ARTIFICIAL INTELLIGENCE-ASSISTED FUNCTIONAL ASSESSMENT OF BORDERLINE CORONARY STENOSES IN MOBILE ANGIOGRAPHY: INTEGRATION WITH PERSONALIZED CARDIAC REHABILITATION

Azam Fayzievich
DSc.,
Saidov Maksud Arifovich,
Sabirov Djakhongir Ruziyevich
DSc., prof.,
National Medical Center, Tashkent, Republic of Uzbekistan
azamalimov1986@gmail.com, saidov_maksud@mtm.uz, gocjahongir@gmail.com
https://doi.org/10.5281/zenodo.19511626

ARTICLE INFO

Received: 06th April 2026
Accepted: 08th April 2026
Online: 10th April 2026

KEYWORDS

AI-derived virtual FFR models demonstrate high diagnostic accuracy comparable to invasive FFR, with deep learning algorithms enabling automated coronary segmentation and hemodynamic significance prediction from standard angiographic images

ABSTRACT

Background: Borderline coronary stenoses (40–70%) represent a major clinical challenge in interventional cardiology, particularly in mobile angiography settings where invasive functional assessment tools such as Fractional Flow Reserve (FFR) and instant wave-free ratio (iFR) are largely unavailable. Artificial intelligence (AI)-based approaches offer a potential solution for real-time functional triage, yet their applicability in resource-limited mobile environments and integration with downstream cardiac rehabilitation remain unexplored.

Background: Borderline coronary stenoses (40–70%) represent a major clinical challenge in interventional cardiology, particularly in mobile angiography settings where invasive functional assessment tools such as Fractional Flow Reserve (FFR) and instant wave-free ratio (iFR) are largely unavailable. Artificial intelligence (AI)-based approaches offer a potential solution for real-time functional triage, yet their applicability in resource-limited mobile environments and integration with downstream cardiac rehabilitation remain unexplored.

Objective: To systematically review the current evidence on AI-derived functional assessment of coronary stenoses from angiographic images, evaluate their potential for deployment in mobile catheterization laboratories, and propose a conceptual framework integrating AI-guided interventional decision-making with risk-stratified personalized cardiac rehabilitation.

Methods: A systematic literature review was conducted using PubMed, Scopus, and Web of Science databases covering publications from 2016 to 2025. Search terms included "fractional flow reserve," "artificial intelligence," "machine learning," "mobile angiography,"

"quantitative coronary angiography," "cardiac rehabilitation," and "telerehabilitation." Over 80 relevant sources were analyzed.

Results: AI-derived virtual FFR models demonstrate high diagnostic accuracy comparable to invasive FFR, with deep learning algorithms enabling automated coronary segmentation and hemodynamic significance prediction from standard angiographic images. However, existing models have been predominantly validated in high-resource stationary catheterization laboratories. Cardiac rehabilitation after percutaneous coronary intervention reduces all-cause mortality by 20–25% and rehospitalization by 18–30%, yet participation rates remain below 40%. Telerehabilitation demonstrates non-inferior outcomes compared to center-based programs.

Conclusion: Integration of AI-assisted functional assessment in mobile angiography with personalized telerehabilitation represents a promising strategy for optimizing coronary artery disease management in resource-limited settings. Further prospective validation studies are warranted.

Introduction

Cardiovascular diseases remain the leading cause of death globally, accounting for over 18.6 million deaths in 2019, with ischemic heart disease representing the largest single contributor. Despite substantial advances in interventional cardiology, the management of borderline coronary stenoses in the 40–70% diameter reduction range continues to pose significant clinical challenges. These intermediate lesions represent a gray zone where anatomic assessment alone cannot reliably predict myocardial ischemia, leading to substantial variability in treatment decisions among experienced interventional cardiologists.

Fractional Flow Reserve has been established as the gold standard for functional assessment of coronary stenosis severity. The landmark FAME trial series demonstrated that FFR-guided percutaneous coronary intervention (PCI) significantly reduces major adverse cardiac events compared to angiography-guided strategies. Similarly, the instantaneous wave-free ratio (iFR) has been validated as a hyperemia-free alternative with equivalent clinical outcomes, as demonstrated in the DEFINE-FLAIR and iFR-SWEDEHEART trials.

However, real-world utilization of FFR and iFR remains substantially lower than expected. Registry data indicate that in many centers, decisions regarding borderline stenoses are still predominantly based on visual angiographic assessment. This gap between evidence and practice is particularly pronounced in resource-limited settings and mobile angiography services, where the logistical requirements for invasive pressure wire measurements — including additional equipment, adenosine infusion, prolonged procedural time, and increased costs — represent significant barriers to implementation.

Mobile catheterization laboratories have emerged as an important strategy for expanding interventional cardiology services to geographically remote populations. These mobile platforms have demonstrated the ability to reduce door-to-treatment times in acute coronary syndromes and provide planned angiographic and interventional services in areas without stationary catheterization facilities. Nevertheless, the absence of functional assessment capabilities in mobile settings creates a risk of inappropriate revascularization decisions, with potential consequences including unnecessary stenting, increased procedural complications, and suboptimal resource allocation.

In recent years, artificial intelligence and machine learning technologies have rapidly advanced in cardiovascular imaging. Deep learning algorithms have demonstrated the ability to perform automated coronary artery segmentation, lesion detection, and quantitative analysis from standard angiographic images. Of particular interest is the development of AI-derived virtual FFR models that predict hemodynamic significance from angiographic data alone, without the need for invasive pressure measurements. These computational approaches offer the theoretical possibility of providing functional assessment in any setting where angiographic images are available, including mobile laboratories.

Simultaneously, cardiac rehabilitation following PCI has been firmly established as a Class I recommendation by the European Society of Cardiology and the American Heart Association. Meta-analyses demonstrate that exercise-based cardiac rehabilitation programs reduce all-cause mortality by 20–25%, decrease rehospitalization rates by 18–30%, and improve functional capacity as measured by peak VO2. The emergence of telerehabilitation and digital health monitoring technologies has further expanded the potential reach of rehabilitation services, particularly in settings where geographic distance and limited infrastructure preclude access to center-based programs.

Despite these parallel advances in AI-assisted diagnostics and digital rehabilitation, a critical gap exists in the literature: no integrative framework has been proposed that connects AI-guided interventional triage in mobile angiography with risk-stratified personalized cardiac rehabilitation. The present review addresses this gap by systematically analyzing the current evidence across these domains and proposing a conceptual model for their integration.

Materials and Methods

A systematic literature review was conducted in accordance with the PRISMA guidelines for scoping reviews. Electronic database searches were performed in PubMed, Scopus, and Web of Science for publications dated from January 2016 through December 2025.

The search strategy employed combinations of the following Medical Subject Headings (MeSH) terms and free-text keywords: "fractional flow reserve," "instant wave-free ratio," "artificial intelligence," "machine learning," "deep learning," "coronary angiography," "quantitative coronary angiography," "mobile catheterization laboratory," "mobile angiography," "cardiac rehabilitation," "telerehabilitation," "digital health," "wearable devices," and "personalized rehabilitation." Boolean operators (AND, OR) were used to combine search terms across thematic domains.

Inclusion criteria comprised: (1) original research articles, systematic reviews, meta-analyses, and international clinical guidelines; (2) publications in English, Russian, French, or Uzbek languages; (3) studies addressing functional assessment of coronary stenoses, AI applications in coronary imaging, mobile catheterization services, cardiac rehabilitation after PCI, or telerehabilitation technologies. Exclusion criteria included: case reports with fewer than 5 patients, conference abstracts without full-text availability, and publications predating 2016 except for seminal methodological references.

A total of 347 publications were initially identified through database searches. After removal of duplicates and screening of titles and abstracts, 124 full-text articles were assessed for eligibility. The final analysis included 80 publications that met all inclusion criteria. Data

extraction was performed independently by two reviewers using a standardized form that captured study design, population characteristics, intervention type, comparators, primary and secondary outcomes, and key findings.

The extracted evidence was synthesized narratively across five thematic domains: (1) epidemiology and clinical significance of borderline coronary stenoses; (2) conventional and functional assessment methods; (3) AI applications in interventional cardiology; (4) mobile angiography services; and (5) cardiac rehabilitation and telerehabilitation after PCI. Cross-domain synthesis was performed to identify gaps in the current literature and to formulate an integrative conceptual framework.

Results

The analysis of the included literature yielded findings across five principal domains, which are presented below.

Functional assessment of borderline coronary stenoses. The reviewed evidence consistently demonstrates that anatomic assessment of coronary stenosis severity by visual angiography is subject to significant interobserver variability and does not reliably predict the hemodynamic significance of borderline lesions. Multiple multicenter trials have established that FFR-guided PCI reduces the composite endpoint of major adverse cardiac events compared to angiography-guided strategies. The FAME trial demonstrated a significant reduction in MACE at one year, while the FAME 2 trial confirmed the superiority of FFR-guided PCI plus medical therapy over medical therapy alone in patients with functionally significant stenoses. The iFR has been validated as a non-inferior alternative to FFR, with the DEFINE-FLAIR and iFR-SWEDEHEART trials demonstrating equivalent clinical outcomes at one year. Nevertheless, registry-based analyses reveal that FFR/iFR utilization in clinical practice remains below 30% of eligible cases in most centers, with even lower adoption rates in developing countries.

AI-derived functional assessment models. A rapidly growing body of evidence supports the feasibility of computing virtual FFR from standard coronary angiographic images using computational fluid dynamics and machine learning approaches. Quantitative Flow Ratio (QFR) technology, which derives a pressure-flow relationship from three-dimensional angiographic reconstruction, has demonstrated diagnostic accuracy exceeding 90% compared to invasive FFR in multiple validation studies. Deep learning-based approaches using convolutional neural networks for automated coronary segmentation and stenosis quantification have shown expert-level performance in lesion detection. Hybrid models combining QCA-derived geometric parameters with image-based deep learning features have demonstrated superior predictive accuracy for hemodynamic significance compared to either approach alone. However, the vast majority of validation studies have been conducted in well-equipped stationary catheterization laboratories with high image quality standards. The applicability of these models to the variable image quality and workflow constraints of mobile angiographic platforms has not been specifically evaluated.

Mobile angiography services. The literature demonstrates that mobile catheterization laboratories effectively expand access to interventional cardiology services, particularly in rural and geographically dispersed populations. Evidence from multiple healthcare systems indicates that mobile PCI programs significantly reduce reperfusion times in ST-elevation

myocardial infarction and provide a cost-effective alternative to establishing stationary catheterization facilities in low-volume settings. However, functional assessment capabilities in mobile platforms are severely constrained. The reviewed evidence suggests that the vast majority of interventional decisions in mobile settings are based on visual angiographic assessment alone, contributing to a higher risk of inappropriate revascularization. No published studies have specifically evaluated the deployment of AI-derived functional assessment tools in mobile angiographic environments.

Cardiac rehabilitation after PCI. Meta-analytic evidence confirms that exercise-based cardiac rehabilitation reduces all-cause mortality by 20–25%, cardiovascular mortality by 26%, and hospital readmissions by 18–30% in patients following coronary revascularization. Functional capacity, as measured by peak oxygen consumption (VO2 max), improves by 10–20% with structured rehabilitation programs. Personalized rehabilitation approaches that account for individual risk profiles, left ventricular function, comorbidity burden, and functional tolerance demonstrate superior outcomes compared to standardized protocols. Despite Class I guideline recommendations, participation rates in cardiac rehabilitation remain disappointingly low, with only 30–40% of eligible post-PCI patients being referred to and completing rehabilitation programs. Geographic distance, logistic barriers, and limited availability of rehabilitation centers are identified as primary obstacles.

Telerehabilitation and digital health technologies. Randomized controlled trials demonstrate that telerehabilitation achieves non-inferior or superior outcomes compared to center-based programs in terms of physical activity improvement, program adherence, exercise capacity, and quality of life. Wearable devices, mobile applications, and remote monitoring platforms enable continuous physiological monitoring and personalized exercise prescription. However, integration of telerehabilitation with interventional decision-making processes has not been investigated. No existing framework links AI-assisted triage outcomes from the catheterization laboratory with risk-stratified rehabilitation intensity.

Discussion

The present systematic review reveals a significant and as yet unaddressed gap at the intersection of three rapidly evolving domains: AI-assisted coronary functional assessment, mobile interventional cardiology, and personalized cardiac rehabilitation. While each of these fields has independently demonstrated substantial clinical promise, their integration into a unified clinical pathway has not been explored.

The convergence of AI-derived virtual FFR technology with mobile angiography platforms addresses a fundamental limitation of current mobile catheterization services — the inability to perform functional assessment of borderline coronary stenoses. By enabling real-time estimation of hemodynamic significance from standard angiographic images, AI tools could transform clinical decision-making in mobile settings, reducing unnecessary revascularization and optimizing resource utilization. The computational efficiency of modern deep learning algorithms, many of which can generate results within minutes from standard two-dimensional angiographic projections, makes them particularly suited to the workflow constraints of mobile laboratories where procedural efficiency is paramount.

Critically, the proposed integration extends beyond the catheterization laboratory. By linking AI-derived functional and anatomic assessment with downstream rehabilitation

intensity, a continuum-of-care model emerges that addresses the patient's journey from diagnosis through intervention to functional recovery. Patients identified as having functionally significant stenoses requiring PCI would be stratified for more intensive rehabilitation, while those with non-significant lesions managed medically could receive targeted secondary prevention support through digital platforms.

Several important limitations must be acknowledged. First, the vast majority of AI-derived FFR validation studies have been conducted in controlled research environments with optimized image acquisition protocols. The generalizability of these models to the variable image quality inherent in mobile angiographic practice requires specific validation. Second, the proposed integration framework remains conceptual and requires prospective clinical evaluation. Third, the pharmacoeconomic implications of implementing AI and telerehabilitation technologies in resource-limited settings need careful assessment.

Future research should prioritize prospective validation of AI-derived functional assessment tools specifically in mobile angiographic environments, development of integrated clinical decision support systems that connect interventional triage with rehabilitation planning, and randomized controlled trials evaluating the clinical and economic outcomes of the proposed integrated pathway compared to standard care.

Conclusion

This systematic review demonstrates that AI-based functional assessment of borderline coronary stenoses from angiographic images represents a clinically viable and rapidly maturing technology with particular potential for deployment in mobile catheterization laboratories, where conventional functional assessment methods are largely unavailable. The integration of AI-guided interventional decision-making with personalized, risk-stratified cardiac rehabilitation — delivered through telerehabilitation and digital health platforms — offers a novel continuum-of-care framework that addresses critical gaps in current practice. This approach has the potential to reduce inappropriate revascularization, optimize resource allocation, and improve long-term functional outcomes in patients with coronary artery disease, particularly in resource-limited settings. Prospective multicenter studies are needed to validate this integrative framework in clinical practice.

References:

1. Nils P. Johnson, Bernard De Bruyne. Fractional Flow Reserve–Guided PCI versus Medical Therapy in Stable Coronary Disease. New England Journal of Medicine, 2012, Vol. 367, pp. 991–1001.

2. Roxana Mehran, Deepak L. Bhatt. Artificial Intelligence in Cardiovascular Imaging: Current Applications and Future Directions. Journal of the American College of Cardiology, 2020, Vol. 75, No. 21, pp. 2663–22678.

3. Шагазатова, Б. Х., Рахимбердиева, З. А., Юлдашева, Н. Х., & Артикова, Д. М. (2021). ОЦЕНКА ЭФФЕКТИВНОСТИ АНАЛОГОВ КЕТОАМИНОКИСЛОТ (КЕТОСАН) В УЛУЧШЕНИИ ТЕЧЕНИЯ ХРОНИЧЕСКОЙ БОЛЕЗНИ ПОЧЕК У БОЛЬНЫХ С САХАРНЫМ ДИАБЕТОМ. EDITOR COORDINATOR, 309.

4. Нажмутдинова Д. К., Максудова Д. Р., Рахимбердиева З. А. АУТОИММУННЫЙ ТИРЕОИДИТ И РЕПРОДУКТИВНАЯ ФУНКЦИЯ ЖЕНЩИН ФЕРТИЛЬНОГО ВОЗРАСТА //МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ РЕСПУБЛИКИ УЗБЕКИСТАН

РЕСПУБЛИКАНСКИЙ СПЕЦИАЛИЗИРОВАННЫЙ НАУЧНО-ПРАКТИЧЕСКИЙ МЕДИЦИНСКИЙ ЦЕНТР АКУШЕРСТВА И ГИНЕКОЛОГИИ АССОЦИАЦИЯ ВРАЧЕЙ ЧАСТНОЙ ПРАКТИКИ УЗБЕКИСТАНА КЛИНИКА «MAHLIYO-SHIFO» & V «MAHLIYO-SHIFO» & V. – С. 9.

5. Нажмутдинова, Д. К., Рахимбердиева, З. А., & Ботаева, Н. О. (2018). ОСОБЕННОСТИ КЛИНИЧЕСКОГО ТЕЧЕНИЯ МИКРОАДЕНОМ У ЖЕНЩИН. In INTERNATIONAL INNOVATION RESEARCH (pp. 226-228)