CARDIAC PATHOLOGIES: HEMODYNAMIC ASSESSMENT AND COMPLICATIONS

PATOLOGIAS CARDÍACAS: AVALIAÇÃO HEMODINÂMICA E INTERCORRÊNCIAS

PATOLOGÍAS CARDÍACAS: EVALUACIÓN HEMODINÁMICA E INTERCURRENCIAS

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ABSTRACT

Cardiovascular diseases are the leading cause of mortality worldwide and remain a major challenge for public health in Brazil, especially in light of population aging and the high prevalence of cardiometabolic risk factors. In this context, hemodynamics, or interventional cardiology, plays a central role in the diagnosis and minimally invasive treatment of coronary syndromes and other cardiovascular pathologies. This chapter discusses the physiology of myocardial blood flow, the epidemiology of heart diseases, and the main clinical entities associated with coronary obstruction, with emphasis on atherosclerosis, angina, acute myocardial infarction, and heart failure. It also addresses the main procedures performed in hemodynamic services, such as cardiac catheterization, coronary angiography, coronary angioplasty, and stent implantation, emphasizing their indications and technical foundations. In addition, the text examines complications related to these procedures, especially vascular complications and events associated with arterial access routes, such as hematoma, spasm, pseudoaneurysm, radial artery occlusion, and contrast-induced nephropathy. Finally, the chapter reinforces the need for careful patient assessment, continuous monitoring, and early identification of clinical and laboratory predictive factors in order to reduce complications, improve patient safety, and enhance outcomes in hemodynamics.

Keywords: Cardiovascular Diseases. Hemodynamics. Interventional Cardiology. Percutaneous Coronary Intervention. Vascular Complications.

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RESUMO

As doenças cardiovasculares constituem a principal causa de mortalidade no mundo e permanecem como importante desafio para a saúde pública no Brasil, especialmente diante do envelhecimento populacional e da elevada prevalência de fatores de risco cardiometabólicos. Nesse contexto, a hemodinâmica, ou cardiologia intervencionista, assume papel central no diagnóstico e no tratamento minimamente invasivo das síndromes coronarianas e de outras patologias cardiovasculares. O capítulo discute a fisiologia do fluxo miocárdico, a epidemiologia das doenças cardíacas e as principais entidades clínicas associadas à obstrução coronariana, com destaque para aterosclerose, angina, infarto agudo do miocárdio e insuficiência cardíaca. Também são abordados os principais procedimentos realizados no serviço de hemodinâmica, como cateterismo cardíaco, cinecoronariografia, angioplastia coronariana e implante de stents, enfatizando suas indicações e fundamentos técnicos. Além disso, o texto examina as intercorrências relacionadas a esses procedimentos, especialmente complicações vasculares e eventos associados à via de acesso arterial, como hematoma, espasmo, pseudoaneurisma, oclusão radial e nefropatia induzida por contraste. Por fim, o capítulo reforça a necessidade de avaliação criteriosa dos pacientes, do monitoramento contínuo e da identificação precoce de fatores preditores clínicos e laboratoriais, visando reduzir complicações, aprimorar a segurança assistencial e qualificar os desfechos em hemodinâmica.

Palavras-chave: Doenças Cardiovasculares. Hemodinâmica. Cardiologia Intervencionista. Intervenção Coronária Percutânea. Complicações Vasculares.

RESUMEN

Las enfermedades cardiovasculares constituyen la principal causa de mortalidad en el mundo y continúan siendo un importante desafío para la salud pública en Brasil, especialmente ante el envejecimiento poblacional y la elevada prevalencia de factores de riesgo cardiometabólicos. En este contexto, la hemodinámica, o cardiología intervencionista, desempeña un papel central en el diagnóstico y tratamiento mínimamente invasivo de los síndromes coronarios y de otras patologías cardiovasculares. El capítulo discute la fisiología del flujo miocárdico, la epidemiología de las enfermedades cardíacas y las principales entidades clínicas asociadas con la obstrucción coronaria, con énfasis en la aterosclerosis, la angina, el infarto agudo de miocardio y la insuficiencia cardíaca. También se abordan los principales procedimientos realizados en los servicios de hemodinámica, como el cateterismo cardíaco, la cinecoronariografía, la angioplastia coronaria y el implante de stents, destacando sus indicaciones y fundamentos técnicos. Además, el texto examina las complicaciones relacionadas con estos procedimientos, especialmente las complicaciones vasculares y los eventos asociados a la vía de acceso arterial, como hematoma, espasmo, pseudoaneurisma, oclusión radial y nefropatía inducida por contraste. Finalmente, el capítulo refuerza la necesidad de una evaluación cuidadosa de los pacientes, del monitoreo continuo y de la identificación temprana de factores predictivos clínicos y de laboratorio, con el objetivo de reducir complicaciones, mejorar la seguridad asistencial y optimizar los resultados en hemodinámica.

Palabras clave: Enfermedades Cardiovasculares. Hemodinámica. Cardiología Intervencionista. Intervención Coronaria Percutánea. Complicaciones Vasculares.

1 INTRODUCTION

Cardiovascular diseases (CVDs) are the leading cause of global mortality, accounting for approximately 31% of deaths worldwide, according to the World Health Organization (WHO, 2023). According to the *Global Burden of Disease* (GBD, 2019), the number of people with CAD in Brazil increased from 1.48 million in 1990 to more than 4 million in 2019.

In Brazil, these diseases cause about 360 thousand deaths annually, corresponding to almost a thousand deaths per day. According to the publication Cardiovascular Statistics - Brazil 2023, CVDs account for about one-third of national deaths, disproportionately impacting socioeconomically vulnerable populations that face barriers to accessing specialized health services (Brazilian Society of Cardiology, 2023). Among the CVDs of greatest epidemiological relevance are coronary artery disease (CAD), acute myocardial infarction (AMI), heart failure, and cardiac arrhythmias, all of which are associated with high morbidity and mortality.

In this scenario, hemodynamic services play an essential role in the diagnosis and treatment of acute and chronic cardiovascular diseases, providing minimally invasive interventions that reduce the need for open surgeries and improve clinical outcomes (Mesquit; Ker, 2021). Among the procedures offered, coronary angiography, coronary angioplasty with stent implantation, valvuloplasty, embolizations, closure of cardiac communications and the implantation of cardiac devices such as pacemakers and defibrillators stand out (Ribeiro, 2008).

In the diagnosis and management of cardiovascular emergencies, coronary angiography is considered the gold standard, since it allows anatomical visualization of the coronary tree by means of injection of iodinated contrast via the femoral, radial, ulnar or brachial route. In addition, hemodynamic services are of great importance in diagnosing and subsidizing early interventions and reducing complications, length of hospital stay, and mortality.

Thus, this chapter seeks to describe the main complications in hemodynamic services, as well as the cardiac pathologies investigated and treated by diagnostic or therapeutic percutaneous coronary intervention.

2 MYOCARDIAL FLOW PHYSIOLOGY

The heart is surrounded by its own membrane, the pericardium, and is located in the thoracic mediastinum, between the two pleural cavities. Approximately two-thirds of the heart mass is located to the left of the midline of the body. Anatomically, the organ is composed of four muscular chambers - two atria and two ventricles - and the associated valve structures.

The right side of the heart (right atrium and ventricle) receives venous blood from the body and pumps blood to the lungs through the pulmonary arterial system, characterized by low pressure. The left side (left atrium and ventricle) receives oxygenated blood from the lungs and pumps it into the high-pressure systemic circulation (Woods, 2005).

The atria are separated from the ventricles by fibrous tissue that surrounds the atrioventricular valves. The electrical impulse that promotes cardiac contraction crosses the atrioventricular node, in which there is a physiological delay necessary to ensure synchronism between atrial and ventricular contraction, allowing adequate filling of the ventricles before ejection. This electrical activity is followed by contraction (systole) and relaxation (diastole) of the cardiac muscle fibers, composing the cardiac cycle - which is repeated 60 to 100 times per minute, depending on the heart rate. This cycle is responsible for cardiac output, that is, the volume of blood ejected by the heart per minute. Cardiac muscle contraction is essential to maintain adequate hemodynamics and ensure metabolic supply to the tissues. Changes in this mechanical activity can compromise cardiac function, with potential progression to heart failure (Jatene *et al*., 2022).

The coronary artery system is made up of the epicardial coronary arteries, which branch into arterioles - resistance vessels - and, later, into an extensive capillary network. Under physiological conditions, the main coronary arteries do not offer significant resistance to blood flow, acting as conductors to the microcirculation. Myocardial blood flow is dynamically adjusted by self-regulatory mechanisms, in order to balance the supply and consumption of oxygen, preventing the occurrence of ischemia (Ribeiro; Filho, 2008).

According to Woods (2005), coronary circulation depends on the continuous activity of the heart, which needs to ensure the supply of oxygen and metabolic substrates to its own tissues, while removing carbon dioxide and other metabolic excreta, maintaining aerobic metabolism and contractile capacity. Unlike other tissues, the myocardium needs to generate force to promote its own perfusion. In human cardiac anatomy, two main coronary arteries stand out - the right and the left - which originate from the aorta, in the region of the sinuses of Valsalva. These arteries usually emerge from the aorta at angles close to 90 degrees, penetrate the myocardial wall, and branch extensively. There is significant individual anatomical variation in this branching pattern. In general, the right coronary artery irrigates the right atrium and ventricle, while the left coronary artery is responsible for irrigating the left atrium and ventricle.

3 EPIDEMIOLOGY OF HEART DISEASE

Cardiovascular diseases (CVD) are a relevant public health problem, being the main cause of mortality and disability among adults of full working age. It is estimated that they correspond to about 31% of global deaths (Mansur; Favarato, 2021; WHO, 2017) and approximately 27.7% of deaths in Brazil (Brasil, 2025). In addition to their impact on public health, CVDs impose high economic costs on the country, reflected in the loss of potential years of life and a significant burden on the public health system, both due to the high demand for hospitalizations and the costs associated with prolonged treatment (Schmidt *et al*., 2011; Siqueira; Siqueria-Filho; Land, 2017; Malta; Morais Neto; Silva Júnior, 2011; Ribeiro *et al*., 2016).

With population aging, increased longevity and also with the proportional reduction of infectious diseases, they have contributed substantially to the growth in the prevalence of chronic diseases, including cardiovascular diseases (Salomon *et al*., 2012; Morera *et al*., 2021). This scenario is aggravated by persistent socioeconomic inequalities, which are reflected in the distribution of risk factors and mortality from CVD (Johnson-Lawrence; Kaplan; Galea, 2013; Stringhini *et al*., 2012). Studies on cardiovascular mortality trends in Brazil point to a reduction in death rates among the elderly, related to the postponement of deaths from chronic diseases (Martins *et al*., 2020; Moreira *et al*., 2021).

Historically, humanity has undergone important transformations in the patterns of illness and mortality. In the first half of the twentieth century, infectious diseases and hunger were the main causes of death, reflected in a low life expectancy. In that period, cardiovascular diseases accounted for only 10% of deaths. However, over the last century, demographic, socioeconomic, nutritional transformations and the strengthening of public health policies have contributed to the reduction of deaths from infectious diseases and malnutrition. As a result, chronic non-communicable diseases, such as acute myocardial infarction and stroke, have come to occupy a prominent position as the main causes of death on a global scale (Jatene *et al*., 2022)

This change is understood in the context of the epidemiological transition, the process by which societies evolve from a profile dominated by infectious diseases and malnutrition to a profile characterized by chronic diseases. Factors such as urbanization, changes in lifestyle and diet, sedentary lifestyle, population aging, and prolonged exposure to cardiovascular risk factors (such as hypertension, dyslipidemia, obesity, and smoking) are determinants of this process (Omram, 1971; Martins *et al*., 2020).

According to data from the *Global Burden of Disease* study (GBD, 2017), ischemic heart disease and cerebrovascular diseases together account for about 32% of global

deaths. In high-income countries, these diseases were responsible for 32% of deaths, while in low-income countries this figure was 15%. Among individuals over 70 years of age, CVD mortality exceeded 40%, with no significant difference between the sexes.

In Brazil, the epidemiological transition has profoundly altered the mortality profile. Until the 1960s, infectious and parasitic diseases predominated as the main causes of death, except in large urban centers such as São Paulo and Rio de Janeiro. The reduction in mortality from coronary heart disease was observed first in the United States, starting in 1968, in Europe in the 1970s, and only from the 1990s onwards in Brazil. Currently, coronary and cerebrovascular diseases are the main causes of death in the country for both sexes. Among women, coronary heart disease has surpassed cerebrovascular disease as the leading cause of death. Cardiomyopathies, on the other hand, occupy the fourth position among the causes of cardiovascular death, influenced by the high homicide rates among young men (Jatene *et al*., 2022).

Data from DATASUS (2019) reveal that early mortality from diseases of the circulatory system increases with age, both in men and women. Male excess mortality tends to decrease with advancing age, a phenomenon possibly related to the protective action of estrogens, or the androgen/estrogen ratio, against atherosclerosis (Brasil, 2019).

Recently, the COVID-19 pandemic, which began in 2020, changed the scenario of chronic diseases in Brazil. The country has recorded more than 700 thousand deaths and approximately 37 million confirmed cases of the disease (Brasil, 2023). The mobilization of health resources and scientific efforts aimed at confronting the pandemic directly and indirectly impact cardiovascular care. Since the first reports, a relationship between SARS-CoV-2 infection and cardiovascular health has been observed, both due to the direct involvement of the virus in the cardiovascular system and the overload on health services, which compromised access and regular care for patients with CVD (Ribeiro *et al*., 2021).

Reports from *Cardiovascular Statistics – Brazil* show that, in 2021, COVID-19 surpassed acute coronary syndrome and stroke as the main cause of death in the country. Despite the reduction in hospitalizations due to CVD between 2020 and 2021 - especially due to heart failure and cardiomyopathies - there was an increase in the severity of the cases treated, with an increase of 19.4% in admissions to intensive care units and 13.6% in hospital deaths. Such data suggest that less severe patients stopped seeking care, while more critical cases arrived at health services late, compromising clinical outcomes (Ribeiro *et al*., 2021).

4 MYOCARDIAL FLOW PATHOLOGIES

4.1 ATHEROSCLEROSIS

Atherosclerotic coronary artery disease presents in different clinical forms, one of which is chronic coronary occlusion (OCC), characterized by total obstruction of the vessel lumen for a presumed period equal to or greater than three months. This condition is present in approximately 16 to 18% of patients with significant coronary heart disease (Di Mario, 2022).

Atherosclerosis (AS) is a chronic inflammatory disease marked by the progressive development of atheromatous plaques on arterial walls. These plaques are composed of lipids, fibrous tissue, and calcium, and their growth results from the interaction between atherogenic lipoproteins and inflammatory processes. Inflammation plays a central role in the formation, progression, and destabilization of these lesions, making AS the most common and clinically relevant vascular manifestation (Ridker, 2016).

In this context, lipoprotein(a) [Lp(a)] has been highlighted as an independent risk factor for atherosclerotic cardiovascular diseases. In addition to actively participating in the inflammatory response, Lp(a) interacts with cellular components of the arterial wall, contributing to endothelial dysfunction and smooth muscle cell proliferation. Lp(a) can act by amplifying or mitigating inflammation depending on the context, making it a potential therapeutic target for cardiovascular prevention and treatment strategies (Ajoolabady, 2024).

Ischemic heart disease of atherosclerotic origin results from stenosis or obstruction of the lumen of the coronary arteries, causing reduced blood flow (ischemia), hypoxia and, in more severe cases, myocardial necrosis. In this context, cardiovascular diseases (CVDs) are among the greatest global public health challenges, with atherosclerosis being its main cause. Ischemic heart disease, a direct consequence of this process, remains the leading cause of mortality from heart disease in the world (Lu; Daugherty, 2015; GBD 2017).

The current understanding of atherogenesis recognizes this process as active and dynamic, involving complex inflammatory mechanisms, rather than as a simple passive accumulation of cholesterol in the arteries. The immune response, both innate and adaptive, actively participates from the early stages to the clinical complications of atherosclerosis. According to Song *et al*. (2022), anti-inflammatory strategies have been investigated as effective alternatives in reducing cardiovascular risk, complementing the control of traditional risk factors. The effects of lipid-lowering drugs on inflammatory markers are also studied, as well as the use of classic anti-inflammatory drugs, immunomodulatory therapies directed to specific cytokines, and the development of vaccines with preventive potential.

Modulating inflammation has been shown to be a promising strategy in the prevention and treatment of atherosclerosis. Clinical evidence indicates that the control of the inflammatory process can prevent adverse cardiovascular events, reinforcing the importance of translational research for the development of new therapeutic approaches. Among the emerging strategies, the following stand out: the blocking of inflammasomes, the inhibition of cytokines, the modulation of the adaptive immune response, and the stimulation of mechanisms for the resolution of inflammation. Such interventions, together with lifestyle changes and the control of dyslipidemia, systemic arterial hypertension and diabetes mellitus, constitute an advance in the management of atherosclerotic risk (Soehnlein; Libby, 2021).

Coronary stenosis, caused by the deposition of atherosclerotic plaques, reduces arterial caliber. The degree of obstruction is measured in percentage terms, considering the relationship between the normal diameter of the vessel and the diameter of the stenosed segment. A 50% stenosis can reduce coronary reserve by up to 3 to 4 times; above 70%, this reserve is practically non-existent, severely compromising myocardial perfusion (Jatene *et al*., 2022).

Partial or total reduction in coronary blood flow triggers myocardial ischemia, a condition that has a close correlation with clinical prognosis, especially in relation to the severity, location, and extent of the obstruction. In symptomatic patients, the main therapeutic goal is to relieve chest pain and improve quality of life. Atherosclerosis significantly impacts the functionality of patients, is associated with worsening quality of life, higher prevalence of depressive symptoms, and increased hospital admissions. Therapeutic interventions include myocardial revascularization, either through coronary artery bypass grafting (CABG) or percutaneous coronary intervention (PCI), with the aim of restoring blood flow, reducing symptoms, and improving functional capacity (Feres *et al*., 2017)

According to Mariani *et al*. (2023), knowledge about the national reality is essential for Brazil's adequate positioning on the international scene, especially in relation to public policies and continuing education programs aimed at the treatment of coronary heart disease. Access to advanced therapies requires not only technical training, but also the availability of high-cost devices, which are not always accessible in the public network. In this sense, Silva *et al*. (2023), through the *LATAM CTO Registry* - a Latin American multicenter registry on chronic total coronary occlusion (OTC) recanalization in 26 Brazilian centers - demonstrated that PCI can be performed effectively and safely in Brazil, with a technical success rate of 84%, adverse events in 2.3% of cases, and mortality of only 0.75%.

These results reinforce the quality of Brazilian cardiology practice and its representativeness in the main institutions dedicated to the treatment of complex coronary obstructions.

Coronary artery disease, as previously mentioned, represents the most prevalent form of cardiovascular disease, and is strongly associated with severe outcomes such as acute myocardial infarction, heart failure, and death. Inflammation plays a central role in the pathophysiology of coronary heart disease, acting both in the onset and progression of the atherosclerotic process. In this context, the adipose tissue that surrounds the blood vessels, called perivascular adipose tissue, plays an important role as a metabolic mediator and vascular regulator (Nomura *et al*., 2020; Goeller *et al*., 2019).

In healthy individuals, perivascular adipose tissue secretes adipokines with anti-inflammatory and vasodilatory properties, contributing to the maintenance of vascular homeostasis. However, in pathological conditions, such as the presence of cardiovascular risk factors, this tissue begins to secrete adipokines and pro-inflammatory cytokines, promoting structural and functional changes in the vascular wall and favoring the formation and progression of atherosclerosis. Specifically in the coronary arteries, this compartment is called pericoronary adipose tissue (PAT), whose evaluation has been carried out through imaging tests, such as computed tomography (Nomura *et al*., 2020; Goeller *et al*., 2019).

Pericoronary adipose *tissue (PCAT) analysis* by computed tomography (CT) has been shown to be a promising marker of inflammatory status and coronary artery health. This approach is especially relevant with the increasing use of coronary computed *tomography angiography (CCTA*) in the evaluation of patients with suspected or diagnosed coronary artery disease (CAD). The CCTA allows a comprehensive investigation, including the quantification of the total atherosclerotic burden, the analysis of the severity of the strictures, the functional evaluation of the lesions by means of fractional flow reserve by CT (FFR-CT) or CT-induced pharmacological stress (CT *stress*), in addition to the characterization of the inflammatory component by means of PCAT (Uretsky; Aldaia, 2020). In this scenario, percutaneous coronary intervention is no longer a first-line approach in the diagnostic investigation of CAD, but is reserved for cases indicated after stratification by noninvasive methods.

4.2 ANGINA

Angina pectoris is a classic clinical manifestation of coronary artery disease (CAD), characterized by transient chest pain or discomfort, secondary to myocardial ischemia without necrosis. This pain is usually retrosternal and can radiate to the jaw, neck, left shoulder, and arm. It is commonly triggered by physical exertion, emotional stress, or

exposure to cold, and relieved with rest or nitrate use (Rajkumar *et al*., 2024; Chotai *et al*., 2025).

Angina can be classified as stable or unstable, according to the clinical pattern of pain. Stable angina presents predictably, with pain triggered by exertion and relief at rest. Unstable angina, on the other hand, is characterized by the recent onset of symptoms, worsening of the usual pattern, or occurrence at rest, and may progress to acute myocardial infarction. This instability is associated with changes in atherosclerotic plaque, such as rupture or erosion, followed by thrombus formation. Diagnosis and risk stratification are based on clinical evaluation and the use of complementary tests, such as electrocardiogram (ECG), exercise stress test, myocardial scintigraphy, and coronary angiography (Mansur *et al*., 2012).

The ORBITA study (*Objective Randomised Blinded Investigation with optimal medical Therapy of Angioplasty in stable angina - 2024)* made important contributions to the understanding of the efficacy of percutaneous coronary intervention (PCI) in patients with stable angina. When randomizing 200 patients with significant single-vessel CAD using clinical treatment optimized for PCI or placebo procedure, it was observed that, after six weeks, there was no significant difference in the primary outcome between the groups. This finding raised questions about the relationship between symptoms, stenosis, and ischemia (Chotai *et al*., 2025).

Subsequently, the ORBITA-2 study was conducted with methodological modifications, including less interference from antianginal drugs and longer follow-up time. Its results demonstrated that PCI, in patients with greater selection rigor and without previous intensive use of antianginal medication, provided significant symptomatic improvement, measured by angina scores, reinforcing the role of intervention in specific situations (Chotai *et al*., 2025).

In the context of Chronic Coronary Syndrome (CCS), PCI continues to be discussed as a therapeutic strategy. Studies such as FAME 2 (*Fractional Flow Reserve versus Angiography for Multivessel Evaluation*) and ISCHEMIA (*International Study of Comparative Health Effectiveness with Medical and Invasive Approaches*) reinforce that PCI guided by invasive physiological assessment, especially fractional flow reserve (FFR) and instantaneous flow reserve index (iFR), is associated with a reduction in angina symptoms and hospitalizations. although it has not demonstrated a significant impact on mortality (Fearon *et al*., 2025).

Additional analyses of FAME 2 (2012) showed that lower FFR values before PCI, as well as higher deltas between pre- and post-procedure FFR, correlated with greater symptomatic relief, suggesting a direct relationship between the degree of ischemia and the

clinical benefits of the intervention. These findings were reinforced by ORBITA-2 (2023), which showed that patients with reduced FFR or iFR values showed greater functional improvement and reduced angina after PCI.

The comprehensive clinical evaluation of patients with angina should consider not only typical or atypical chest pain, but also variables such as the anatomical location of the lesions, the number of vessels affected, the extent of the disease (assessed by the retraction pressure gradient), and the presence of microvascular dysfunction. The absence of abnormal heart sounds and atypical pain features also influence the clinical interpretation. These elements highlight the importance of an individualized, physiological evidence-driven approach to identifying patients with the greatest potential for benefit from PCI (Fearon *et al*., 2025).

The main objectives of angina treatment are to control symptoms, improve quality of life, and prevent major cardiovascular events, a study by Fearon *et al*., 2025 brings therapeutic strategies that include lifestyle changes, strict control of risk factors (such as hypertension, dyslipidemia, diabetes mellitus, and smoking), and the use of antianginal drugs, as beta-blockers, calcium channel blockers, and nitrates. In selected cases, PCI revascularization or coronary artery bypass grafting may be indicated. Evidence indicates that the association between optimized clinical treatment and revascularization provides more significant benefits in patients with high ischemic risk or significant functional impairment.

In the context of ST-segment elevation AMI (STEMI), PCI of an artery unrelated to infarction should follow criteria similar to those of elective PCI. On the other hand, the routine performance of PCI in intermediate or complex strictures during the primary procedure requires careful evaluation. According to Hussain *et al*. (2024), the decision should integrate clinical status, comorbidities, complexity of the lesion, and medical judgment, in order to determine the optimal strategy and timing for PCI in these patients.

4.3 ACUTE MYOCARDIAL INFARCTION (AMI)

Acute Myocardial Infarction (AMI) is a serious clinical condition characterized by the sudden interruption of blood flow in a coronary artery, usually due to the rupture of an unstable atherosclerotic plaque, followed by the formation of a thrombus. This obstruction leads to sustained ischemia and necrosis of myocardial areas, causing significant hemodynamic and electrical repercussions. Clinically, AMI is manifested by intense, oppressive, and persistent chest pain, often accompanied by sweating, nausea, dyspnea, and a feeling of imminent death (Calderaro, D.et *al*, 2022).

Based on the electrocardiographic findings, AMI is classified into two main forms: ST-elevation (STEMI) and non-ST-elevation (NSTEMI). This distinction is crucial to define the initial therapeutic strategy. STEMI requires emergency reperfusion, preferably by percutaneous coronary intervention (PCI), ideally performed within 90 minutes of symptom onset. NSTEMI, on the other hand, is managed with antithrombotic therapy and clinical and laboratory stratification for an eventual early invasive approach (Ibanez *et al*., 2018).

In recent decades, mortality from AMI has been significantly reduced due to advances in reperfusion strategies, the use of antithrombotic agents and neurohormonal blockers, as well as the standardization of evidence-based clinical protocols. However, long-term survival still depends on residual ventricular function, the presence of comorbidities, and adherence to treatment. In this context, cardiovascular rehabilitation and lifestyle changes play a central role in the prevention of new events (Biener, M. *et al*., 2022).

Among the diagnostic resources, cardiac biomarkers represent a fundamental tool for the early detection and risk stratification of AMI. Cardiac troponin (TnI or TnT) is considered the most sensitive and specific marker currently available, allowing the identification of myocardial necrosis even at minimal levels. Its serum increase directly reflects the integrity of the myocyte and has a high prognostic value. Serial troponin dosing is recommended, especially in the first hours after symptom onset, in order to confirm the diagnosis (Biener, M. *et al*., 2022).

In addition to troponin, other laboratory biomarkers have prognostic relevance in patients with AMI, such as:

a) B-type natriuretic peptide (BNP and NT-proBNP): indicative of ventricular dysfunction and hemodynamic overload, associated with the risk of heart failure and mortality;
b) ultrasensitive C-reactive protein (hs-CRP): an inflammatory marker that, when elevated, reflects a higher risk of post-infarction complications;
c) myoglobin and CK-MB: less used today, but still useful in specific situations, such as early reinfarction or initial rapid evaluation;
d) emerging biomarkers such as asymmetric dimethylarginine (ADMA), interleukin-6 (IL-6), galectin-3, and soluble ST2 (sST2), studied for correlation with inflammation, myocardial fibrosis, and cardiovascular prognosis (Sabatine, 2022).

Primary PCI is considered the standard treatment for patients with STEMI, with different strategies available, such as balloon angioplasty, uncoated metal stents, drug-eluting stents, thrombus aspiration, direct stent implantation, rotational atherectomy (rotablation), and cutting balloon angioplasty. In cases of multivessel coronary disease, the therapeutic decision must be individualized, and may include PCI only of the culprit vessel,

multivessel PCI in the same procedure, or PCI staged during hospitalization or after discharge (HUSSAIN *et al*., 2024).

From a therapeutic point of view, multicenter studies have demonstrated the superiority of primary PCI over fibrinolysis in STEMI. The European EORP STEMI registry revealed that, while in 2001 only 20% of patients underwent primary PCI, by 2011 this number had already reached 80% in the member countries of the European Society of Cardiology (ESC), largely due to the *Stent for Life initiative* (Kaifoszova *et al*., 2014).

International guidelines reinforce primary PCI as the treatment of choice in STEMI (IBANEZ *et al*., 2018; STEG *et al*., 2012). However, approximately 10% of patients do not receive early reperfusion, mainly due to late presentation, which contributes to in-hospital mortality of up to 15% (Zeymer *et al*., 2021). When performed in a timely manner, PCI significantly reduces mortality compared to fibrinolysis, consolidating itself as the main advance in the treatment of coronary artery disease (CAD) in emergency settings.

The effectiveness of ICP in non-emergency contexts, however, has been the subject of debate. Clinical trials such as the *ISCHEMIA Trial* and the *Culprit-Only Revascularization Strategies* have shown benefits in patients with unstable CAD, especially in reducing major cardiovascular events. On the other hand, in patients with stable and asymptomatic CAD, invasive intervention has not demonstrated a significant impact on outcomes such as mortality or new infarctions, underscoring the importance of individualized risk stratification (Chackro, 2020). Thus, the benefit of PCI is proportional to clinical instability and ischemic load, and laboratory biomarkers are fundamental not only for diagnosis, but also as prognostic tools and therapeutic decision support.

In this sense, the meta-analysis by Fazel *et al*. (2020), which systematically reviewed 31 clinical trials, compared different reperfusion strategies in STEMI: fibrinolysis alone (n = 4,212), primary PCI (n = 6,139), and fibrinolysis followed by early PCI (n = 5,006). The outcomes of mortality, nonfatal reinfarction, stroke, and severe bleeding were evaluated using Bayesian analysis. The results showed that primary PCI was the strategy associated with the lowest risk of adverse events, with an odds ratio of 0.73 (95% CI: 0.61–0.89) for mortality compared to fibrinolysis. The invasive drug approach (fibrinolysis followed by early PCI) was the second most favorable, with an odds ratio of 0.79 (95% CI: 0.59–1.08). The study concluded that the invasive drug approach is safer and more effective than facilitated PCI and fibrinolysis alone, highlighting the importance of the interval between fibrinolysis and PCI as a determinant for the prognosis of the disease.

4.4 HEART FAILURE

Heart failure (HF) is a complex clinical syndrome, characterized by the inability of the heart to pump blood adequately to meet the metabolic demands of tissues, or to do so only at the expense of high filling pressures. This condition may result from structural or functional abnormalities that compromise ventricular filling, blood ejection, or both. From the pathophysiological point of view, HF establishes a vicious cycle of compensatory neurohormonal activation, mainly involving the sympathetic nervous system and the renin-angiotensin-aldosterone system. Although these mechanisms temporarily maintain tissue perfusion, they progressively contribute to ventricular remodeling, sodium and water retention, and deterioration of cardiac function. This process results in typical clinical manifestations, such as dyspnea, fatigue, orthopnea, peripheral edema, and exercise intolerance (Oliveira *et al*., 2023)

The classification of HF is based on left ventricular ejection fraction (LVEF): heart failure with reduced ejection fraction (HFrEF), when LVEF < 40%; preserved ejection fraction (HFpEF), when LVEF ≥ 50%; and intermediate form, when LVEF is between 40 and 49%. This stratification has prognostic and therapeutic relevance, directing specific pharmacological conducts. The diagnosis of the syndrome should be based on clinical evaluation, complemented by imaging tests, such as echocardiography, which allows the analysis of systolic and diastolic function. In addition, biomarkers, such as B-type natriuretic peptide (BNP) or NT-proBNP, have diagnostic and prognostic value, helping to differentiate causes of dyspnea and monitor the progression of the disease (Steg *et al*., 2012).

The treatment of HF is multifactorial, encompassing lifestyle changes, sodium restriction, strict control of comorbidities (hypertension, diabetes mellitus, obesity, among others) and the use of drugs with proven efficacy in reducing mortality and hospitalizations. These include angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers (ARBs), beta-blockers, aldosterone antagonists, neprilysin inhibitors in combination with angiotensin receptor antagonist (sacubitril-valsartan) and, more recently, sodium-glucose cotransporter type 2 inhibitors (iSGLT2). In cases refractory to optimized clinical treatment, ventricular assist devices, cardiac resynchronization therapy, or, ultimately, heart transplantation are indicated, especially in young patients with a low burden of comorbidities (Oliveira *et al*., 2023).

HF is a relevant public health problem, due not only to the high rates of hospitalization and mortality, but also to the functional, emotional, and economic impact on patients and caregivers. In this context, primary prevention, based on the control of cardiovascular risk factors and the early detection of subclinical cardiac dysfunction, represents a fundamental

strategy to contain the progression of the syndrome. It is important to emphasize that HF, in isolation, does not constitute a direct criterion for percutaneous coronary intervention (PCI). However, in patients with significant coronary artery disease or other associated cardiovascular conditions, HF may be a complication that justifies the indication of the procedure (Steg *et al*., 2012).

Heart failure with preserved ejection fraction (HFpEF) corresponds to a specific clinical entity, defined by the presence of HF signs and symptoms associated with an LVEF ≥ 50%. The universal definition states that, in addition to maintaining the ejection fraction, elevated levels of natriuretic peptides and objective evidence of functional or structural abnormalities, with signs of pulmonary or systemic congestion, must be present (Kittlesen *et al*., 2023).

The prevalence of HFpEF is on the rise, driven by population aging, increased obesity, and high incidence of cardiometabolic disorders. The diagnosis, however, is challenging, since associated comorbidities, such as pulmonary or renal disease, can confuse the interpretation of symptoms and clinical signs. Although clinical evaluation is essential, complementary tests, such as chest X-ray, echocardiography, and hemodynamic measurement (pulmonary artery or right heart catheterization), are often necessary for diagnostic confirmation. In some cases, stress tests associated with echocardiography or right heart catheterization allow to demonstrate increased filling pressures, especially in patients with unexplained intolerance to physical exercise (Bozkurt *et al*., 2021).

In the context of HFpEF, percutaneous intervention is not considered a central therapeutic strategy. The priority remains in the optimization of clinical treatment, the control of associated comorbidities, and the adoption of measures that improve the patient's quality of life. Thus, detailed diagnostic investigation and individualized approach are essential for the proper management of this population (Bozkurt *et al*., 2021).

5 HEMODYNAMICS SERVICE

The Hemodynamics Service, also called Interventional Cardiology, is a medical subspecialty focused on performing minimally invasive procedures aimed at the diagnosis and treatment of diseases of the cardiovascular system. This approach, less aggressive when compared to conventional surgeries, has gained increasing prominence in the face of the increase in the incidence of cardiovascular diseases, as it allows safe, effective interventions with shorter recovery time for patients. Among the main procedures performed in this service are cardiac catheterization, vascular arteriography, coronary angioplasty, electrophysiological studies with ablation of arrhythmias, embolization of vascular

malformations and implantation of endoprostheses. These techniques aim to restore blood flow, diagnose obstructions, and correct structural anomalies in a precise and minimally invasive way (Ribeiro; Filho, 2008).

Coronary angiography, also known as cardiac catheterization, is considered the gold standard for diagnosing coronary artery disease (CAD). It is an imaging test that, through the injection of iodinated contrast directly into the coronary arteries, allows the radiological visualization of the arterial lumen and the identification of stenosis or occlusions (Abizaid *et al*., 2013).

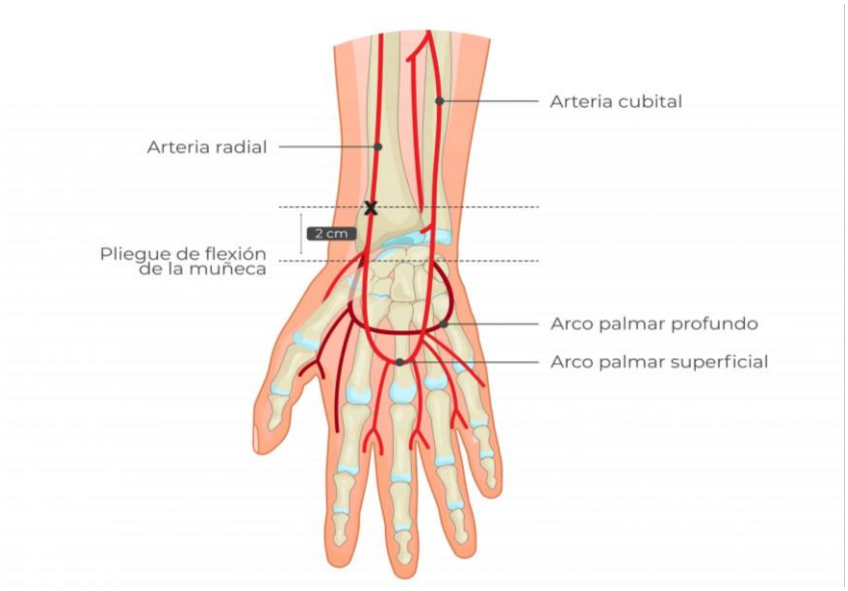
The initial milestone of percutaneous coronary intervention occurred in 1977, at the University of Zurich, when Andréas Roland Gruentzig performed the first percutaneous transluminal angioplasty in a patient with critical obstruction of the anterior descending artery, using a balloon catheter inserted via femoral access. This procedure inaugurated a new era in the treatment of ischemic heart disease, enabling the development of increasingly advanced techniques and devices of interventional cardiology (Ribeiro; Filho, 2008).

Coronary angioplasty aims to remodel the atherosclerotic plaque, transforming an obstructive lesion into a stable and non-obstructive condition, favoring myocardial perfusion and reducing ischemic symptoms. With the evolution of the technique, the use of stents, expandable devices responsible for maintaining the arterial lumen after dilation, was incorporated, which significantly reduced restenosis rates and increased therapeutic efficacy (Woods, 2005).

Arterial access is a critical step in percutaneous procedures, being defined according to the clinical characteristics of the patient and the experience of the medical team. Initially performed through the brachial approach, the approach evolved to the femoral approach and, more recently, to the radial approach, currently preferred because it offers greater safety, ease of compression and lower rate of hemorrhagic complications (Abizaid *et al*., 2013).

Figure 1

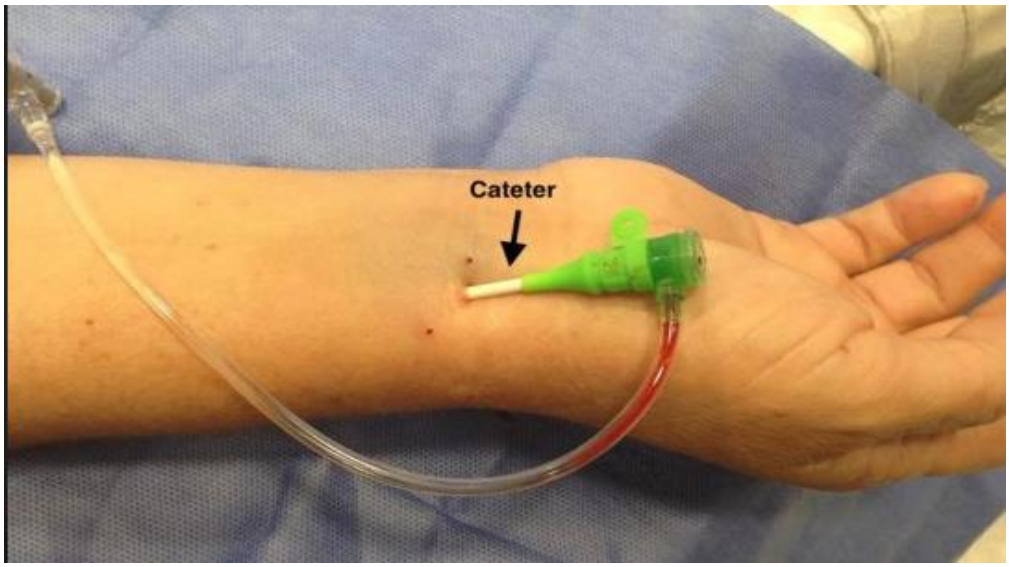
Anatomical location for radial artery puncture



Source: Adapted from Guedes A. (2012).

Figure 2

Radial access in hemodynamic services



Source: Adapted from medizzy.com.

To choose the radial approach, it is recommended that the patency of the palmar arches be previously evaluated using the Allen test. The test is considered normal when there is return of palmar perfusion within 10 seconds after the release of the flow through the ulnar artery. This procedure can be performed with a pulse oximeter on the thumb, observing the presence or absence of the pulse wave. The results are classified into types A to D, with type D being a contraindication for the radial approach (Abizaid *et al.*, 2013).

Figure 3

Allen test

Source: Adapted from medizzy.com.
Legend: Allen Test Method of Performance. A) Negative Allen's test, the return of the reddish color of the palm of the hand takes more than 10 seconds, indicating that the circulation parallel to the radial artery is not intact. B) Positive Allen test, the blood flow of the ulnar artery should reperfuse the vessels of the hand in less than 10 seconds, being identified by the return of the reddish color to the palm of the hand.

The radial artery puncture technique must follow standardized protocols in order to ensure safety and efficacy. Because it has a high density of adrenergic receptors, the radial artery requires specific measures to prevent spasms, such as the administration of analgesics and sedatives. Proper positioning of the patient is essential, and the right arm is often used on an acrylic support (Woods, 2005)

Local anesthesia is performed with 0.5 to 1.0 mL of 2% lidocaine. Next, the Seldinger technique is applied, using a short 22G or 20G catheter, with the bevel facing upwards, and a 0.021-in metal guide. After puncture, a 5 or 6 Fr hydrophilic sheath is introduced. To prevent thrombosis, 5,000 IU of heparin is administered; in cases of arterial spasm, nitroglycerin can be used in doses of 100 to 200 mcg (Abizaid *et al*., 2013).

Radial coronary angiography uses the same pre-molded catheters applied in the femoral approach. For the left coronary artery, the JL 3.5 or 4.0 type catheter is used; to the right, the JR 4.0 catheter is used. Ventriculography is performed with a pigtail catheter. Catheter exchange occurs with the aid of a 0.035-in teflon guide with a J-tip (Abizaid *et al*., 2013). After the procedure, compression of the radial artery is performed to obtain hemostasis, which can be achieved by different methods. The hemostatic process, as described by Woods (2005), involves the sequential activation of coagulation factors, resulting in the formation of a fibrin clot at the site of vascular injury and preventing blood leakage. Disturbances in this process can result in bleeding of different intensities, from petechiae and ecchymosis to severe hemorrhages.

In this sense, Petroglou (2018) compared manual and mechanical compression after transradial angiography, concluding that mechanical compression tends to be more effective, as it offers continuous and stable pressure, reducing hemostasis time, the occurrence of bleeding, and the risk of radial artery occlusion (RAO). Such evidence reinforces the importance of maintaining vessel patency, especially in view of the increased use of radial access in cardiovascular therapies.

In order to assist in this process, different hemostasis devices have been employed. Santos *et al*. (2018) reported the use of the TR Band device (Terumo Medical, Tokyo, Japan), similar to a transparent bracelet. Positioned directly over the introducer insertion hole, it is inflated with 15 mL of air through a syringe, promoting controlled compression. After removal of the sheath, the anterograde flow of the radial artery is maintained, ensuring adequate distal perfusion. The removal protocol provides for gradual deflation of 3 mL every 30 minutes, starting two hours after the procedure. In cases of bleeding, the balloon is re-inflated with 5 mL of air and the protocol is restarted after 60 minutes.

Santos *et al*. (2018) also describe an alternative hemostasis technique, conducted by a nursing professional with medical support, which consists of applying a roll of compressive gauze over the puncture site, fixed with a tape band. On the dressing, two strips of adhesive tape are applied crossed in an "X" shape, without fully involving the limb. After 3 to 4 hours, the dressing is removed, as long as there is no active bleeding, and the site is protected with a simple dressing consisting of gauze and tape.

5.1 CARDIAC CATHETERIZATION

Cardiac catheterization has its origins in 1844, when Claude Bernard performed pioneering experiments in catheterization of the jugular veins and carotid artery in horses, allowing hemodynamic measurements in cardiac chambers. In 1929, Werner Forssmann proved the feasibility of intracardiac access in humans by introducing a ureteral catheter into his own right atrium, paving the way for clinical techniques. The modern era of interventional cardiology was consolidated in 1958, with Mason Sones at the Cleveland Clinic, when he developed coronary cineangiography and initiated percutaneous interventions (Ribeiro; Filho, 2008).

5.1.1 Right Heart Catheterization

Right heart catheterization is performed intravenously - femoral, internal jugular, subclavian or antecubital - and enables hemodynamic evaluation of the right chambers and pulmonary circulation. Its main indications include:

a) determination of cardiac output in advanced heart failure;
b) diagnosis of pulmonary hypertension;
c) detection of intracardiac shunts;
d) investigation of cardiomyopathies, constrictive pericarditis, and cardiac tamponade (Jatene *et al*., 2022).

The most frequent complications involve inadvertent arterial puncture, formation of pseudoaneurysm or arteriovenous fistula, lymphatic duct injury and, in rare cases, rupture of pulmonary vessels or episodes of hypoxia (Ribeiro; Filho, 2008).

5.1.2 Left Cardiac Catheterization and Coronary Angiography

Left heart catheterization, also called coronary angiography, is the gold standard for the study of coronary anatomy. The procedure begins with arterial puncture (femoral or radial), followed by careful introduction of catheters to the root of the aorta and selective catheterization of the coronary ostia. The injection of iodinated contrast, combined with serial radiographic projections, allows the identification of the arterial lumen, quantify the degree of stenosis, and evaluate vascular morphology (Jatene *et al*., 2022).

Coronary anatomy is presented in two main systems:

a) left coronary artery: originates from the left coronary sinus and bifurcates into the anterior descending artery (ADA) and circumflex artery (ACX), supplying a large part of the myocardium;
b) right coronary artery (RCA): arises from the right coronary sinus, runs through the atrioventricular sulcus, and divides into the crux cordis into the posterior descending and posterolateral branches.

5.2 RADIOGRAPHIC PROJECTIONS AND VENTRICULOGRAPHY

For an accurate analysis, each artery must be evaluated in at least two distinct projections, avoiding overlapping segments. Ventriculography, often performed together, provides information on global and segmental systolic function, presence of intracavitary thrombi, and mitral regurgitation. It is contraindicated in patients with mechanical aortic prosthesis, known ventricular thrombus, decompensated heart failure, or acute pulmonary edema (Ribeiro; Filho, 2008).

5.3 AORTOGRAPHY AND PRINCIPLES OF LUMINOGRAPHY

Intraventricular aortography can be used to evaluate the aortic valves, the diameter of the aortic root, and to identify dissections. However, the additional use of contrast

increases the risk of induced nephropathy, and a careful risk-benefit assessment is necessary. Luminography, a fundamental technique in angiography, exclusively delineates the luminal contour of the vessels, without allowing direct analysis of the arterial wall (Ribeiro; Filho, 2008).

5.4 CORONARY ANGIOPLASTY

Coronary angioplasty, also called percutaneous coronary intervention (PCI), is a therapeutic strategy frequently performed after the diagnosis of relevant obstructive lesions during catheterization. The procedure can be performed in two main ways: with a balloon or with stent implantation (Ribeiro; Filho, 2008).

Balloon angioplasty consists of the introduction of a balloon catheter to the site of stenosis, where controlled balloon inflation occurs, promoting artery dilation and atherosclerotic plaque remodeling. This process generates a "controlled injury" to the arterial wall, redistributing plaque along the vessel and restoring blood flow. The clinical efficacy of this technique is high, with symptomatic relief in about 90% of treated patients (Abizaid *et al*., 2013).

Angioplasty with *stent*, in turn, represents the evolution of percutaneous treatment, and is currently the most used method. The stent is a small expandable metal structure implanted inside the coronary artery, with the objective of maintaining the luminal diameter after dilation and avoiding restenosis. *Stents* can be classified as conventional (*bare-metal stents*) or pharmacological (*drug-eluting stents*), the latter coated with antiproliferative drugs that significantly reduce the incidence of vessel re-obstruction (Ribeiro; Filho, 2008).

Historically, the term "*stent*" was first used in 1916 by Dutch plastic surgeon Jan Esser, in reference to a dental prosthesis developed by English dentist Charles Thomas Stent. Initially, stents were produced with metal alloys such as nitinol, tantalum, platinum and stainless steel, materials that are easy to handle and have good biocompatibility. However, some limitations, such as low radiopacity, reduced flexibility, and high nickel content, potentially allergenic, have led to the search for new compositions (Abizaid *et al*., 2013).

As an alternative, stents made of cobalt-chromium alloys appeared, which presented greater radiological visibility, thinner stems, and less nickel in their structure. Subsequently, platinum was incorporated into metal alloys, resulting in stents with superior properties, such as greater malleability, corrosion resistance, and lower risk of fracture. These innovations contributed to the technical improvement of the procedure and to the expansion of its safety and clinical efficacy (Abizaid *et al*., 2013).

6 HEMODYNAMIC COMPLICATIONS

Despite technological advances and the wide use of coronary angiography as a diagnostic and therapeutic tool in the context of cardiovascular diseases, the procedure is not without risks, especially when performed in populations with greater clinical vulnerability. As described by Jatene *et al*. (2022), although coronary angiography is currently considered a safe test in elective scenarios, it is essential to carefully evaluate the risk-benefit ratio before performing it, especially in patients with factors predisposing to complications.

Among the main risk factors are: advanced age, presence of complex congenital heart diseases (especially in children), significant lesions in the left main coronary artery, multivessel coronary artery disease, advanced peripheral arterial disease, severe ventricular dysfunction with heart failure, diabetes mellitus using insulin and important valvular heart diseases, such as aortic stenosis. These factors require individualized planning in order to mitigate the risks inherent in the procedure (Jatene *et al*., 2022).

Also according to Jatene *et al*. (2022), the most common complications associated with the test and their estimated frequency include: deaths (0.08%), acute myocardial infarction (0.05%), stroke (0.07%), cardiac arrhythmias (0.4%), vascular complications (0.5%), and adverse reactions to iodinated contrast (0.4%). Although relatively rare, these complications can have significant clinical implications, requiring close attention to pre-procedure preparation and post-intervention monitoring.

Perioperative drug management should also be carefully adjusted. Drugs such as metformin should be discontinued 24 to 48 hours before the procedure, with reintroduction only after 48 hours or after normalization of renal function, in order to avoid the risk of lactic acidosis. Direct anticoagulants, such as rivaroxaban, apixaban, and dabigatran, should be stopped at the same interval, with resumption 24 hours after the procedure. Antiplatelet agents, such as acetylsalicylic acid (ASA), should be maintained. In the case of patients using coumarin anticoagulants (such as warfarin), it is recommended to suspend them for five days before the procedure, with a target International Normalized Ratio (INR) between 1.5 and 1.8 at the time of the intervention. In these cases, full heparinization can be considered as a therapeutic bridge, especially in patients with high thromboembolic risk. It is important to note that, in emergency situations, these pharmacological protocols often cannot be followed, prevailing the clinical conduct aimed at preserving the patient's life and hemodynamic stabilization. Thus, the management of hemodynamic complications requires a trained multidisciplinary team, adequate hospital structure and well-established clinical protocols to ensure the safety and efficacy of the procedure (Ribeiro, Filho, 2008).

6.1 VASCULAR COMPLICATIONS

6.1.1 Clinical Complications of Patients Undergoing Percutaneous Coronary Intervention

Percutaneous coronary intervention (PCI), although widely disseminated and considered a safe and effective procedure for the treatment of coronary artery disease, may be associated with different clinical complications. The occurrence of these complications is often related to the clinical profile of patients, usually with multiple comorbidities, and to the emergency situations in which the technique is applied (Jatene *et al*., 2022).

According to Ribeiro (2008), the most prevalent complications are associated with arterial puncture sites, especially femoral and radial punctures, manifesting in the form of hematomas, pseudoaneurysms and bleeding. Less frequently, events such as neurological lesions, lymphatic fistulas, catheter fragmentation, incoercible bleeding, and even stent migration may occur.

Cerebrovascular events, although uncommon, deserve to be highlighted due to their high severity and potential prognostic impact. These events may manifest during or immediately after PCI, and in some cases, diagnosis may be delayed by up to 36 hours. Vascular spasms and idiosyncratic reactions to iodinated contrast medium represent less frequent, but still relevant, causes of post-procedure neurological changes (Ribeiro; Filho, 2008).

Another complication of clinical relevance is contrast-induced nephropathy (CIN), characterized by acute worsening of renal function after exposure to iodinated contrast. CIN is at higher risk in patients with impaired baseline renal function, and its occurrence is related to factors such as total volume and type of contrast used, presence of comorbidities (especially diabetes mellitus), advanced age, episodes of hypotension, heart failure, and elevated serum creatinine levels before the procedure. Prevention strategies include adequate hydration, judicious use of contrast, choice of agents with less nephrotoxicity and, in selected cases, the use of medications with a nephroprotective effect.

Currently, it is observed that patients undergoing PCI have increasingly complex clinical and anatomical profiles, which reinforces the need to adopt additional safety measures. In this context, the use of ultra-low contrast agents is highlighted, with the objective of reducing the risk of renal complications without compromising diagnostic quality. The conscious performance of the professional regarding the selection of catheters, guidewires and auxiliary techniques is essential to minimize risks. In addition, the incorporation of advanced methods, such as intracoronary imaging (OCT- optical coherence tomography and IVUS - intravascular ultrasound) and invasive physiology, should be

prioritized whenever possible, partially replacing the need for contrast to ensure safer and more accurate results in PCI (Hennessey, 2023).

Technological advances and the availability of new navigation tools, such as dynamic coronary mapping and co-registration technologies, have been simplifying interventions and expanding the safety margin for high-risk patients, consolidating PCI as an increasingly effective and safe procedure (Hennessey, 2023).

6.1.2 Complications in the Access Road

Complications related to the arterial access route, whether femoral or radial, represent one of the main challenges in the post-procedure period of percutaneous coronary intervention (PCI). Strict care in the immediate postoperative period is essential for the early detection and appropriate management of these complications, which, if not identified in a timely manner, can progress to more severe conditions, requiring surgical intervention, blood transfusion, or even risk of death (Abizaid *et al*., 2013).

According to Abizaid *et al*. (2013), among the most frequently observed complications at arterial puncture sites are: local hematomas, femoral artery pseudoaneurysms, retroperitoneal hematoma (particularly associated with femoral access), arteriovenous fistula, significant hemorrhages, arterial thrombosis, and local infections. The occurrence of these events is related to factors such as inadequate puncture technique, use of anticoagulants, advanced age, obesity, and lack of effective compression after removal of the vascular sheath.

Regarding the radial approach, although it has a lower rate of hemorrhagic complications compared to the femoral approach, there are contraindications that should be strictly observed. According to Abizaid *et al*. (2013), the radial approach should not be used in cases of Raynaud's disease, post-mastectomy upper limb lymphedema, presence of arteriovenous fistula (AVF) for hemodialysis, provision for the use of the radial artery as a graft in coronary artery bypass grafting, and lack of adequate collateral circulation between the superficial and deep palmar arches.

Kotowycz *et al*. (2012) describe that the radial and ulnar arteries are connected at the wrist by the deep and superficial palmar arches. Thus, if the radial artery is occluded, hand perfusion is usually maintained by increasing flow in the ulnar collateral circulation. To evaluate this circulation, the modified Allen test is used, which is considered a simple qualitative method. In this examination, the patient is instructed to clench the fist, while the examiner simultaneously compresses the radial and ulnar arteries. Then, the patient relaxes the hand, the ulnar artery is released, and the time required for the return of maximum palmar

flushing is recorded. Return within 5 to 10 seconds is considered normal, indicating adequate collateral circulation. Acute loss of radial artery patency after cardiac catheterization is often related to a thrombotic process, resulting from local endothelial injury and interruption of blood flow after sheath insertion.

Transradial access (ART) has been consolidated as the preferred route in PCIs due to the reduction of hemorrhagic complications. However, radial artery occlusion (RAO) can occur and often goes undetected clinically due to the dual blood supply to the hand. Munir *et al*. (2022) report that more than 50% of operators do not assess radial artery patency after PCI. In the initial phase of RAO, thrombi formation occurs due to endothelial injury and reduced blood flow after cannulation. Repeated manipulations of the catheter increase the risk of thrombosis. In general, RAO manifests soon after catheterization, but about 50% of patients undergoing ART procedures have spontaneous recanalization of the radial artery within three months. The incidence described in the literature ranges from 1.5% to 30.5%, with a mean of 5% to 12% of patients undergoing ART. Once occluded, the radial artery cannot be reused as an access route in future catheterizations or as an arterial graft in coronary artery bypass graft surgeries, in addition to making the ipsilateral ulnar artery vulnerable to the risk of hand ischemia.

Also according to Munir *et al*. (2022), advances in interventional cardiology require specific knowledge and skills for careful evaluation of access routes, especially in view of the growing adoption of the radial approach as a preferred choice. The preservation of radial artery patency is essential, especially in patients who require serial procedures. Strategies to minimize RAO include the use of smaller sheaths or even sheathless guides, adequate anticoagulation, and non-occlusive hemostasis. It is also recommended that the radial artery patency be systematically evaluated before hospital discharge, in addition to individualized clinical follow-up, in order to ensure greater safety and preservation of the access route for future procedures.

7 FINAL CONSIDERATIONS

Scientific evidence reinforces that cardiovascular diseases are one of the greatest challenges to public health, requiring increasingly resolute care responses. In this scenario, hemodynamic services play a strategic role by integrating accurate diagnosis and immediate intervention, which are decisive for reducing morbidity and mortality, especially in acute coronary syndromes.

Percutaneous coronary intervention has been consolidated as a therapeutic strategy for the identification and treatment of myocardial ischemia, bringing benefits to the individual

in restoring coronary flow and improving clinical outcomes. It is known that the precise investigation of the health professional in the face of patients with symptoms of coronary disease is essential for the good prognosis of the patient.

In percutaneous coronary intervention, the patient is exposed to surgical intervention in which the occurrence of vascular complications related to the percutaneous access route, even in established techniques such as the radial approach, shows that technological advances do not eliminate risks inherent to the procedure, especially in individuals affected by determinant diseases and established risk factors. In this sense, the identification of clinical and laboratory predictors of changes in arterial patency emerges as a key element for risk stratification and for more assertive clinical decision-making.

Thus, in hemodynamic services, it is essential to develop strategies and skills that reinforce the need for continuous qualification of care processes. Seeking improvements in processes through future investigations that validate predictive models and expand the applicability of findings, aiming to consolidate strategies that concretely impact patient safety and quality of care in interventional cardiology.

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