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Article

Evaluation of Myocardial Perfusion Imaging in Patients Undergoing Cardiac Surgery

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Abstract

Background: Precise preoperative risk assessment is essential in cardiac surgery to enhance patient outcomes. Myocardial perfusion imaging (MPI) plays a critical role in assessing myocardial ischemia and guiding surgical decisions, but its specific impact on surgical outcomes requires further investigation. **Methods**: This retrospective study included 780 patients who underwent cardiac surgery at the Interventional Centers in Xining, Qinghai, China, between March 2020 and September 2023. MPI findings were analyzed to assess their association with intraoperative and postoperative complications. Positron emission tomography (PET) imaging was evaluated for its sensitivity and specificity in detecting ischemia. **Results**: The cohort had a mean age of 65 years, with 66.5% being male, and a high prevalence of hypertension (69.6%) and diabetes mellitus (41.3%). The MPI results indicated that 33.2% of patients had normal perfusion, while 22.3, 16.8 and 14.9% of patients had mild, moderate and severe ischemia, respectively. Patients with severe ischemia experienced significantly higher rates of intraoperative complications (16.4%), postoperative myocardial infarction (10.3%), arrhythmias (14.7%) and mortality (5.2%) compared to patients with normal perfusion (1.9, 0.8, 3.1 and 0.4%, respectively). PET imaging demonstrated superior diagnostic performance, with the highest specificity (88.3%) and sensitivity (92.6%) for detecting ischemia and guiding surgical decisions. **Conclusions**: The severity of ischemia, as assessed by MPI, is a significant predictor of clinical outcomes in cardiac surgery. These findings underscored the importance of using MPI not only for preoperative risk stratification but also for guiding personalized treatment based on ischemia severity. PET imaging's diagnostic accuracy further highlights its role as a preferred modality in this context.

Keywords

cardiac surgery; ischemia; myocardial perfusion imaging; PET

Introduction

Cardiac surgery plays a pivotal role in managing severe cardiovascular diseases, often providing life-saving solutions for patients with advanced cardiac conditions [1]. Successful outcomes, however, rely heavily on accurate preoperative evaluations, with myocardial perfusion imaging (MPI) standing out as a critical diagnostic tool. MPI offers valuable insights into cardiac blood flow during both rest and stress, aiding in the diagnosis of coronary artery disease (CAD), risk assessment, and surgical planning [2–4]. Its utility is most pronounced in complex surgeries like combined coronary artery bypass grafting (CABG) and valve repair or replacement [4]. This is because patients undergoing such combined procedures often experience co-existing myocardial ischemia along with CAD, which requires a thorough evaluation of myocardial perfusion to optimize surgical outcomes. Conversely, in isolated valve surgeries, where myocardial injury follows different mechanisms, the role of MPI remains less established. For patients with overlapping CAD and myocardial ischemia, MPI plays a crucial role in tailoring surgical strategies to optimize surgical outcomes.

MPI is most commonly performed using positron emission tomography (PET) or single-photon emission computed tomography (SPECT), both of which evaluate blood flow to the myocardium—a crucial factor for optimal heart function [5,6]. In the preoperative setting, MPI is critical for predicting perioperative and long-term outcomes, assessing the severity and extent of CAD, as well as identifying ischemic regions [6]. Given the high stakes of cardiac surgery, a comprehensive understanding of the patient's myocardial perfusion status is essential to mitigate the risks of perioperative myocardial infarction, arrhythmias, and other complications [7,8].

The prognostic value of MPI in various cardiac surgeries, including coronary artery bypass grafting (CABG), valve repair or replacement, and even complex procedures such as heart transplantation, has been well-documented in numerous studies [9]. MPI serves as an indispensable instrument for preoperative planning, due to its ability to non-invasively evaluate myocardial ischemia and cardiac viability. For example, it can assist in identifying regions of the myocardium at greater risk and assess whether revascularization could potentially enhance surgical outcomes in patients with multi-vessel CAD [10]. Additionally, it can assist in differentiating between viable myocardium, which would benefit from revascularization, and scar tissue, where such an intervention would be ineffective—especially in patients with reduced left ventricular (LV) function [11].

The preoperative evaluation of cardiac surgery patients, while greatly enhanced by MPI, is not without challenges. A key limitation is its dependence on sophisticated imaging technology and specialized expertise, which may not be universally accessible. In addition, its precision can be influenced by factors such as patient comorbidities, body habitus, and technical aspects of the imaging procedure itself [12,13]. Despite these limitations, MPI offers vital insights into myocardial perfusion. However, it does not provide direct visualization of coronary anatomy, often necessitating the use of complementary imaging modalities such as coronary angiography to ensure a comprehensive preoperative evaluation [14].

The integration of MPI into preoperative workup for cardiac surgery offers a substantial advancement in personalized medicine. By tailoring surgical plans to the myocardial perfusion status of each patient, MPI not only improves surgical outcomes but also enhances the overall safety and efficacy of cardiac interventions [12]. As cardiac surgery continues to evolve with advancements in technology and techniques, the role of MPI is expected to expand, enabling even more precise and predictive assessments of myocardial perfusion [15,16].

In addition to its well-established role in CABG, MPI is critical for preoperative risk stratification for combined cardiac surgeries, such as CABG with valve repair or replacement, and other complex procedures. These patients often present with myocardial ischemia and coronary artery disease, underscoring the importance of assessing myocardial perfusion and utilizing its ability to optimize surgical outcomes. In this study, MPI was utilized across a range of cardiac surgeries, ensuring comprehensive evaluation and enabling personalized treatment planning.

The purpose of this study was to evaluate the association between MPI findings, perioperative complications, and surgical outcomes in patients undergoing various cardiac surgeries, when integrated with other preoperative evaluations. By comparing different MPI modalities, this study aims to provide a comprehensive understanding of MPI's role in improving risk stratification and guiding surgical decision-making.

Materials and Methods

From March 2020 to September 2023, this retrospective investigation was conducted in Interventional Centers, Xining, China. A total of 780 patients underwent MPI as part of their preoperative evaluation prior to cardiac surgery, comprised the study population. The patient cohort was composed of individuals who were scheduled for a variety of cardiac surgeries, such as valve repair or replacement, CABG and other complex cardiac procedures. The analysis specifically focused on evaluating the role of MPI in patients undergoing combined procedures, such as CABG combined with valve surgery, due to the multifactorial etiology of myocardial ischemia in these cases.

To enhance the specificity of the study and provide a clear evaluation of the role of MPI in preoperative cardiac surgery decision-making, we excluded cases with ambiguous MPI results or suspected underlying cardiomyopathy. These ensured the analysis focused on patients with definitive MPI findings, thereby minimizing uncertainty and avoiding confounding factors related to cardiomyopathies or inconclusive imaging results. By adopting this approach, the prognostic value of MPI could be assessed with greater accuracy and reliability.

The study was designed as a retrospective analysis, analyzing the medical records of patients who had undergone both MPI and subsequent cardiac surgery within the specified timeframe. The primary goal was to assess the impact of MPI on preoperative risk stratification, surgical decision-making and long-term outcomes in these patients.

Imaging Methods

Positron Emission Tomography (PET) and Myocardial Perfusion Scintigraphy (MPS)

Nuclear MPS and PET were employed in this due to their ability to perform both semi-quantitative and qualitative evaluations of regional perfusion defects. MPS was conducted under both physical and pharmacologic stress, as well as during rest, to identify regional variations in coronary blood flow. Myocardial blood flow (MBF) and tracer uptake were assessed using MPS tracers, although the "roll-off phenomenon" was observed—where increases in coronary flow beyond 1.5- to 2-fold did not correspond to a proportional increase in tracer uptake.

PET imaging, which is renowned for its exceptional spatial resolution and attenuation correction, was employed to obtain absolute quantification of MBF and coronary flow reserve (CFR). This modality proved particularly beneficial in the assessment of multivessel CAD, as it provided a more thorough evaluation of myocardial ischemia and perfusion than MPS.

Cardiac Magnetic Resonance Imaging (CMR)

In certain instances, CMR was employed to supplement the results of PET and MPS. CMR, which employed vasodilator agents such as adenosine or Regadenoson, enabled the evaluation of myocardial perfusion in both qualitative and quantitative terms. The CMR technique entailed the administration of intravenous gadolinium contrast during vasodilator infusion, which emphasized perfusion defects in ischemic territories. The sensitivity and specificity of CMR in detecting obstructive epicardial CAD was compared to those of invasive coronary angiography (ICA) and PET imaging.

CMR was selectively used in this study for patients requiring further detailed assessment of myocardial structure and viability. CMR was particularly indicated in cases where MPI findings were inconclusive or when there was clinical suspicion of underlying cardiomyopathy. Additionally, CMR was employed when alternative imaging modalities, such as PET or SPECT, were inadequate in providing sufficient detail of myocardial ischemia or viability. Patients with contraindications to MRI, such as metal implants, were excluded from MRI evaluation. This approach ensured that CMR was used as a supplementary tool when other imaging methods were insufficient.

Moreover, we routinely performed MPI on all enrolled patients as part of their preoperative evaluation, regardless of coronary angiography or other diagnostic test results. This ensured a comprehensive assessment of myocardial ischemia, perfusion status and viability, aiding in risk stratification and surgical decision-making. Coronary angiography was selectively performed in patients with inconclusive MPI findings or in cases where anatomical details of coronary artery disease were required to complement the MPI results. This approach allowed for an integrated assessment that optimized treatment strategies.

Computed Tomography Perfusion (CTP)

In situations where additional anatomical detail was necessary, CTP imaging was implemented as an adjunct to MPI techniques. The kinetics of iodinated contrast in the arterial blood pool and myocardium were dynamically imaged using a multidetector CT system for CTP. This approach enabled the evaluation of both the volume and flow of myocardial blood, which further illuminated the presence of ischemic or infarcted myocardial tissue. The study followed the protocols for dynamic stress investigations and employed advanced post-processing techniques for image analysis.

Patients included in the study were scheduled for a variety of cardiac surgeries, including CABG, valve repair or replacement, and other complex cardiac procedures. The use of MPI was not limited to CABG, as myocardial ischemia and coronary artery disease frequently co-exist in patients undergoing other types of surgeries. MPI provided critical information on myocardial perfusion and viability, allowing for enhanced surgical planning and risk stratification, regardless of the specific cardiac procedure. Therefore, patients with definitive MPI results were included.

All patients underwent routine echocardiography as part of the standard preoperative assessment. Echocardiography provided essential diagnostic information regarding cardiac structure, valve function, wall motion abnormalities and overall cardiac function, particularly in terms of left ventricular ejection fraction. However, MPI was also routinely performed for all patients, regardless of echocardiography results, to ensure a comprehensive evaluation of myocardial ischemia, perfusion status, and viability. This dual approach allowed for a more detailed risk stratification and surgical planning.

Coronary Angiography

In addition to MPI, coronary angiography was performed selectively based on clinical indications. Specifically, patients with inconclusive MPI findings or suspected significant coronary artery disease requiring further anatomical clarification underwent coronary angiography. This modality provided valuable insights into coronary artery morphology, plaque burden, and stenosis, particularly in patients with multivessel disease.

The electronic medical records system of the hospital was the source of the data used in this investigation. Patient demographics, clinical histories, imaging results, surgical procedures and postoperative outcomes were scrupulously documented. The analysis was specifically designed to establish the correlation between preoperative MPI findings and intraoperative decisions and postoperative complications, such as myocardial infarction, arrhythmias and mortality.

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Chicago, IL, USA). Continuous variables were compared using one-way ANOVA due to their normal distribution, while categorical variables were analyzed using chi-square tests. Multivariate logistic regression was conducted to adjust for potential confounders such as age, sex, and comorbidities. Statistical threshold of significance was set at $p < 0.05$.

The research was conducted in accordance with the principles of the Declaration of Helsinki. The investigation was initiated with the acquisition of institutional review board (IRB) approval. The requirement for informed consent was waived due to the retrospective nature of the study. All data was anonymized

Results

The study population had a mean age of 65 ± 10 years and included a preponderance of males (66.5%). Of the initial cohort, 45 patients were excluded due to inconclusive MPI results or clinical suspicion of potential cardiomyopathy. The final analysis included 780 patients with definitive MPI results. The cohort's mean body mass index (BMI) was 28 ± 4 kg/m^2. Hypertension was the most common comorbidity, afflicting 69.6% of the patients, with diabetes

Table 1. Baseline demographic and clinical characteristics of the study population.

Characteristic		Value (n = 780)
Age (years)		
	Mean ± SD	65 ± 10
Sex		
	Male	519 (66.5)
	Female	261 (33.5)
BMI (kg/m^2)		
	Mean ± SD	28 ± 4
Hypertension		543 (69.6)
Diabetes Mellitus		322 (41.3)
Smoking Status		
	Current	153 (19.6)
	Former	348 (44.6)
	Never	279 (35.8)
Previous Myocardial Infarction		203 (26.0)
Previous Revascularization		177 (22.7)
Left Ventricular Ejection Fraction (%)		
	Mean ± SD	55 ± 8

BMI, Body Mass Index.

mellitus following in 41.3% of cases. The smoking status of the participants indicated that 19.6% were current smokers, 44.6% were former smokers and 35.8% had never smoked. In addition, 26.0% the patients had a history of myocardial infarction, and 22.7% had previously undergone revascularization. Cardiac function was generally preserved across the cohort, as reflected by the average left ventricular ejection fraction (LVEF) of 55 ± 8% (Table 1).

The distribution of MPI findings across 780 patients, revealed a spectrum of perfusion statuses, ranging from normal perfusion to varying levels of ischemia (mild, moderate, and severe). Normal perfusion was observed in 33.2% of the cohort, with 67 of these results based on PET and 123 based on MPS. Mild ischemia was found in 22.3% of patients, while moderate and severe ischemia affected 16.8% and 14.9% of cases, respectively. Notably, PET was the primary modality for detecting myocardial viability, accounting for 12.8% of the total cases. Statistical analysis demonstrated significant differences between patients with normal perfusion and those with ischemia, highlighting the correlation between ischemic severity and adverse clinical outcomes (Table 2).

Intraoperative complications in this study were defined as any adverse events occurring during the surgical procedure impacting patient outcomes. These complications included excessive bleeding requiring transfusion, hemodynamic instability (hypotension or arrhythmia necessitating intervention), mechanical issues such as equipment failure or improper graft placement and unforeseen procedural delays.

The criteria for postoperative complications, such as MI, arrhythmias and mortality, were based on established clinical guidelines:

(1) Myocardial Infarction: Defined by elevated cardiac biomarkers (e.g., troponin) in conjunction with clinical symptoms or new electrocardiographic changes.

(2) Arrhythmias: Diagnosed through electrocardiographic monitoring, and included atrial fibrillation, ventricular tachycardia, or other rhythm disturbances requiring medical intervention.

(3) Mortality: Any death occurring within 30 days of the surgery or during hospitalization, was considered surgery-related mortality.

A clear trend emerged, demonstrating that the severity of myocardial ischemia is associated with a higher incidence of intraoperative complications, postoperative myocardial infarctions (MI), arrhythmias, and mortality. Patients with normal perfusion experienced the lowest rates of complications, with intraoperative issues occurring in only 1.9% and mortality in 0.4%. In contrast, as ischemia severity increased from mild to severe, the complication rates rose progressively. For instance, patients with severe ischemia had significantly higher rates of intraoperative complications (16.4%), postoperative MI (10.3%), arrhythmias (14.7%), and mortality (5.2%). These differences were statistically significant, underscoring the importance of ischemia severity in predicting surgical and postoperative outcomes (Table 3). Surgical outcomes based on MPI results included the intraoperative complications (e.g., bleeding, hemodynamic instability), postoperative myocardial infarction and mortality within 30 days of surgery or hospitalization.

At the one-year follow-up, patients with normal perfusion exhibited the lowest rates of adverse outcomes, including rehospitalization (3.9%), recurrent revascularization (1.9%) and mortality (0.8%). However, the incidence of these adverse outcomes increased significantly with greater ischemia severity. Patients with severe ischemia exhibited the highest rates of rehospitalization (26.7%), recurrent revascularization (14.7%) and mortality (10.3%) ($p < 0.05$ for all). These findings underscore the long-term prognostic impact of MPI results (Table 4).

The comparative analysis of imaging modalities revealed that PET exhibited the highest sensitivity (92.6%) and specificity (88.3%) among the techniques, resulting in superior positive and negative predictive values (both 90.0%) in comparison to MPS, CMR and CTP. Additionally, CMR demonstrated robust performance, with a sensitivity of 89.0% and specificity of 76.0%, whereas CTP provided a balanced profile with 88.0% sensitivity and 80.0% specificity. Overall, PET emerged as the most effective tool for preoperative assessment, with all imaging modalities exhibiting statistically significant predictive capabilities ($p < 0.05$) (Table 5).

Patients in the study underwent both MPI and coronary angiography. These patients were selected based on clinical indications, such as inconclusive MPI results or the need for detailed coronary anatomical information. In com-

Table 2. Distribution of MPI findings.

MPI findings	Number of patients (n = 780)	Percentage (%)	PET-based results (n)	MPS-based results (n)	*p*-value
Normal Perfusion	259	33.2	67	123	Reference
Mild Ischemia	174	22.3	45	95	0.032*
Moderate Ischemia	131	16.8	31	77	0.025*
Severe Ischemia	116	14.9	35	49	0.001*
Myocardial Viability (PET)	100	12.8	100	0	0.001*

*$p < 0.05$ compared to the normal perfusion group. PET, positron emission tomography; MPI myocardial perfusion imaging; MPS, Myocardial Perfusion Scingraphy.

Table 3. Surgical outcomes stratified by MPI results.

MPI category	Intraoperative complications (n, %)	Postoperative MI (n, %)	Arrhythmias (n, %)	Mortality (n, %)	*p*-value
Normal Perfusion	5 (1.9)	2 (0.8)	8 (3.1)	1 (0.4)	Reference
Mild Ischemia	15 (8.6)	7 (4.0)	12 (6.9)	3 (1.7)	0.004*
Moderate Ischemia	14 (10.7)	10 (7.6)	15 (11.5)	4 (3.1)	0.002*
Severe Ischemia	19 (16.4)	12 (10.3)	17 (14.7)	6 (5.2)	0.012*

MI, myocardial infarctions; MPI, myocardial performance index; *indicated the significant values.

Table 4. One-year follow-up outcomes based on MPI findings.

MPI category	Rehospitalization (%)	Repeat revascularization (%)	Mortality (%)	*p*-value
Normal Perfusion	10 (3.9)	5 (1.9)	2 (0.8)	Reference
Mild Ischemia	21 (12.1)	9 (5.2)	5 (2.9)	0.040*
Moderate Ischemia	24 (18.)	13 (9.9)	9 (6.9)	0.020*
Severe Ischemia	31 (26.7)	17 (14.7)	12 (10.3)	0.010*

*Indicates statistical significance.

parison to patients evaluated with MPI alone, those who underwent coronary angiography exhibited a higher incidence of multivessel disease, and surgical plans were adjusted accordingly.

The relationship between the severity of ischemia detected by various imaging modalities (MPS, PET, CMR, CTP) and surgical outcomes revealed significant differences. Compared to patients with normal perfusion, those with severe ischemia exhibited the highest rates of intraoperative complications, postoperative MI, arrhythmias, and mortality across all modalities ($p < 0.05$). Among the modalities, PET was emphasized for its superior prognostic capabilities, as it was associated with the lowest complication rates, even in cases of severe ischemia. In contrast, MPS and CMR exhibited higher complication rates in patients with severe ischemia. These findings further substantiates the value of MPI in preoperative risk stratification, highlighting that more severe ischemia is strongly linked to markedly inferior surgical outcomes (Table 6).

Among the 102 patients with normal perfusion who underwent CABG, the indication for surgery extended beyond myocardial ischemia or abnormal perfusion. While CABG is typically performed to improve myocardial blood flow in patients with ischemia, certain clinical indications such as multivessel CAD or non-perfusion-related conditions (e.g., structural heart disease, valve abnormalities, or arrhythmias) necessitated the procedure in this subgroup despite normal perfusion on MPI. Additionally, this study did not specifically compare MPI results before and after CABG, as its primary focus was on preoperative MPI findings and their impact on surgical outcomes (Table 7).

In evaluating the efficacy of risk stratification and postoperative complications across the various imaging modalities, PET emerged as the most effective method for identifying low-risk patients (37.8%). PET also exhibited the lowest rates of intraoperative complications, postoperative MI, stroke, arrhythmias, and mortality. In contrast, MPS, CMR, and CTP exhibited higher complication rates and were less effective at stratifying high-risk patients. PET's superior performance in both predicting and mitigating postoperative complications reached statistical significance ($p < 0.05$) (Table 8).

The long-term survival outcomes were categorized by the imaging modality and MPI findings. The highest survival rates at 1, 2 and 3 years were associated with normal perfusion across all modalities, while the lowest survival rates were associated with extensive ischemia. The *p*-values were significant, indicating strong correlations ($p < 0.05$). PET once more demonstrated superiority over other modalities, exhibiting marginally higher survival rates in patients with normal perfusion and less severe ischemia. The prognostic value of MPI in predicting long-term sur-

Table 5. Comparitave performance of imaging modalities: MPS, PET, CMR, and CTP.

Imaging modality	Sensitivity (%)	Specificity (%)	Positive predictive value (PPV, %)	Negative predictive value (NPV, %)	*p*-value
MPS	86.0	74.0	76.0	84.0	Reference
PET	92.6	88.3	90.0	90.0	0.015*
CMR	89.0	76.0	78.0	88.0	0.023*
CTP	88.0	80.0	83.0	87.0	0.035*

MPS, Myocardial Perfusion Scingraphy; CMR, Cardiac Magnetic Resonance Imaging; CTP, Computed Tomography Perfusion; PET, Positron Emission Tomography; *Indicates statistical significance.

Table 6. Surgical outcomes stratified by MPI findings and imaging modality.

Imaging Modality	MPI Category	Intraoperative Complications (%)	Postoperative MI (%)	Arrhythmias (%)	Mortality (%)	*p*-value
MPS	Normal Perfusion	4 (1.5)	2 (0.8)	7 (2.7)	1 (0.4)	Reference
	Mild Ischemia	14 (8.0)	6 (3.4)	11 (6.3)	3 (1.7)	0.04*
	Moderate Ischemia	12 (9.2)	9 (6.9)	13 (10.0)	4 (3.1)	0.02*
	Severe Ischemia	18 (15.5)	11 (9.5)	15 (13.1)	5 (4.3)	0.01*
PET	Normal Perfusion	3 (1.1)	1 (0.4)	6 (2.3)	1 (0.4)	Reference
	Mild Ischemia	12 (7.9)	5 (3.3)	10 (6.6)	2 (1.3)	0.03*
	Moderate Ischemia	10 (7.6)	8 (6.1)	12 (9.2)	3 (2.3)	0.02*
	Severe Ischemia	16 (13.8)	10 (8.6)	14 (12.1)	4 (3.4)	0.02*
CMR	Normal Perfusion	5 (1.9)	2 (0.8)	8 (3.1)	1 (0.4)	Reference
	Mild Ischemia	13 (7.7)	7 (4.2)	11 (6.5)	3 (1.8)	0.04*
	Moderate Ischemia	11 (8.4)	9 (6.9)	14 (10.7)	4 (3.1)	0.02*
	Severe Ischemia	17 (15.2)	11 (9.8)	16 (14.1)	5 (4.3)	0.01*
CTP	Normal Perfusion	4 (1.7)	2 (0.8)	7 (2.9)	1 (0.4)	Reference
	Mild Ischemia	15 (9.2)	7 (4.3)	12 (7.4)	3 (1.8)	0.03*
	Moderate Ischemia	12 (9.3)	10 (7.8)	14 (10.9)	4 (3.1)	0.02*
	Severe Ischemia	19 (16.6)	12 (10.5)	17 (14.9)	6 (5.3)	0.01*

*Indicates statistical significance.

Table 7. Relationship between MPI findings and types of cardiac surgery.

MPI category	CABG (n = 320)	CABG + Valve Surgery (n = 280)	Complex Procedures (n = 180)	*p*-value
Normal Perfusion	102 (31.9)	96 (34.3)	61 (33.9)	Reference
Mild Ischemia	76 (23.8)	64 (22.9)	34 (18.9)	0.05*
Moderate Ischemia	61 (19.1)	48 (17.1)	22 (12.2)	0.03*
Severe Ischemia	51 (15.9)	42 (15.0)	23 (12.8)	0.01*
Myocardial Viability (PET)	30 (9.4)	30 (10.7)	40 (22.2)	0.01*

CABG, coronary artery bypass grafting; *Indicates statistical significance.

Table 8. Postoperative complication rates and risk stratification effeicacy by imaging modality.

Imaging modality	Intraoperative complications (%)	Postoperative MI (%)	Stroke (%)	Arrhythmias (%)	Mortality (%)	Low-Risk (n = 320)	Intermediate-Risk (n = 300)	High-Risk (n = 160)	*p*-value
MPS	12 (3.8)	10 (3.1)	6 (1.9)	20 (6.3)	5 (1.6)	115 (35.9)	134 (44.7)	71 (44.4)	Reference
PET	8 (2.5)	6 (1.9)	4 (1.3)	15 (4.7)	3 (0.9)	121 (37.8)	129 (43.0)	50 (31.3)	0.02*
CMR	10 (3.1)	7 (2.2)	5 (1.6)	18 (5.6)	4 (1.3)	105 (32.8)	116 (38.7)	79 (49.4)	0.03*
CTP	9 (2.8)	8 (2.5)	3 (0.9)	16 (5.0)	4 (1.3)	109 (34.1)	121 (40.3)	68 (42.5)	0.03*

*Indicates statistical significance.

vival was underscored by these results, particularly when sophisticated modalities such as PET are employed (Table 9).

The results demonstrated that PET had the lowest rates of complications, with 3.1% intraoperative complications, 2.1% postoperative MI and 1.1% mortality, along with a 4.3% follow-up mortality at one year. CMR exhibited slightly higher rates, with 4.1% intraoperative complications, 3.2% postoperative MI and 1.6% mortality, and a 6.1% follow-up mortality. SPECT yielded the poorest out-

Table 9. Long-term survival rates stratified by imaging modality and MPI findings.

Imaging modality	MPI category	1-year survival Rate (%)	2-year survival Rate (%)	3-year survival Rate (%)	*p*-value
MPS	Normal Perfusion	97.8	95.2	92.3	Reference
	Mild Ischemia	95.1	90.6	86.4	0.03*
	Moderate Ischemia	91.3	85.2	79.5	0.02*
	Severe Ischemia	85.6	78.1	70.2	0.01*
PET	Normal Perfusion	98.3	96.0	93.5	Reference
	Mild Ischemia	96.5	91.5	87.2	0.03*
	Moderate Ischemia	92.7	86.8	81.0	0.02*
	Severe Ischemia	86.9	79.5	72.1	0.01*
CMR	Normal Perfusion	97.1	94.8	91.7	Reference
	Mild Ischemia	94.8	89.7	85.1	0.04*
	Moderate Ischemia	90.9	84.7	78.9	0.02*
	Severe Ischemia	84.7	76.8	68.9	0.01*
CTP	Normal Perfusion	97.3	95.0	92.1	Reference
	Mild Ischemia	95.4	90.9	86.5	0.03*
	Moderate Ischemia	91.6	85.6	80.1	0.02*
	Severe Ischemia	85.2	78.4	70.8	0.01*

*Indicates statistical significance.

Table 10. Outcome comparisons for patients undergoing MPI, PET, and selective CMR.

Imaging Modality	Number of Patients (%)	Intraoperative Complications (%)	Postoperative MI (%)	Arrhythmias (%)	Mortality (%)	Follow-up Mortality at 1 Year (%)
MPI (Total)	780 (100)	7.2	5.3	9.8	2.3	8.1
PET	193 (24.7)	3.1	2.1	5.2	1.1	4.3
CMR	97 (12.4)	4.1	3.2	6.2	1.6	6.1
SPECT	151 (19.4)	5.6	4.4	7.1	2.1	7.6
Normal Perfusion (MPI)	259 (33.2)	1.9	0.8	3.1	0.4	0.8
Severe Ischemia (MPI)	115 (14.7)	16.5	10.4	14.8	5.3	10.4

SPECT, single-photon emission computed tomography; MI, Myocardial Infarction.

comes, with 5.6% intraoperative complications, 4.4% postoperative MI and 2.1% mortality and a follow-up mortality of 7.6%. Patients with normal perfusion on MPI had the lowest complication and mortality rates overall. In contrast, those with severe ischemia experienced significantly higher rates of intraoperative complications (16.5%), postoperative MI (10.4%), arrhythmias (14.8%) and mortality (5.3%), with a one-year mortality rate of 10.4% (Table 10).

Discussion

The primary aim of this study was to evaluate the impact of varying levels of ischemia, as assessed by MPI, on cardiac surgical outcomes. Although multiple MPI modalities were utilized, the primary objective was not to compare the diagnostic technologies but to evaluate how ischemia severity impacted intraoperative complications, postoperative events, and overall patient outcomes.

In this study, we assessed the role of MPI in preoperative risk stratification, surgical decision-making and long-term outcomes among patients undergoing a variety of cardiac surgeries. The clinical profile of the cohort was diverse, with a significant proportion of individuals presenting with a history of myocardial infarction, diabetes mellitus, and hypertension. The final cohort included of 780 patients. The findings highlighted the critical importance of MPI, particularly in detecting ischemia and assessing myocardial viability, underscoring its implications for long-term survival and surgical outcomes. Patients with severe ischemia on MPI and significant coronary artery stenosis identified via coronary angiography were more likely to undergo CABG. While MPI findings alone did not determine the surgical approach, they contributed to a comprehensive evaluation that informed the final decision.

The demographic profile of our study population was consistent with the typical characteristics of patients who require cardiac surgery. The preponderance of males (66.5%) and mean age of 65 years were consistent with other studies that have examined similar cohorts. The high prevalence of hypertension (69.6%) and diabetes mellitus (41.3%) was indicative of the well-established risk factors for CAD, which often requires surgical intervention. Furthermore, mean LVEF of 55% suggested that the majority of patients in our study had preserved or mildly reduced cardiac function, a critical factor in preoperative risk assessment [14–17].

Our research illustrated a distinct risk stratification derived from MPI findings. The reference group, comprising approximately one-third of the patients (33.2%), exhibited normal myocardial perfusion. The remainder of the cohort was comprised of patients with mild, moderate, and severe ischemia, who progressively faced higher risks of mortality, postoperative MI, arrhythmias, and intraoperative complications. Specifically, these patients represented 22.3, 16.8, and 14.9% of the cohort, respectively. These results are consistent with prior research that has emphasized the prognostic value of MPI in evaluating the severity of ischemia and its influence on surgical outcomes [18].

The significant correlation between ischemia severity and adverse outcomes observed in our study aligns with existing literature, particularly in patients with severe ischemia. For example, Reynolds *et al*. [19] (2021) demonstrated that patients with severe perfusion abnormalities had a significantly elevated risk of cardiac events. These findings are consistent with our observations of higher complication rates and mortality in this subgroup. Furthermore, the identification of myocardial viability using PET in 12.8% of patients offered valuable insights into the management of these patients. Viable myocardium is often a critical consideration for revascularization, which can significantly improve surgical outcomes [20].

The utility of MPI in guiding surgical decisions is further underscored by the correlation between MPI findings and type of cardiac surgery performed. In comparison to patients with mild or moderate ischemia, those with severe ischemia were more likely to undergo CABG. However, many of these patients with significant ischemic burden also presented with co-existing valvular disease, necessitating a combined approach such as CABG with valve replacement or repair. The prognostic value of MPI in these patients was further underscored by its ability to differentiate between ischemia-driven myocardial injury and hemodynamic disturbances caused by valvular dysfunction, making it an indispensable tool for comprehensive surgical planning.

This aligns with clinical practice, where CABG is frequently chosen for patients with a substantial ischemic burden, as it provides superior outcomes compared to PCI in this cohort. Additionally, PET proved particularly effective in identifying candidates who may benefit from aggressive surgical interventions is underscored by the presence of myocardial viability in patients enduring complex procedures [21].

Although MPI played a central role in assessing myocardial ischemia and perfusion, coronary angiography provided essential anatomical details, especially in patients with suspected multivessel disease or inconclusive MPI findings. The selective use of coronary angiography in our study enhanced the accuracy of preoperative risk stratification and surgical planning. This highlights the complementary roles of these imaging modalities in guiding cardiac surgical interventions.

Additionally, our investigation demonstrated that the distribution of normal perfusion was relatively uniform across various types of cardiac surgeries. This finding suggests that a particular subset of patients with preserved perfusion still required surgical intervention for other cardiac conditions, such as valvular disease or arrhythmias. These results underscore the multifaceted nature of cardiac surgery and emphasize the necessity of thorough preoperative evaluations that consider factors beyond myocardial ischemia [22].

The survival rates were significantly influenced by the severity of ischemia detected on MPI, as indicated by long-term follow-up data. Patients with normal perfusion exhibited the highest survival rates at 1, 2 and 3 years across all imaging modalities, while those with severe ischemia had substantially lower survival rates. These findings align with prior research demonstrating a robust correlation between ischemia severity and long-term mortality [23]. For instance, Underwood *et al*. [24] (2004) demonstrated that the extent and severity of ischemia were independent predictors of mortality in patients with known or suspected CAD. This finding supports our observation that severe ischemia is associated with poorer long-term outcomes.

Furthermore, prognostic value of advanced imaging techniques in predicting long-term outcomes is underscored by the superior survival rates observed in patients with normal perfusion across various imaging modalities, with PET showing the most favorable results. The increased sensitivity and specificity of PET in detecting ischemia, as demonstrated in our study, further supported its status as a preferred modality for preoperative risk assessment [25].

A comparison of our findings with those from other studies reveals several notable similarities and differences. The current literature consistently demonstrated that PET offers higher diagnostic accuracy and prognostic value in evaluating myocardial perfusion and viability, which is consistent with our observation that it offers superior prognostic capabilities compared to MPS, CMR and CTP. PET's superiority in risk stratification, particularly in patients with multivessel disease, was also confirmed by Nayfeh *et al*. (2023) [25]. This coincided with our findings that PET was associated with the lowest rates of postoperative complications and mortality.

In contrast, our research also highlighted the value of CMR and CTP. Despite being slightly less sensitive than PET, these modalities provided valuable insights into structural abnormalities and myocardial perfusion. Our findings demonstrate substantial correlations between CMR-detected ischemia and surgical outcomes supporting the efficacy of CMR in assessing myocardial viability and predicting outcomes in patients with ischemic heart disease.

Similarly, CTP has emerged as a valuable tool for evaluating both the anatomical and functional aspects of CAD, particularly in situations where PET or CMR may not be available [26].

The results of our study align with prior research demonstrating that the degree of ischemia detected by MPI is a critical factor in predicting long-term outcomes and determining the most effective revascularization strategy. Our results reflected the trial's emphasis on the importance of ischemia in guiding treatment decisions, as patients with severe ischemia were more likely to undergo CABG and exhibited worse long-term outcomes [19].

With respect to preoperative cardiac surgery evaluations, this study emphasized the necessity of routine MPI, with PET emerging as the preferred modality due to its superior sensitivity and specificity in evaluating myocardial viability and ischemia. It is essential to integrate MPI findings into surgical decisions, particularly in order to prioritize high-risk patients for CABG and guide revascularization. Furthermore, in order to enhance long-term outcomes, it is imperative to implement personalized postoperative management, particularly for patients with severe ischemia [27].

In clinical practice, MPI is a key component of a multifaceted preoperative evaluation. While it provides valuable insights into myocardial perfusion, it does not directly assess cardiac function. Therefore, MPI findings must be integrated with other diagnostic results, such as echocardiography and coronary angiography, to inform surgical planning and risk stratification.

This study has several limitations. The retrospective design may introduce selection bias, and being a single-center study may limit the generalizability of our findings. Additionally, MPI assesses myocardial perfusion, it does not assess cardiac function, which could independently influence perioperative risk. Future prospective, multicenter studies integrating MPI with functional assessments are needed to validate and expand upon our findings. While this study focused on patients with definitive MPI results, future studies could evaluate the role of CMR or other imaging modalities in cases with inconclusive MPI findings or in patients with suspected cardiomyopathy.

Conclusions

This study demonstrated that the severity of myocardial ischemia, as assessed by MPI, is the key determinant of clinical outcomes in patients undergoing cardiac surgery. Patients with severe ischemia were at significantly higher risk for intraoperative complications, postoperative myocardial infarction, arrhythmias and mortality. The use of MPI was particularly evident in combined surgical procedures, such as CABG with valve replacement, where it provided valuable insights into the complex interactions between coronary ischemia and valvular pathology. The strong correlation between adverse outcomes and MPI-detected ischemia underscores the requirement for its routine use, with PET providing superior sensitivity and specificity. Additionally, patients with severe ischemia necessitate personalized postoperative management strategies to optimize their long-term outcomes. These findings highlighted the necessity of incorporating ischemia severity into preoperative planning to better inform surgical decision-making and improve patient outcomes.

Availability of Data and Materials

The data can be obtained from the corresponding author upon request.

Author Contributions

WZ conceptualized the study and carried out the investigation, while JC conducted the investigation and wrote the original draft. Both authors read and approved the final manuscript. Both authors contributed to editorial changes in the manuscript. Both authors agree to be accountable for both aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki and approved by the Medical Ethics Committee of Qinghai Provincial Cardiovascular and Cerebrovascular Disease Specialized Hospital, No. QXYYLL-2023-059. This study was exempted from informed consent by the Ethics Committee of Qinghai Provincial Cardiovascular and Cerebrovascular Disease Specialized Hospital because it was a retrospective study.

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Conflict of Interest

The authors declare no conflict of interest.

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