Human Heart-Anatomy and its role in Blood Circulation: A Detailed Review

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Abstract

The human heart is a highly specialized muscular organ responsible for maintaining continuous blood circulation through the pulmonary and systemic circulatory systems. Its efficiency depends on the coordinated interaction of cardiac chambers, valves, coronary arteries, and great vessels, which collectively ensure adequate myocardial and systemic perfusion. This literature review examines the anatomy of the human heart and its role in blood circulation by synthesizing evidence from contemporary studies on cardiac structure, coronary artery anatomy, congenital heart disease, and advanced cardiovascular imaging. The review highlights the significance of coronary artery variations and dominance patterns in influencing myocardial perfusion, surgical decision-making, and clinical outcomes, particularly in patients with congenital heart disorders. Furthermore, it discusses the growing role of multimodality imaging techniques, including cardiovascular magnetic resonance (CMR), computed tomography (CT), echocardiography, and nuclear imaging, in accurately assessing cardiac anatomy, myocardial viability, and coronary perfusion. Emerging computational models that integrate anatomical and physiological data are also explored for their potential to improve personalized diagnosis, risk stratification, and treatment planning. Overall, the findings emphasize that a comprehensive understanding of cardiac anatomy, coronary circulation, and functional imaging is essential for improving the diagnosis and management of cardiovascular diseases. Future research should focus on standardizing imaging protocols, validating patient-specific computational models, and integrating structural and functional assessments to advance precision cardiovascular medicine.

Keywords: Human heart, Cardiac anatomy, Blood circulation, Coronary arteries, Coronary perfusion, Congenital heart disease, Cardiovascular magnetic resonance (CMR), Computed tomography (CT), Multimodality imaging, Precision cardiovascular medicine.

1. Introduction

Understanding the human heart requires integrating its anatomical structure with the physiology of coronary and ventricular perfusion that sustains systemic circulation. A coherent view draws on descriptions of cardiac anatomy, the coronary arterial system, and how variations or anomalies influence myocardial perfusion and circulatory outcomes. The selected sources converge on three central themes: (1) cardiac anatomy and its relation to blood flow pathways, (2) coronary artery anatomy and its variations in health and congenital disease, and (3) contemporary imaging and modeling approaches that illuminate structure–function relationships in both normal and diseased states. Throughout, the evidence supports a synthesis in which precise anatomical detail informs decisions about perfusion, surgical strategy, and risk stratification.

2. Anatomy of Human Heart

The heart functions as the central pump of the cardiovascular system, maintaining continuous blood circulation through two interconnected pathways: the pulmonary circulation, which oxygenates blood in the lungs, and the systemic circulation, which delivers oxygen and nutrients to tissues throughout the body. This essential function depends on the coordinated structure of the heart's chambers, valves, and great vessels, which ensure unidirectional blood flow while preventing regurgitation. The anatomical integrity of the ventricles, atrioventricular valves, and ventricular outflow tracts is fundamental for maintaining efficient hemodynamics and adequate tissue perfusion. In addition, the coronary circulation provides a specialized arterial network that supplies the myocardium with oxygen and nutrients, enabling the heart to meet its exceptionally high metabolic demands. Coronary blood flow is carefully regulated according to myocardial oxygen requirements and varies across different regions of the heart depending on coronary dominance and physiological loading conditions. Recent advances in cardiovascular imaging, including cardiovascular magnetic resonance (CMR), computed tomography (CT), and nuclear imaging, have greatly enhanced the evaluation of cardiac anatomy, myocardial perfusion, and tissue viability. These complementary imaging modalities provide detailed visualization of both structural and functional aspects of the heart, making them invaluable for diagnosing cardiovascular diseases, particularly congenital heart disorders, while minimizing radiation exposure in pediatric patients (Grandmougin, 2019; Spaan et al., 2008; Buechel et al., 2015; Frommelt et al., 2020).

Coronary artery anatomy demonstrates considerable variation among individuals, and these anatomical differences have significant clinical implications, particularly in patients with congenital heart disease. Variations in coronary artery origin, course, and branching patterns can influence myocardial perfusion, surgical planning, and long-term clinical outcomes. In conditions such as pulmonary atresia with intact ventricular septum (PA-IVS), abnormal ventriculocoronary connections may create right ventricular-dependent coronary circulation, substantially affecting the feasibility of biventricular repair and increasing perioperative risk. Consequently, detailed assessment of coronary anatomy using advanced imaging techniques is essential before surgical intervention. Similarly, patients with transposition of the great arteries (D-TGA) and other complex congenital heart diseases often exhibit coronary anomalies that may increase the risk of myocardial ischemia, arrhythmias, and sudden cardiac death. However, current evidence suggests that clinical outcomes are influenced not only by coronary anatomy but also by microvascular function, ventricular morphology, and myocardial loading conditions. Furthermore, computational studies have demonstrated that coronary dominance patterns and systemic hemodynamic states significantly influence regional myocardial perfusion, highlighting the importance of integrating anatomical and physiological information when assessing cardiovascular risk and planning treatment (Forsha et al., 2012; Lowry et al., 2013; Gleich et al., 2017; Addis & Townsley, 2020; Asaad et al., 2022; Perreux et al., 2020; Wang et al., 2019; Mynard & Smolich, 2016).

Modern cardiovascular medicine increasingly relies on multimodality imaging to evaluate coronary anatomy and myocardial perfusion. Cardiovascular magnetic resonance (CMR), computed tomography (CT), and catheter-based angiography each provide unique but complementary information regarding coronary vessel anatomy, myocardial function, tissue viability, and perfusion. CMR is particularly valuable because it offers comprehensive anatomical visualization, stress perfusion imaging, and tissue characterization without exposing patients to ionizing radiation, making it especially suitable for children and individuals with congenital heart disease. CT angiography provides high-resolution images of coronary origins and vessel pathways, facilitating preoperative planning and the identification of coronary anomalies, whereas nuclear imaging techniques such as single-photon emission computed tomography (SPECT) complement anatomical studies by identifying regional perfusion defects. Clinical reports have demonstrated that these imaging modalities are indispensable for evaluating patients with right ventricular-dependent coronary circulation and other complex congenital cardiac anomalies, where precise anatomical mapping directly influences surgical decision-making. More recently, computational modeling has emerged as an important advancement by integrating imaging-derived coronary anatomy with physiological data to generate personalized simulations of coronary blood flow. These patient-specific models improve the prediction of myocardial perfusion, support virtual treatment planning, and enhance clinical risk stratification, representing a significant step toward precision cardiovascular medicine (Addis & Townsley, 2020; Adebo et al., 2021; Buechel et al., 2015; Frommelt et al., 2020; Grandmougin, 2019; Gaemperli et al., 2007; Menon et al., 2023).

3. Synthesis and implications

Anatomy establishes the framework for cardiac perfusion and circulation, but in congenital and complex acquired conditions, variations in coronary origins, course, and RV–coronary connections can fundamentally alter myocardial perfusion and clinical risk. This necessitates precise anatomic delineation using multimodal imaging, augmented by functional perfusion assessment, to guide surgical planning, timing of transplantation, and long-term management (Buechel et al., 2015; Frommelt et al., 2020; Gleich et al., 2017; Grandmougin, 2019; Lowry et al., 2013).

The field increasingly recognizes that coronary dominance and regional flow patterns interact with systemic or pulmonary pressures to shape myocardial perfusion. Multiscale modeling and imaging-guided assessment can help predict perfusion deficits and inform risk stratification, particularly in diseases where proximate coronary anatomy alone does not fully explain ischemic risk (Mynard & Smolich, 2016).

Discrepancies among studies concerning the predictive value of proximal coronary anatomy vs. distal microvascular factors reflect a nuanced reality: in many congenital contexts, ischemia-related risk emerges from an interplay of anatomy, loading conditions, myocardial demand, and collateral development rather than a single dominant determinant. Clinicians should therefore integrate detailed anatomical mapping with functional imaging and, when possible, computational simulations to tailor interventions and surveillance (Addis & Townsley, 2020; Asaad et al., 2022; Mynard & Smolich, 2016; Perreux et al., 2020; Wang et al., 2019).

4. Limitations and areas for future research

Following are the limitations and areas of future research:

- While imaging advances provide rich anatomical and perfusion data, heterogeneity in study designs, populations (pediatric vs. adult; congenital vs. acquired disease), and imaging modalities complicates cross-study synthesis. Future work would benefit from standardized reporting of coronary anatomy variants, perfusion metrics, and outcomes to better quantify risks associated with specific anatomical configurations (Addis & Townsley, 2020; Buechel et al., 2015; Frommelt et al., 2020).
- Pending work in personalized hemodynamics models suggests substantial potential benefits in clinical decision-making, but requires broader validation in diverse patient cohorts and integration with routine imaging workflows to become standard practice in congenital cardiology (Menon et al., 2023).
- There remains debate about the primacy of proximal coronary anatomy as a predictor of adverse events in certain congenital conditions, underscoring the need for holistic approaches that weigh microvascular function, ventricular geometry, and physiological loading alongside anatomy (Addis & Townsley, 2020; Asaad et al., 2022; Perreux et al., 2020; Wang et al., 2019).

5. Conclusion

The human heart's function depends on an intricate integration of anatomy and perfusion. Coronary artery anatomy, including variants and dominance, exerts a major influence on myocardial perfusion, particularly in congenital disease contexts where ventriculocoronary connections and RV-dependent coronaries can complicate surgical planning and outcomes. Contemporary literature emphasizes multimodal imaging and emerging computational approaches as essential tools for mapping anatomy, assessing perfusion, and guiding personalized management. While the precise role of proximal anatomy versus distal microvascular and load-related factors varies by condition, an integrated framework that combines detailed anatomical delineation with functional assessment and, where possible, personalized simulations, provides the most robust basis for understanding the heart's circulatory dynamics and optimizing patient care.

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