.0)             | 7 (4.4)         | 6 (5.9)         |         |
| Pain-to-wire time, min, median | 178.0 (126.5–298.0) | 167.0 (125.0–256.0) | 204.5 (127.3–339.0) | 0.11 |
| Door-to-wire time, min, median | 20.0 (15.0–28.0) | 20.0 (15.0–29.0) | 18.0 (13.3–25.8) | 0.20 |
| **Culprit vessel, n**    |                        |                 |                 |         |
| Left anterior descending | 112 (42.9)           | 69 (43.4)       | 43 (42.2)       | 0.83    |
| Left circumflex          | 27 (10.3)            | 15 (9.4)        | 12 (11.8)       |         |
| Right coronary artery    | 122 (46.7)           | 75 (47.2)       | 47 (46.1)       |         |
| BARI jeopardy score, median | 30.8 (26.8–38.7) | 31.0 (27.7–38.7) | 29.8 (25.3–37.7) | 0.61 |
| **Number of vessels with disease, n** |                        |                 |                 |         |
| 1                        | 172 (65.9)           | 110 (69.2)      | 62 (60.8)       | 0.31    |
| 2                        | 52 (19.9)            | 30 (18.9)       | 22 (21.6)       |         |
| 3                        | 37 (14.2)            | 19 (11.9)       | 18 (17.6)       |         |
| **TIMI flow before PCI, n** |                        |                 |                 |         |
| 0/1                      | 217 (83.1)           | 127 (79.9)      | 90 (88.2)       | 0.29    |
| 2                        | 29 (11.1)            | 20 (12.6)       | 9 (8.8)         |         |
| 3                        | 12 (4.6)             | 9 (5.7)         | 3 (2.9)         |         |

Continued
frequent history of smoking, more frequently impaired postprocedural TIMI flow, lower CFR, higher fractional flow reserve, and more frequently positive PAMI-II score (Table 1). Ischemic time, preprocedural TIMI flow, culprit vessel, BARI jeopardy score, and implanted stent volume did not significantly differ between the high- and low-IMR groups. Clinical characteristics at the time of discharge revealed that infarct size measured by troponin was larger, left ventricular ejection fraction was more often impaired, and more patients stayed in hospital longer than the median of 3 days in the high-IMR group than in the low-IMR group (Table 3).

**Discussion**

This study demonstrates that IMR measured at the time of PPCI for STEMI can independently select patients at very low risk of in-hospital cardiac complications and outperforms current guideline-recommended risk scores. These novel findings suggest that measuring IMR following PPCI may identify patients who could be triaged for less intensive nursing care and early discharge.

**Risk Scores as Predictors of Early Major Cardiac Complications**

The risk stratification of patients with an acute myocardial infarction has been a longstanding clinical challenge. Current international guidelines suggest that PPCI patients with a “low-risk of complications” might be candidates for non-ICU admission and early discharge and mention the PAMI-II and Zwolle scores as useful risk-stratification tools.

**Table 1. Continued**

| TIMI flow after PCI, n | Whole Cohort (N=261) | IMR ≤40 (n=159) | IMR >40 (n=102) | P Value |
|-----------------------|----------------------|-----------------|-----------------|---------|
| TIMI flow after PCI, n |                      |                 |                 |         |
| 0/1                   | 2 (0.8)              | 0 (0.0)         | 2 (2.0)         | 0.02    |
| 2                     | 25 (9.6)             | 10 (6.3)        | 15 (14.7)       |         |
| 3                     | 234 (89.7)           | 149 (93.7)      | 85 (83.3)       |         |
| Stent volume, mm³, median | 251.3 (188.5–365.6) | 268.6 (192.4–352.0) | 240.6 (173.2–457.7) | 0.51 |
| Stent diameter, mm    | 3.5 (3.5–4.0)        | 3.5 (3.5–4.0)   | 3.5 (3.4–4.0)   | 0.71    |
| Stent length, mm      | 24.0 (18.0–36.0)     | 24.0 (18.0–33.0) | 26.0 (18.0–38.0) | 0.55    |
| PAMI-II score >0, n   | 148 (56.7)           | 76 (47.8)       | 72 (70.6)       | <0.001   |
| Zwolle score >3, n    | 54 (20.7)            | 27 (17.0)       | 27 (26.5)       | 0.07    |
| Coronary physiology, median |                  |                 |                 |         |
| IMR                   | 32.3 (16.9–54.5)     | 21.4 (16.0–30.7) | 69.8 (51.8–107.1) | <0.001   |
| CFR                   | 1.46 (1.08–1.92)     | 1.68 (1.28–2.24) | 1.18 (0.92–1.50) | <0.001   |
| FFR                   | 0.93 (0.89–0.98)     | 0.92 (0.89–0.97) | 0.94 (0.90–0.99) | 0.01    |

Values are n (%), mean (±SD), or median (interquartile range). ACE indicates angiotensin-converting enzyme; BARI, Bypass Angioplasty Revascularization Investigation; CFR, coronary flow reserve; FFR, fractional flow reserve; IHD, ischemic heart disease; IMR, index of microcirculatory resistance; PAMI-II, Primary Angioplasty in Myocardial Infarction II; PCI, percutaneous coronary intervention; TIMI, Thrombolysis in Myocardial Infarction.

**Table 2. Major Cardiac Complications at 30 Days Stratified by IMR**

| Major cardiac complications | Whole Cohort (N=261) | IMR ≤40 (n=159) | IMR >40 (n=102) | P Value |
|-----------------------------|----------------------|-----------------|-----------------|---------|
| Major cardiac complications | 17 (6.5)             | 0 (0.0)         | 17 (16.7)       | <0.001  |
| Cardiac death               | 2 (0.8)              | 0 (0.0)         | 2 (2.0)         | 0.15    |
| Cardiogenic shock           | 3 (1.2)              | 0 (0.0)         | 3 (2.9)         | 0.06    |
| Pulmonary edema             | 8 (3.1)              | 0 (0.0)         | 8 (7.8)         | <0.001  |
| Malignant ventricular tachyarrhythmia | 4 (1.5) | 0 (0.0) | 4 (3.9) | 0.02 |
| Malignant bradyarrhythmia   | 1 (0.4)              | 0 (0.0)         | 1 (1.0)         | 0.39    |
| Cardiac rupture             | 0 (0.0)              | 0 (0.0)         | 0 (0.0)         | –       |
| Intraventricular thrombus   | 4 (1.5)              | 0 (0.0)         | 4 (3.9)         | 0.02    |

Values are n (%). IMR indicates index of microcirculatory resistance.
In our cohort, the PAMI-II criteria identified 43% of patients as low risk but, importantly, misclassified 12% who developed a major cardiac complication during the hospital stay (AUC: 0.71). A Zwolle score ≤3 identified 79% as low-risk candidates, but more than two-thirds of in-hospital complications subsequently occurred in this group (AUC: 0.72).

Patients developing heart failure and ventricular arrhythmia after an acute myocardial infarction are discrete groups:

Acute severe heart failure, cardiac rupture, and intraventricular thrombus occur after extensive myocardial damage. Life-threatening ventricular arrhythmia during the early postinfarct phase in apparently stable patients is associated with ongoing ischemia, making such adverse events difficult to predict. Ischemia may occur as a consequence of microvascular injury, despite restoring the flow in the epicardial coronary artery. Angiographic parameters such as the TIMI flow grade

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**Figure 2.** Diagnostic value to predict early major cardiac complications. Comparison of receiver operating characteristic curves of individual tests to predict early major cardiac complications. IMR performed significantly better than CFR, PAMI-II, and Zwolle score (DeLong: \( P = 0.006 \), \( P = 0.001 \), and \( P = 0.004 \), respectively). There was no difference among CFR, PAMI-II, and Zwolle score. Individual cutoff values are marked on the curves. AUC indicates area under the receiver operating characteristic curve; CFR, coronary flow reserve; CI, confidence interval; IMR, index of microcirculatory resistance; PAMI-II, Primary Angioplasty in Myocardial Infarction II; Sens, sensitivity; Spec, specificity.
which is incorporated in the PAMI-II and Zwolle scores) and myocardial blush grade were widely accepted as semiquantitative measures of microvascular perfusion; however, it has become increasingly evident that angiographic perfusion characteristics alone do not reliably predict the occurrence of microvascular dysfunction.26–28 Moreover, angiographic assessment of left ventricular ejection fraction at the time of PPCI (which is incorporated in the PAMI-II score) cannot differentiate between reversible stunning and irreversibly damaged myocardium, and the latter carries a higher risk for poor outcome. These limitations of angiographic assessment may in part account for the poor performance of the PAMI-II and Zwolle risk scores in predicting early major cardiac complications.

**Microvascular Indices as Predictors of Early Major Cardiac Complications**

IMR is an objective and specific index to assess the microcirculation, which can easily and safely be measured at the time of PPCI.7,8 The strength of IMR is not only in predicting myocardial recovery, final infarct size, and left ventricular ejection fraction,9–11 which are related to subsequent heart failure, but also in predicting the presence of microvascular dysfunction,10,11 which is itself associated with early life-threatening ventricular arrhythmias.29

In our cohort, the lowest IMR value in a patient who developed an adverse event was 65. A cutoff value ≤64 would offer the highest specificity while still maintaining sensitivity of 100%. We appreciate that a cutoff value of 40 is rather conservative; however, misclassifying a patient may have important clinical consequences. To provide a clinical safety margin, we adopted the previously validated IMR threshold of 40 (which confers longer term prognostic value such as death and rehospitalization for heart failure12) and defined 159 of the 261 STEMI patients (61%) as low risk, allowing correct prediction of all 22 major cardiac complications in our sample.

The lower predictive value of CFR compared with IMR for early major cardiac complications was mainly driven by low specificity (26.6%) and low positive predictive value (8.2%). This maybe explained by the influence of hemodynamic factors, such as heart rate and blood pressure on CFR,8 which have less impact on IMR. Furthermore, CFR is unable to distinguish between the contribution of epicardial and microvascular beds to total resistance.7

A prior study investigated whether microvascular dysfunction predicts in-hospital cardiac complications.30 This study was limited to anterior acute myocardial infarction and used Doppler wire technology. Cardiac death or ventricular rupture occurred in 16 of the 169 patients and was reported only in the group with microvascular dysfunction. In that study, all types of ventricular tachyarrhythmia (including benign reperfusion arrhythmias and nonsustained ventricular tachycardia) and “protocol-defined” heart failure (including any type of dyspnea or Killip class >1) were reported more frequently in the group with severe microvascular dysfunction. These findings are in line with our results, but our study extends these observations to all territories, focuses on clinically relevant complications, and uses more accessible technology to measure microvascular dysfunction.
Furthermore, our study extends the original report of the utility of IMR measured at PPCI to identify a high-risk group. In that study, the adverse outcomes of patients with an IMR >40 continued to be poorer, with ongoing separation of the Kaplan–Meier curves out to 3-year follow-up, but no analysis of the early time point was conducted. We suggest that a significant number of adverse events occur very early in that group and may be a target for closer monitoring and treatment while allowing those with very low early risk to be triaged.

**Clinical Implications**

IMR <40 following PPCI predicts uneventful in-hospital recovery, providing a basis to investigate whether this low-risk group may be safely managed in a lower monitoring environment. This information is available at the time of completing the PPCI and may apply to ≈60% of STEMI patients, based on our cohort, and would have major implications on the ICU admission rate. In addition, this approach may improve patient experience and shorten the overall hospital stay by facilitating early discharge, with consequent reduction in hospital costs. Furthermore, those patients with an IMR >40 represent a group at very high risk of early in-hospital complications and may benefit from even more intensive monitoring.

**Limitations**

Several limitations must be taken into account when interpreting our results. First, this is a single-center observational cohort study. Nevertheless, our cohort of 261 compares well in size with the original study reporting the long-term prognostic value of IMR in 253 patients. Second, the 6.5% rate of in-hospital major cardiac complications in our study is lower than reported in registry data. Coronary physiology measurements were undertaken if there were no safety or clinical concerns, and that causes a selection bias toward lower risk patients. The rate of in-hospital cardiac complications in the 78 patients without coronary physiology measurements was 14.1% (cardiac death, 2.6%; cardiogenic shock, 1.3%; pulmonary edema, 5.1%; malignant ventricular tachyarrhythmia, 5.1%; malignant bradyarrhythmia, 2.6%; intraventricular thrombus, 1.3%). Sixteen of these patients (20.5%) were hemodynamically unstable following PPCI and would have been judged as high risk at the outset. In 13 patients (16.6%), IMR could not be calculated because of nonmeasurable transit times. A detailed list of excluded patients is available in Figure 1. These limitations do not allow generalization to all STEMI patients; however, they may strengthen the potential value of our findings because IMR reliably identified the low-risk patients in an already preselected lowest risk group. A comprehensive analysis in a clinical prospective all-comers cohort is needed, but clinician recognition that the patient is too sick for this assessment appears in itself to be an important marker of risk.

The safety, feasibility, efficacy, and economic analysis of using IMR obtained at the time of PPCI to allow very early identification of high- and low-risk patients and the subsequent implications for where and how they are managed based on an IMR strategy requires prospective validation.

**Conclusion**

Coronary guidewire-based assessment of IMR immediately at the end of PPCI for STEMI reliably predicted early cardiac complications and outperformed current guideline-recommended strategies in terms of risk stratification. These novel findings provide evidence to test IMR as a tool to identify low-risk patients, who may not require admission to an ICU and are candidates for early discharge, and high-risk patients, who may need more intensive treatment.

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**Disclosures**

None.

**References**

1. Floyd KC, Yarzebski J, Spencer FA, Lessard D, Dalen JE, Alpert JS, Gore JM, Goldberg RJ. A 30-year perspective (1975–2005) into the changing landscape of patients hospitalized with initial acute myocardial infarction: Worcester Heart Attack Study. Circ Cardiovasc Qual Outcomes. 2009;2:88–95.
2. Steg PG, James SK, Badano LP, Blomstrom-Lundqvist C, Borger MA, Mario C D I, Dickstein K, Ducroq G, Fernandez-Aviles F, Gershlick AH, Giannuzzi P, Halvorsen S, Huber K, Juni P, Kastrati A, Knutti J, Lenzen MJ, Mahaffey KW, Valgimigli M, van’t Hof A, Wåhlin K, Zeller T, ESC guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation. Eur Heart J. 2012;33:2569–2619.
3. Silverman MG, Morrow DA. Hospital triage of acute myocardial infarction: is admission to the coronary care unit still necessary? Am Heart J. 2016;175:172–174.
4. Barbash IJ, Kahn JM. Assessing the value of intensive care. JAMA. 2015;314:1240–1241.
5. Antman EM, Anbe DT, Armstrong PW, Bates ER, Green LA, Hand M, Hochman JS, Krumholz HM, Kushner FG, Lamas GA, Mullany C, Ornato JP, Pearle DL,
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Sloan MA, Smith SC, Alpert JS, Anderson JL, Faxon DP, Fuster V, Gibbons RJ, Gregoratos G, Halperin JL, Hiratzka LF, Hunt SA, Jacobs AK. ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction—executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 1999 Guidelines for the Management of Patients With Acute Myocardial Infarction). Circulation. 2004;110:588–636.

6. Ahmed N, Layland J, Carrick D, Petrie MC, McIntegart M, Eteiba H, Hood S, Lindsay M, Watkins S, Davie A, Mahrous A, Carberry J, Teng V, McConnachie A, Curzen N, Oldroyd KG, Berry C. Safety of guidewire-based measurement of fractional flow reserve and the index of microvascular resistance using intravenous adenosine in patients with acute or recent myocardial infarction. Int J Cardiol. 2016;202:305–310.

7. Aarnoudse W, Fearon WF, Manoharan G, Geven M, van de Vosse F, Rutten M, Aarnoudse W, Fearon WF, Manoharan G, Geven M, van de Vosse F, Rutten M, van de Vosse F, Rutten M, van de Vosse F, Rutten M. Epicardial stenosis severity does not affect minimal coronary flow velocity pattern immediately after percutaneous coronary intervention in patients with ST-segment elevation myocardial infarction. J Am Coll Cardiol. 2008;51:560–565.

8. Ng MKC, Yeung AC, Fearon WF. Invasive assessment of the coronary microcirculation: superior reproducibility and less hemodynamic dependence of index of microcirculatory resistance compared with coronary flow reserve. Circulation. 2006;113:2054–2061.

9. Fearon WF, Shah M, Ng M, Brinton T, Wilson A, Schnittger I, Lee DP, Vagelas RH, Fitzgerald PJ, Yock PG, Yeung AC. Predictive value of the index of microcirculatory resistance in patients with ST-segment elevation myocardial infarction. J Am Coll Cardiol. 2008;51:650–655.

10. Goodarzi F, Tzemos N, Weale P, McComb C, Foster J, Ford I, Oldroyd KG. Microvascular resistance predicts myocardial salvage and infarct characteristics in ST-elevation myocardial infarction. JACC Cardiovasc Interv. 2010;3:715–722.

11. Payne AR, Berry C, Doolin O, McIntegart M, Petrie MC, Lindsay MM, Hood S, Carrick D, Tzemos N, Weale P, McComb C, Foster J, Ford I, Oldroyd KG. Microvascular resistance measured acutely predicts the extent and severity of myocardial infarction in patients with ST-segment elevation myocardial infarction. JACC Cardiovasc Interv. 2010;3:715–722.

12. Fearon WF, Low AF, Yong AS, McGeoch R, Berry C, Shah MG, Hy MY, Kim H-S, Lee PW, Granger CB. Incidence of and outcomes associated with ventricular fibrillation in patients undergoing primary percutaneous coronary intervention for ST-segment elevation myocardial infarction: a prospective study of 100 consecutive unselected patients with the aid of electrocardiographic monitoring. Am J Med. 1964;37:915–927.

13. Mehta D, Curvin J, Gomes JA, Fuster V. Sudden death in coronary artery disease: acute ischemia versus myocardial substrate. Circulation. 1997;96:3215–3223.

14. Gorenek B, Blomstrom Lundqvist C, Brugada Terradellas J, Camm AJ, Halperin G, Huber K, Kirchhof P, Kuck KH, Kudaibergenov G, Lin T, Raviele A, Santini M, Titz RR, Valgimigli M, Vos MA, Vrints C, Zeymer U. Cardiovascular arrhythmias in acute coronary syndromes: position paper from the joint EHRA, ACCA, and EAPCI task force. EuroIntervention. 2015;10:1095–1108.

15. Nijveldt R, Beek AM, Hirsch A, Stoel MG, Hofman MMB, Umana VAWM, Algra PR, Twisk JWR, van Rossum AC. Functional recovery after acute myocardial infarction: comparison between angiography, electrocardiography, and cardiovascualar magnetic resonance measures of microvascular injury. J Am Coll Cardiol. 2008;52:181–189.

16. Mehta RH, Starr AZ, Lopes RD, Hochman JS, Widimsky P, Pieper KS, Armstrong PW, Twisk JWR, van Rossum AC. Functional recovery after acute myocardial infarction provides the best invasive index for predicting the extent of myocardial salvage derived from cardiovascular magnetic resonance-derived microvascular obstruction on patient admission in STEMI. Int J Cardiol. 2013;166:77–84.

17. Wong DTL, Leung MCH, Richardson JD, Puri R, Bertaso AG, Armstrong PW, Granger CB. Incidence of and outcomes associated with ventricular fibrillation in patients undergoing primary percutaneous coronary intervention. JAMA. 2009;301:1779–1789.

18. Yamamuro A, Akasaka T, Tamita K, Yamabe K, Katayama M, Takagi T, Morikita S. Coronary flow velocity pattern immediately after percutaneous coronary intervention as a predictor of complications and in-hospital survival after acute myocardial infarction. Circulation. 2002;106:3051–3056.

19. Barret ML, Smith MW, Elkahsairi A, Honigman LS, Pines JM. Utilization of Intensive Care Services, 2011. Statistical Brief #185. In: Healthcare Cost and Utilization Project (HCUP) Statistical Briefs. Rockville (MD): Agency for Healthcare Research and Quality (US); 2016.

20. Konkani A, Oakley B. Noise in hospital intensive care units—a critical review of a critical topic. J Crit Care. 2012;27:522.e1–522.e9.

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Table S1. Guideline-recommended Risk Scores for ST-segment Elevation Myocardial Infarction

| PAMI-II Risk Score | Zwolle Risk Score |
|--------------------|------------------|
| **Age**            | **Points**       |
| ≤ 70               | 0                |
| > 70               | 1                |
| **LVEF**           | **Points**       |
| > 45%              | 0                |
| ≤ 45%              | 1                |
| **Killip Class**   | **Points**       |
| 1                  | 1                |
| 2                  | 4                |
| 3-4                | 9                |
| **3-vessel disease** | **Points**   |
| No                 | 0                |
| Yes                | 1                |
| **TIMI flow post** | **Points**       |
| 2 or 3             | 0                |
| 0 or 1             | 1                |
| **Anterior infarction** | **Points** |
| No                 | 0                |
| Yes                | 1                |
| **Residual stenosis** | **Points** |
| < 50%              | 0                |
| ≥ 50%              | 1                |
| **Ischemic time (> 4 h)** | **Points** |
| No                 | 0                |
| Yes                | 1                |
| **Low Risk if**    | **Points**       |
| ≤ 3                |                  |

(LVEF: Left Ventricular Ejection Fraction, TIMI: Thrombolysis In Myocardial Infarction)
Figure S1. Scatter Plot of IMR (A) and CFR (B) and Mosaic Plot of PAMI-II (C) and Zwolle score (D) against Major Cardiac Complications at 30 Days
Major Cardiac Complications at 30 days

C

D