THE UNIVERSITY OF PARDUBICE

FACULTY OF HEALTH STUDIES

BACHELOR'S THESIS

2022 MARIA KANYEMBA

The University of Pardubice

Faculty of health studies

The role of MRI in the assessment of valvular heart disease

Bachelor's Thesis

2022 Maria Kanyemba

Univerzita Pardubice
Fakulta zdravotnických studií
Akademický rok: 2020/2021

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

(projektu, uměleckého díla, uměleckého výkonu)

Jméno a příjmení:	**Maria Kanyemba**
Osobní číslo:	**Z19414**
Studijní program:	**B5345 Specializace ve zdravotnictví**
Studijní obor:	**Radiologický asistent**
Téma práce:	**Úlohu MRI při hodnocení chlopenního srdečního onemocnění**
Téma práce anglicky:	**The role of MRI in the assessment of valvular heart disease**
Zadávající katedra:	**Katedra klinických oborů**

Zásady pro vypracování

1. Studium literatury, sběr informací a popis současného stavu řešené problematiky.
2. Stanovení cílů a metodiky práce.
3. Příprava a realizace výzkumného šetření dle stanové metodiky.
4. Analýza a interpretace získaných dat.
5. Zhodnocení výsledků práce.

Rozsah pracovní zprávy:	**35 stran**
Rozsah grafických prací:	**dle doporučení vedoucího**
Forma zpracování bakalářské práce:	**tištěná/elektronická**
Jazyk zpracování:	**Angličtina**

Seznam doporučené literatury:

Ellenbogen, K.A., Wilkoff, B.L., Kay, G.N. and Lau, C.P. 2011. *Clinical Cardiac Pacing, Defibrillation and Resynchronization Therapy*. Elsevier Health Sciences. ISBN 978-1-4377-1616-0.
MAKKAR, A., PRISCIANDARO, J., AGARWAL, S., et al. Effect of radiation therapy on permanent pacemaker and implantable cardioverter-defibrillator function. *Heart Rhythm* [online]. 2012, 9 (12), pp.1964-1968, [cit.2022-2-20]. ISSN 1547-5271. Available from: https://doi.org/10.1016/j.hrthm.2012.08.018
NEČASOVÁ, Lucie, Irena KONIAROVÁ, Josef KAUTZNER, a kol. Souhrn odborného stanoviska k péči o pacienty s implantovanými kardiostimulátory a kardiovertery-defibrilátory s indikací k radioterapii. Cor et Vasa [online]. 2021, 63 (4), pp. 518-522 [cit. 2022-2-22]. Available from: https//doi.org/10.33678/cor.2021.094
SHARIFZADEHGAN, Ardalan, Marc LAURANS, Marine THUILLOT, et al. Radiotherapy in Patients With a Cardiac Implantable Electronic Device. The American Journal of Cardiology [online]. 2020, 128, [cit. 2022-2-22]. ISSN 0002-9149. Available from: https://doi.org/10.1016/j.amjcard.2020.04.045
ŠLAMPA, Pavel a kol., 2022. Radiační onkologie. Praha: Maxdorf. 772p. ISBN 978-80-7345-674.

Vedoucí bakalářské práce:	**Mgr. Jan Pospíchal, Ph.D.** Katedra klinických oborů
Datum zadání bakalářské práce:	**1. prosince 2020**
Termín odevzdání bakalářské práce:	**28. dubna 2022**

L.S.

doc. Ing. Jana Holá, Ph.D. v.r.
děkanka

Mgr. Jan Pospíchal, Ph.D. v.r.
vedoucí katedry

V Pardubicích dne 14. března 2022

AUTHOR'S DECLARATION

I declare:

The thesis entitled the role of MRI in the evaluation of valvular heart diseases

Is my own work. All literary sources and information that I used in the thesis are referenced in the bibliography. I have been acquainted with the fact that my work is subject to the rights and obligations arising from Act No. 121/2000 Sb., On Copyright, on Rights Related to Copyright and on Amendments to Certain Acts (Copyright Act), as amended, especially with the fact that the University of Pardubice has the right to conclude a license agreement for the use of this thesis as a school work under Section 60, Subsection 1 of the Copyright Act, and that if this thesis is used by me or a license to use it is granted to another entity, the University of Pardubice is entitled to request a reasonable fee from me to cover the costs incurred for the creation of the work, depending on the circumstances up to their actual amount. I acknowledge that in accordance with Section 47b of Act No. 111/1998 Sb., On Higher Education Institutions and on Amendments to Other Acts (Act on Higher Education Institutions), as amended, and the Directive of the University of Pardubice No. 7/2019 Rules for Submission, Publication and Layout of Theses, as amended, the thesis will be published through the Digital Library of the University of Pardubice.

In Pardubice on 28.4.2022

Maria Kanyemba b.o.h

ACKNOWLEDGMENTS

I would like to thank my supervisor Mgr. Jan Pospíchal, Ph.D., allowed me to do this topic for his endless support, patience, understanding, and Mgr. Anna Lierova, for allowing me to write this thesis in English. Let me not forget my two awesome classmates, Ariela Mavungo and Selasi Heletsi, and my mentor MUDr. Anicet Ulrich Kanhounnon or their guidance throughout this project.

ANOTACE

Tato bakalářská práce je v podstatě literární rešerší různých článků o významu MRI v diagnostice chlopenních srdečních chorob, jako je stenóza a regurgitace. Dále odlišuje MRI od jiných technik, jako je CT a echokardiografie.

KLÍČOVÁ SLOVA

VHD, stenóza chlopně, regurgitace chlopně, CMRI, zobrazovací techniky chlopní, ultrazvuk chlopní, echokardiografie chlopně, CT chlopně, detailní snímek

TITLE

The role of MRI in the evaluation of valvular heart disease

ABSTRACT

This bachelor thesis is a literature review of different articles about the importance of MRI in diagnosing valvular heart diseases such as stenosis and regurgitation. It further differentiates MRI from other techniques such as CT and echocardiography.

KEYWORDS

VHD, Valve stenosis, Valve regurgitation, CMRI, valve Imaging techniques, valve ultrasound, valve echocardiography, valve CT, detailed image

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

AR -Aortic regurgitation

CHD - congenital heart disease

CMRI -Cardiac magnetic resonance imaging

CT -Computed tomography

ECG- Electrocardiography

EPT -Educational play therapist

FDA -Food and drug administration

LV -left ventricular

MR -Mitral regurgitation

MVP -Mitral valve prolapse

PICO -Population intervention comparison outputs

PMRI -Practice magnetic resonance imaging

RV -Right ventricle

SSFP -Steady-state free precession

INTRODUCTION

The heart is a muscular organ located behind and slightly left of the breastbone. It pumps blood through the network of arteries and veins called the cardiovascular system. It has four valves that keep blood moving through the heart in the right direction. The tricuspid, pulmonary, mitral, and aortic valves have tissue leaflets that open and close when the heartbeats. Leaflets ensure the right blood flows throughout the body. As the heart muscle contracts and relaxes, the valves open and shut, letting blood flow into the ventricles and atria at alternate times (Matthew 2021).

Heart valves can have regurgitation and stenosis simultaneously, and more than one heart valve can be affected simultaneously (Cheung et al., 2015). When the heart valves fail to open and close properly, implications for the heart can be serious, possibly hampering the heart's ability to pump blood adequately through the body. Heart valve problems are one of the causes of heart failure (Sommer et al., 2012). Valvular heart disease evaluation can be achieved with chest radiography, electrocardiography, echocardiography, computed tomography, and cardiac magnetic resonance (Maganti et al., 2010).

Statistically, more than 2% of people between the age of 62-86 suffer from VHD, whereby 45.7% endure heart valve stenosis. Studies show that stenosis is more common than regurgitation since only 26.6% of people suffer from regurgitation (Iung et al., 2019).

This thesis will have two parts. The first part, the theoretical part, will primarily focus on heart valve anatomy, current knowledge of heart valve malfunctions and their leading causes, and main examination methods for evaluating valvular heart diseases. The second part, the literature review part, will be based on n literature search to understand the role of CMRI in assessing valvular heart diseases and comparing it to other alternative medical imaging techniques such as CT, echocardiology, and ultrasound.

The current study seeks to investigate and describe the role of magnetic resonance imaging (MRI) as a tool used to diagnose valvular heart diseases in humans.

1 GOALS AND METHODOLOGY OF THE WORK

1.1 Aim of the thesis

The objective of the theoretical part of the thesis is to describe basic terms and diseases mentioned in the review part of the thesis.

1.2 Methods to achieve the goal

The methodology of this work is the literature review with background review questions. The chosen databases will be PubMed, NCBI, Google Scholar, Science direct, and keyword search, known as PICO and search strategy technique to help compile and narrow down the most important articles.

THEORETICAL PART

2 HEART

The heart contracts and expands rhythmically and involuntarily to pump blood around the body. The heart consists of four chambers, two atriums known as upper chambers and two ventricles known as lower chambers. It also consists of four valves through which blood passes before leaving each heart chamber and serves as one-way outlets of blood that prevent the backward flow of blood. The four valves are: 1. Tricuspid valve (located between the right atrium and right ventricle), 2. Pulmonary valve (located between the right ventricles and pulmonary artery), 3. Mitral valve (located between the left atrium and left ventricle) and 4. Aortic valve (located between left ventricle and aorta (Myerson, 2012). Standard valves have three flaps except for the mitral valve, which has two flaps that open and close to allow blood to flow (John et al., 2003). As the heart muscle contracts and relaxes, the valves open and close, letting blood flow into the ventricles and atria alternately. Healthy valve flaps can fully open and close the valves compared to diseased valves.

The heart is a muscular organ that serves two main functions (1) to collect deoxygenated blood from the body and pump it to the lungs and (2) to collect oxygenated blood from the lungs and pump it to the rest of the body Weinhaus et al., 2005). In humans, the heart is shaped and sized like a human's fist and lies in the protective thorax, posterior to the sternum and costal cartilage, and rests on the superior oblique position in the thorax (Weinhaus et al., 2005). The heart is found covered in a special loose-fitting inextensible sac called pericardium that consists of two parts: a fibrous portion and a serous portion. The sac is made up of tough white fibrous tissue but is lined with a smooth, moist serous membrane which subsequently covers the outer surface of the heart. This covering layer is also referred to as the visceral layer of the serous pericardium or the epicardium. The fibrous sac attaches to the large blood vessels that emerge from the top of the heart (Brant and Helms, 2012). Therefore, it fits loosely around the heart, with a slight space between the visceral layer adhering to the heart and the parietal layer adhering to the inside of the fibrous sac. This space is known as the pericardial space and contains approximately 15 ml of pericardial fluid, a vital lubricating fluid secreted by the serous membrane. The fibrous pericardial sac, a well-lubricated lining, provides protection against friction. Hence, the heart moves easily in the loose-fitting jacket with no danger of irritation from friction between the two surfaces if the serous pericardium remains normal through the continuous production of serous fluid (Patton and Thibodeau, 2014).

The heart forms part of the cardiovascular system and a closed system of vessels called arteries, capillaries, and veins (Peate, 2020). Blood contained in the circulatory system is pumped by the heart around a closed circle or circuit of vessels as it passes continuously through the various circulations of the human body. The internal anatomy of the heart reveals four chambers composed of muscle or myocardium. The two upper chambers (or atria) serve as collecting chambers, while the two lower chambers (known as ventricles) are much more robust and function to pump blood. Furthermore, ventricles are considered the primary pumping chambers of the heart due to the increased force needed when pumping blood and farther distance (Goulbourne et al., 2003). The left chambers are separated from the right chambers by a septum, an extension of the heart wall. The significant role of the right atrium and ventricle is to collect blood from the body and pump it to the lungs, while the part of the left atrium and ventricle is to collect blood from the lungs and pump it throughout the body (Weinhaus et al., 2005). A set of four valves maintains the one-way flow of blood through the heart. The atrioventricular valves (tricuspids and bicuspids) allow blood to flow only from the atria to the ventricles. Semilunar valves (pulmonary and semilunar) allow blood to flow only from the ventricles out of the heart and through the great arteries.

2.2 Heart valves

Structures that permit the flow of blood in one direction are known as blood valves, which necessitate the heart to act as a pump that forces the continuous blood flow. Therefore, four essential valves are of importance to the normal functioning of the heart. Heart valves guard the openings between the atria and the ventricle, and two of these valves are known as atrioventricular (AV) valves. Figure 1 below depicts the four heart valves.

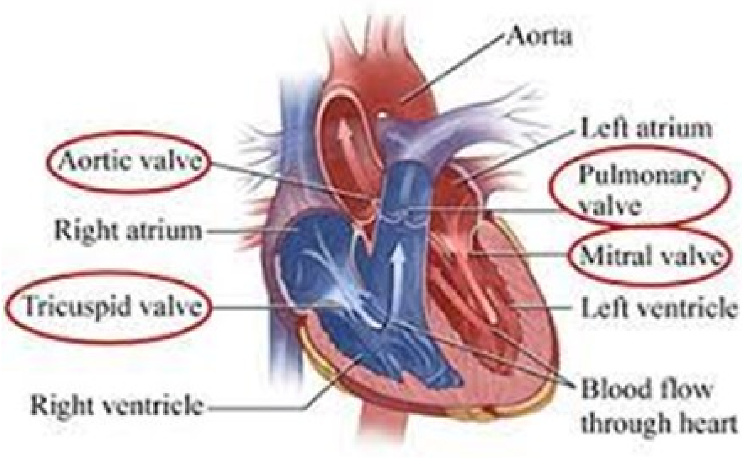

Figure 1 The four heart valves (Source Leo et al., 2006.)

2.2.1 Tricuspid valve

This is located between the right atrium and the right ventricle. According to Weinhaus et al. (2005), blood is pumped from the right atrium through the atrioventricular into the right ventricle. When the right ventricle contracts, blood is prevented from flowing back into the atrium by the ventricular valve or tricuspid ("three cusps") valves. The valve consists of the annulus, three valvular leaflets, three papillary muscles, and three sets of chordae tendineae. The tricuspid valve has three leaflets: anterior (superior), posterior (inferior), posterior (inferior), and septal. The leaflet is the largest and extends from the medial border of the ventricular septum to the anterior free wall. Papillary is attached to the leaflets to secure them in place in preparation for contraction of the ventricle. The leaflets remain relatively close together even during ventricular filling. As the filling of the ventricle reduces, the valve leaflets float toward each other, but the valve does not close. The valve is closed by ventricular contractions, and the valve leaflets, which bulge toward the atrium but do not prolapse, stay pressed together throughout ventricular contraction (Weinhaus et al., 2005).

2.2.2 Pulmonary valve

This is located between the right ventricle and the pulmonary artery (Myerson, 2012). Blood is pumped from the right ventricle into the pulmonary trunk and arteries toward the lungs during ventricular systole. When the right ventricle relaxes, in diastole, blood is prevented from flowing back into the ventricle by the pulmonary semilunar valve. The semilunar valve is composed of three symmetric, semilunar-shaped cusps. Each cusp looks like a cup composed of a thin membrane. Each cusp acts like an upside-down parachute facing the pulmonary trunk, opening as it fills with blood. On complete filling, the three cusps contact each other and block the retrograde flow of blood. Each of the three cusps is attached to an annulus such that the cusp opens into the lumen, forming a U shape. The annulus is anchored to both the right ventricular infundibulum and the pulmonary trunk. The cusps are named according to their orientation in the body: anterior, left (septal), and right.

2.2.3 Mitral valve

The Mitral (Bicuspid) valve is located between the left atrium and the left ventricle. Blood is pumped from the left atrium through the left atrioventricular orifice into the left ventricle. When the left ventricle contracts, blood is prevented from flowing back into the atrium by the left atrioventricular valve or bicuspid ("two cusps") valve. The valve consists of the annulus, two leaflets, two papillary muscles, and two sets of chordae tendineae. The bicuspid valve has two leaflets: anterior (medial or aortic) and posterior (inferior or mural, "wall"). The two opposing leaflets of the valve resemble a bishop's hat or miter. Thus, the bicuspid valve is often referred to as the mitral valve (Weinhaus et al., 2005). As with the tricuspid valve, the leaflets remain relatively close together, even when the atrium is contracting and the ventricle is filling.

2.2.4 The aortic valve

The A is located between the left ventricle and the aorta (Myerson, 2012). During ventricular systole, blood is pumped from the left ventricle into the aortic artery to all of the tissues of the body. When the left ventricle relaxes in diastole, blood is prevented from flowing back into the ventricle by the aortic semilunar valve. Like the pulmonary semilunar valve, the aortic valve is composed of three symmetric, semilunar-shaped cusps; each cusp acts like an upside-down parachute facing the aortic artery, opening as it fills with blood. Like the pulmonary semilunar valve, the aortic valve is composed of three symmetric, semilunar-shaped cusps; each cusp acts like an upside-down parachute facing into aortic artery, opening as it fills with blood. On complete filling, the three cusps contact each other and block the flow of blood. Each of the three cusps is attached to an annulus ("ring") such that the cusp opens into the lumen, forming a U-shape. The cusps are firmly anchored to the fibrous skeleton within the root of the aorta (Myerson, 2012).

2.3 Heart Valvular Diseases

Sometimes one or more of these valves do not function properly. When any valve in the heart has been damaged or is diseased, the condition is referred to as valvular heart disease. Heart valves can have one of the two malfunctions. The heart valves can be affected by (1) ***Stenosis (or narrowing of the valve)*** where the opening is too small and slows the flow of blood, (2) ***Regurgitation (or leakage of the valve)*** where incomplete closure of the valve causes leaks and back-flow of blood. These two lesions can affect the exact opening, thus constituting valvular heart disease (Maganti et al. 2010).

2.3.1 Stenosis

The valves opening becomes narrowed, or valves become damaged or scarred (stiff), inhibiting the flow of blood out of the ventricles or atria. The heart is forced to pump blood with increased force in order to move blood through the narrowed or stiff (stenotic) valves. The aortic valve is mostly affected. Aortic stenosis is usually caused by either degenerative calcification of a trileaflet valve or progressive stenosis of a congenital bicuspid valve (Maganti et al., 2010). Risk factors for the development of degenerative calcific aortic stenosis are like those for the development of vascular atherosclerosis, comprise diabetes, hypertension, smoking, and elevated levels of low-density lipoprotein cholesterol and lipoprotein. Obstruction of left ventricular (LV) outflow can also occur at the subvalvular level (discrete subvalvular obstruction, hypertrophic cardiomyopathy) or above the valve (supravalvular stenosis) (Bonow et al., 2011). The severity of aortic stenosis increases gradually over many years. However, the left ventricle adapts to the obstruction by increasing wall thickness while maintaining standard left ventricular chamber size. This serves as a compensatory mechanism to normalize the left ventricular wall stress and appears to be a critical determinant of ventricular performance in patients with aortic stenosis. In many patients, this compensatory mechanism cannot be maintained forever, and systolic function begins to decline as a result of the pressure overload.

If left ventricular systolic dysfunction is present, it often improves after aortic valve replacement. Eventually, stenosis becomes severe symptoms of angina, syncope, dyspnea, and/or heart failure develop. Once symptoms develop, prompt surgical intervention is required because the average survival is only 2 to 3 years, with an increased risk of sudden death (Maganti et al., 2010).

2.3.2 Regurgitation

Regarding regurgitation (or leakage of the valves), valves do not close completely, causing the blood to flow backward through the valve. This results in leakage of blood back into the atria from the ventricles (in the case of the mitral and tricuspid valves) or leakage of blood back into the ventricles (in the case of the aortic and pulmonary valves). In the aorta, regurgitation results from abnormalities of the aortic leaflets, their supporting structures in the aortic root and annulus, or both, while mitral regurgitation may result from disorders of the valve leaflets themselves or from any of the surrounding structures that comprise the mitral apparatus (Maganti et al., 2010).

Heart valves can have both malfunctions simultaneously with regurgitation and stenosis (Cheung et al., 2015). Also, more than one heart valve can be affected simultaneously. When heart valves fail to open and close properly, the implications on the heart can be serious, possibly hampering the heart's ability to pump blood adequately through the body. Heart valve problems are one of the causes of heart failure (Sommer et al., 2012).

2.3.3 Cardiovascular disorders

Disorders of the cardiac valves can have several effects; for example, a congenital defect in valve structure which results in mild to severe pumping inefficiency (Hoffman et al., 2004). Incompetent valves often leak, allowing a portion of blood to flow backward into the chamber it came from. (Saikrishnan et al., 2015) elaborates that stenosed valves are narrower than expected, which slows blood flow from the heart chamber.

2.4 Congenital heart disease

Congenital heart disease (CHD) is any developmental malformation of the heart. The spectrum of diseases falling into this classification include superficial lesions such as the bicuspid aortic valve, and more complex lesions involving single ventricle lesions like the hypo-plastic left heart syndrome (Ludman et al., 1990). Although rare CHD has an incidence of approximately 8 per 1000 births, CHD has since increased in prevalence due to the success of surgical and medical management in childhood. A significant proportion of patients with repaired CHD surviving into adulthood fall under the care of cardiologists.

2.5 Clinical presentation of CHD

The clinical presentation of CHD in infancy may be dominated by a number of physiological states:

1. Left to right shunts: A scenario whereby the redirection of blood from the systemic (left) to the pulmonary circulation (right) may occur at the atrial or ventricular level. A proportion of already oxygenated blood is recirculated to the lungs with each heartbeat, resulting in inefficiency in the lungs due to the oxygen levels in the blood (Lyen et al., 2017). The volume of the shunt and its location accounts for the observed signs. Chambers and vessels receiving the excessive volume enlarge, and high pulmonary blood flow results in pulmonary plethora. Typical examples include atrial septal defects, ventricular septal defects, and patent ductus arteriosus. Patients are pink but increasingly breathless with more significant shunts.

2. Compromised systemic perfusion: This may result from low stroke volume of a systematic ventricle (hypo-plastic left heart syndrome) and aortic obstruction. The clinical picture is one of poor peripheral perfusion with low pulse volume, patients may be pink or blue (cyanotic).

3. Intra-cardiac mixing: Complete intracardial mixing of blood may occur at the atrial level and ventricular level. Patients are expected to be mildly cyanosed, depending on the relative amount of deoxygenated blood in the mix, and breathless according to the amount of pulmonary blood flow (Garcia et al., 2012).

2.6 Commonly reported heart diseases

Acute rheumatic heart disease results from a delayed inflammatory response to streptococcal infection, mostly in children (Marijon et al., 2012). Characterized by joint pain and swelling, cardiac valvular regurgitation with the potential for secondary heart failure, chorea, skin, and fever (Carapetis et al., 2016). Several weeks after an improperly treated streptococcal infection, the cardiac valves may become inflamed. Figure 2 gives the prevalence of acute rheumatic heart disease around the world.

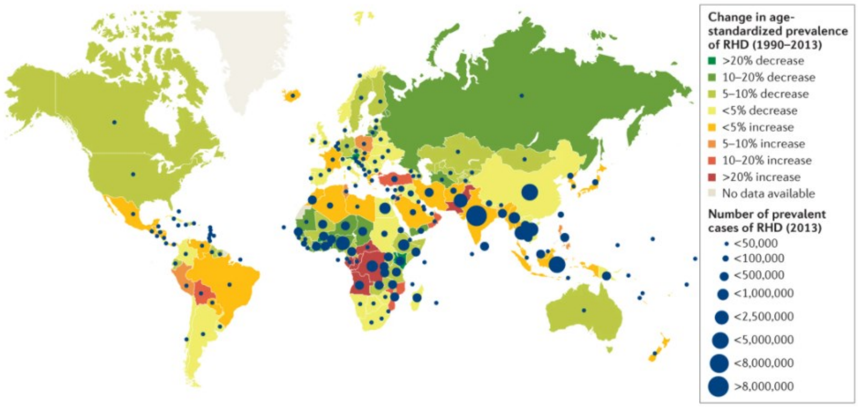

Figure 2 Number of prevalent cases of rheumatic heart disease (RHD) in 2013 by country and the change in age standardized RHD prevalence from 1990 to 2013 (Vos et al., 2015).

2.6.1 Mitral valve prolapses

Mitral valve prolapse (MVP) is defined as an abnormal bulging of the mitral valve leaflets into the left atrium during ventricular systole, which results in leakage (Guy et al., 2012). Patients with MVP often complain of chest pain and severe fatigue. Figure 3 shows a pictorial description of MVP in the heart. Kolibash (1988) describes that progressive worsening of mitral prolapse is often associated with progressive mitral regurgitation and the physiologic consequences of mitral regurgitation, which can progress to congestive heart failure, arrhythmia, and subsequent sudden death.

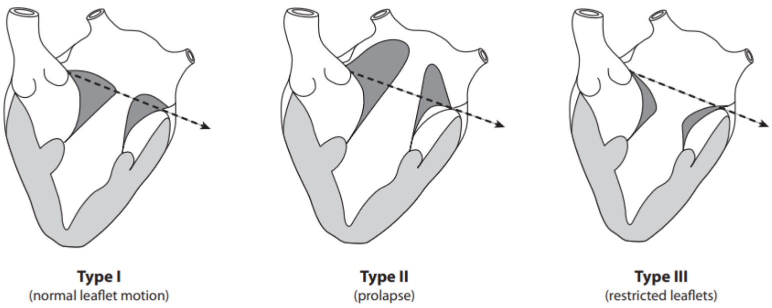

Figure 3 Carpentier's functional classification of mitral regurgitation (MR) (Guy et al., 2012).

Type I MR has normal leaflet motion (e.g., annular dilatation, leaflet perforation); type II has abnormal leaflet motion with prolapse or flail (e.g., myxomatous degeneration, torn chordae tendineae); type III has restricted leaflet motion (e.g., rheumatic heart disease, ischemic cardiomyopathy) (Guy et al., 2012)

2.6.2 Aortic regurgitation

It is a condition in which blood not only ejects forward into the aorta but also regurgitates back into the left ventricle (Kim et al., 2016) because of the leaky aortic semilunar valve. This causes a volume overload on the left ventricle, with subsequent hypertrophy and dilation. The left ventricle attempts to compensate for the increased load by increasing its strength of contraction, which may stress the heart and result in myocardial ischemia (McKay et al., 1986). Figure 4 depicts aortic regurgitation in the heart.

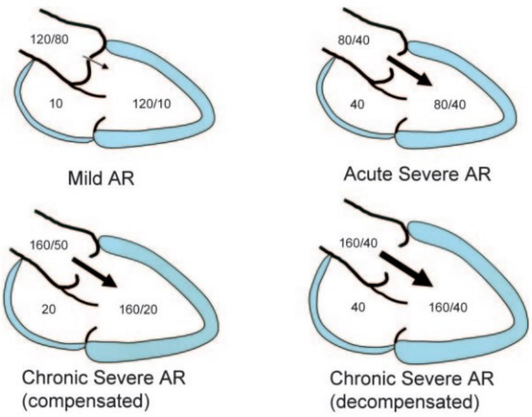

Figure 4 Different stages of AR (Bekeredjian and Grayburn, 2005).

Top left, in mild AR, LV size, function, and hemodynamics are standard. Top right, in acute severe AR, there is equilibration of aortic and LV pressures (80/40 mm Hg in this example). Left atrial pressure is elevated, leading to pulmonary edema. Bottom left, in chronic severe, compensated AR, the LV may begin to dilate, but LVEF is often maintained in the normal range by increased preload. There is systolic arterial hypertension and wide pulse pressure. However, LV filling pressures are normal or only slightly elevated, such that dyspnea is absent. Bottom right, in decompensated chronic severe AR, the LV is dilated and hypertrophied, and LV function is often depressed as a result of afterload excess. Forward output is decreased, leading to fatigue and other low-output symptoms. Fibrosis and hypertrophy decreased LV compliance, increasing filling pressures and dyspnea (Source: Bekeredjian and Grayburn, 2005).

2.7 Techniques employed in evaluation of heart diseases

Sound knowledge of the cardiac anatomy is essential for identifying and understanding cardiovascular conditions in patients (Lilly, 2012). Various techniques such as conventional chest radiography, cardiac magnetic resonance, computed tomography, and echocardiography are used to assess aspects of cardiac and vascular anatomy (Goldstein et al., 2015).

2.7.1 Computed tomography

Computed tomography) has become a powerful and widely used tool among non-destructive techniques, capable of inspecting external and internal structures without destroying them) in many industrial applications. CT is a powerful tool capable of inspecting external and internal structures in many industrial applications as well as providing accurate geometrical information with very high accuracy. A CT system basically consists of an X-ray source Â, a rotary table, an X-ray detector, and a data processing unit for computation, visualization, and data analysis of measurement results. Advantages of CT includes non-destructive allows determination of inner and outer geometry, provides a volume of data of high density, and short scanning time. Disadvantages of CT includes lack of accepted test procedures available so far, complex, and numerous influence quantities affecting measurements, reduced form measurement capability due to measurement errors (artifacts), and measurement uncertainty in many cases unknown (results are not traceable) (Cantatore and Müller, 2011).

2.7.2 Electrocardiography

Nowadays, electrocardiography is an essential part of the initial evaluation for patients presenting with cardiac complaints. As a first-line diagnostic tool, health care providers at different levels of training and expertise frequently find it imperative to interpret electrocardiograms. Specifically, it plays an essential role as a non-invasive, cost-effective tool to evaluate arrhythmias and ischemic heart disease (AlGhatrif and Lindsay., 2012).

2.7.3 Echocardiography

Echocardiography is one of the most commonly performed noninvasive diagnostic tests in patients with known or suspected cardiovascular diseases. Echocardiography provides a comprehensive evaluation of the cardiovascular structure, function, and hemodynamics that characterize disease processes (Gottdiener et al., 2004). Moreover, there are no known side effects associated with echocardiography, even with frequent and repeat testing. Time, nature, portability, and relatively low cost make echocardiography adaptable to most clinical or research situations. Hence, echocardiography has been used successfully to provide mechanistic insights into therapeutic outcomes and in some cases to measure functional and structural changes that are considered to be of therapeutical importance. Identification and qualitative assessment of valvular regurgitation are relatively simple with 2D echocardiography and color flow imaging. Such assessments are routinely used in clinical practice and are well described in standard texts and ASE guidelines. Measurement of color flow jet areas is operator and machine-dependent; however, requiring careful attention to uniform image acquisition. Assessment of change in the magnitude of valvular regurgitation should utilize quantitative methods whenever possible.

Volumetric assessments of regurgitation obtained by subtracting forward volume flow from total flow obtained from LV measurements sum the errors of chamber volume estimations and are of limited utility. However, substantial experience has been obtained with the proximal is velocity surface area (PISA) method with color flow Doppler for quantitation of mitral regurgitation. Effective regurgitation orifice area can be calculated as aliasing velocity/peak regurgitation velocity. Although they are quantitative, these techniques may be subject to acquisition and observer variability. The timing of velocity and PISA radius should be the same at mid-systole to minimize variability. This technique is used primarily in mitral regurgitation and is more difficult to perform in other valvular regurgitant lesions. For studies that primarily assess valvular regurgitation as a covariate in evaluations of other echocardiographic endpoints, such as LV mass or systolic/ diastolic function, traditional qualitative methods are adequate. In general, clinical trials of valvular stenosis have been evaluations of prosthetic valves.

2.7.4 Cardiac magnetic resonance

Magnetic resonance imaging (MRI) is a unique tool for investigating the morphology and function of the cardiovascular system. The advantage of cardiac magnetic resonance (CMR) is based on its high spatial and temporal resolution, the high blood tissue contrasts mainly when using the steady-state free precession (SSFP) techniques, and the capability of three-dimensional (3D) reconstruction of cardiac and vascular structures (Hombach et al., 2010). In contrast to echocardiography, MRI is largely used independent and does not substantially suffer from variations in image quality and poor patient-related echogenicity. CMR imaging is the gold standard for assessing left and right ventricular function and detecting myocardial tissue abnormalities like edema, infarction, or scars. Furthermore, CMR is independent of slice-orientation or acoustic window, and its 3D nature enables direct calculation of ventricular dimensions without any need for geometrical models.

For prognostic reasons, ab-normal structure and dysfunction of the heart, and the detection of myocardial ischemia and/ /or myocardial scars are the primary targets for CMR imaging (Hombach et al., 2010). Cardiac magnetic resonance (CMR) obtains image planes of the cardiovascular anatomy in any arbitrary view as it is not hampered by the limited availability of acoustic windows (van den Bosch, 2018). This is advantageous when imaging the morphology of the right ventricle (RV), which is excellently delineated by CMR. Therefore, medical imaging with X-rays, radionuclides, magnetic resonance imagining (MRI), ultrasound an, computed tomography is increasingly utilized in health care for screening, diagnosis, and disease follow-ups. Furthermore, the presence of anatomic mitral valve prolapse can be specifically defined and characterized using modern imaging modalities (echocardiography and cine MRI).

2.8 Overview of valvular heart diseases

Maganti et al. (2010) postulate that valvular heart disease (VHD) consists of a number of common cardiovascular conditions that account for approximately 10-20% of most cardiac surgical procedures in the United States of America. Therefore, a better understanding of recent advances in diagnostic imaging, interventional cardiology, and surgical approaches have resulted in accurate diagnosis. This could aid in in-depth knowledge of various valvular disorders and the quality care of patients living with VHD. Degenerative valve diseases are a frequent form of valvular heart disease in the United States, whereas rheumatic heart disease accounts for most valve pathology and is reported in developing countries (Iung and Vahanian, 2011). Iung et al. (2003) depict survey results carried out on patients with VHD as shown in Table 3.1.

Table 1 Etiology of single native left-sided valve disease (Iung et al., 2003).

	Aortic stenosis n=1197	Aortic regurgitation n=369	Mitral stenosis n=336	Mitral regurgitation n=877
Degenerative (%)	81.9	50.3	12.5	61.3
Rheumatic (%)	11.2	15.3	85.4	14.2
Endocarditis (%)	0.8	7.5	0.6	3.5
Inflammatory (%)	0.1	4.1	0	0.8
Congenital (%)	5.4	15.2	0.6	4.8
Ischaemic (%)	0	0	0	7.3
Other (%)	0.6	7.7	0.9	8.1

Furthermore, Iung et al. (2003) study reported the distribution of VHD, where aortic stenosis (AS) was the most frequent native valve disease, followed by mitral regurgitation (MR), while aortic regurgitation (AR) and mitral stenosis (MS) were observed with similar frequency. In this survey, patients with previous valve interventions represented a significant sub-group for which unfortunately, have very little data available and very few guidelines. Generally, the patients with VHD are often elderly with a high frequency of cardiovascular risk factors and comorbidities (Stewart et al., 1997).

3.1.1 Aortic stenosis

Aortic stenosis (AS) is the most predominant form of cardiovascular disease in the Western world after hypertension and coronary artery disease (Brickner, 2014). Otto (2002) elaborates that AS is regularly caused by either degenerative calcification of a trileaflet valve or progressive stenosis of a congenital bicuspid valve. Aortic stenosis develops from progressive calcification of leaflets with restriction of leaflet opening over time. In patients with valvular

AS, the severity of stenosis increases. Subsequently, the left ventricle adapts to the obstruction by increasing wall thickness while maintaining normal left ventricular chamber size (concentric hypertrophy) (Maganti et al., 2010).

3.1.2 Physical examination of aortic stenosis

Rheumatic heart disease, being the most common etiology globally, is less common in the United States of America (Watkins et al., 2017). The characteristic murmur of AS is a crescendo-decrescendo systolic murmur along the left sternal border that radiates to the upper right sternal border and into the carotid arteries (Frank and Jacobe, 2011).

Studies have shown that the severity of the AS increases, the duration of the murmur increases, and it is more likely to peak at mid to late systole. A diastolic murmur may be heard if aortic regurgitation (AR) is also present, a distinctive finding in patients with rheumatic AS (Maganti et al., 2010). In young patients with bicuspid AS, the systolic murmur may be preceded by a systolic ejection click. This sound tends to disappear with aging as the valve calcifies and the severity of AS rises. In the presence of severe heart failure, the apical impulse may be diffuse and laterally displaced, a third heart sound may be present, the jugular venous pulse may be elevated, and the systolic murmur may be soft or absent (Rahimtoola, 2010).

Multiple valvular heart disease (VHD), a combination of stenotic or regurgitant lesions occurring on ≥2 cardiac valves, and mixed VHD, are said to be a mixture of stenotic and regurgitant lesions on the same valve, which are highly prevalent conditions (Unger et al., 2018). Lee et al. (2011) elaborates that in an American Society of Thoracic Surgeons Database, which included 290 000 patients who underwent surgery between 2003 and 2007, 11% had double valve procedures (replacement or repair), most often aortic and mitral, and triple valve surgery has been performed in 1% of cases. Moreover, in a Swedish nationwide study based on hospital discharge codes without quantification of valvular dysfunction, multiple VHD accounted for approximately 11% of patients (Andell et al., 2017). Therefore, the most frequent associations were aortic stenosis (AS) plus aortic regurgitation (AR), AS plus mitral regurgitation (MR,) and AR plus MR.

Multiple valve disease is often acquired; in the Euro Heart Survey, rheumatic fever was the predominant pathogenesis (51%), but degenerative VHD was also highly prevalent (41%) (Iung et al., 2007). Other acquired pathogeneses, including infective endocarditis, radiation therapy, drug-induced VHD, and inflammatory diseases, were less frequent. As in single VHD, a shift from rheumatic toward degenerative pathogenesis is currently observed in industrialized countries, reflecting aging and the overall decreased incidence of rheumatic fever (Andell et al., 2017).

The degenerative mitral annulus and leaflet calcifications often coexist with AS in elderly patients and may, when severe, cause significant mitral stenosis (MS). This multiple VHD entity is associated with a worse prognosis. It poses specific therapeutic challenges because balloon commissurotomy or surgical mitral valve replacement is often not an option in these patients. Secondary MR and tricuspid regurgitation (TR) may develop in patients with aortic VHD and in patients with right ventricular volume or pressure overload because of left-sided or pulmonary VHD (Unger et al., 2018).

3 LITERATURE REVIEW

To compile an overview and write this work, a search of professional articles was chosen from magazines and published studies. I followed a well-defined methodology of the Joanna Briggs Institute (JBI), which is currently the leader in the creation of systematic reviews.

Before searching for studies, it was essential to define the topic and establish the selection criteria. I decided on an excellent clinical foreground question according to the PICO formula, i.e. (P) -patient/population/problem, (I) – the primary intervention or the type of exposure used, (C) - comparison with another type of intervention, (O) - outputs. The main aim was to find out if CMRI shows better and well-detailed valve images than other imaging techniques when evaluating valvular heart diseases such as stenosis and regurgitation. Each concept was defined individually (see Table 2).

Table 2 criteria according to the pico

	Keywords
P-population	Valvular heart diseases in humans
I-intervention	Cardiovascular magnetic resonance technique
C-comparison	Valve imaging techniques
O-outcome	Well understandable scan images

I used the google scholar internet database and research gate for the initial overview search of publications. In contrast, PubMed and science direct were used to search for keywords (see Table 3), and many articles and studies were generated. The search was not limited to time but only human beings.

Review question

Does magnetic resonance imaging in the evaluation of valvular heart diseases in human beings generate better and more detailed scans than other valve imaging techniques?

Table 3: PICO keywords

	Keywords
problem	VHD, Valve stenosis, Valve regurgitation
intervention	CMRI
context	valve Imaging techniques, valve ultrasound, valve echocardiography, valve CT
outcome	Detailed image

I entered each keyword individually into each database. PubMed and science direct database search results for individual keywords and variations using the Boolean AND and OR are shown in Table 4.

Table 4: Search strategy in database

Number	Keywords	Number of results in PubMed	Number of results in science direct
1	VHD	106,579	97,325
2	Valve stenosis	44,035	104,309
3	Valve regurgitation	25,673	78,292
4	**1 OR 2 OR 3**	**6,133**	**192,824**
5	CMR	42,832	**73,645**
6	Valve Imaging techniques	28,008	182
7	Valve ultrasound	55,186	57,952
8	Valve echocardiography	39,946	2,189
9	Valve CT	8,266	44,635
10	**6 OR 7 OR 8 OR 9**	**61,713**	**89,407**
11	detailed valve images	1,116	73,645
12	**4 AND 5 AND 10 AND 11**	**36**	**42**

A total number of 72 studies were found. I first discarded two duplicates, which were found in science direct. I excluded 42 studies because they were not part of my inclusion criteria. I studied the remaining articles and again excluded some articles due to geographical, language, and publication type. Of the eligible articles, two articles in science direct were not available in full text, so they got eliminated. Furthermore, the other two were more about the heart and the information was not that clear hence them being removed. Finally, ten articles remained that were relevant to the study. In conclusion to database base research, all included articles are displayed in the PRISMA flow chart (see figure 5).

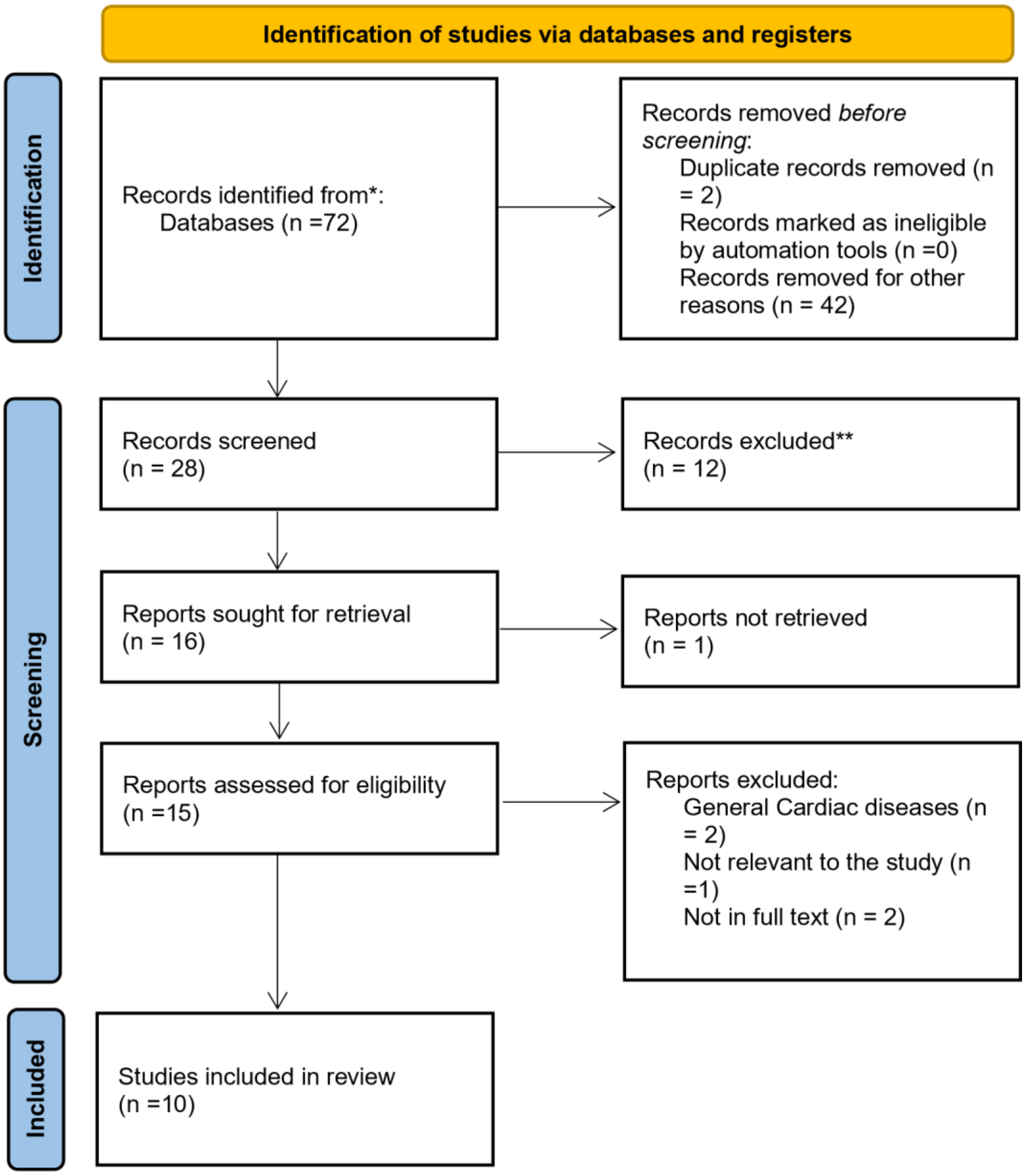

Figure 5 flow chart diagram

Lastly, I included ten studies in my literature review (see Table 5). Studies are randomly ranked according to their relevance to the study.

Table 5: Table of included publication

Number	Title	Author (year)
1.	Outcomes in Degenerative Mitral Regurgitation: Current State-of-the Art and Future Directions	Milynd Y et al (2017)
2.	The Evolving Role of Cardiac Imaging in Percutaneous Valvular Intervention	Darryl P et al. (2013)
3.	Cardiovascular Magnetic Resonance Imaging for Structural and Valvular Heart Disease Interventions	João et al. (2016)
4.	All you need to know about the tricuspid valve: Tricuspid valve imaging and tricuspid regurgitation	Olivier Huttin et al. (2016)
5.	Advanced cardiac MRI techniques for evaluation of left-sided valvular heart disease.	Blanken CPS et al (2016)
6.	Cardiovascular magnetic resonance in the evaluation of heart valve disease.	Gulsin GS et al. (2017)
7.	Reviewing the process of preparing children for MRI	Leanne et al. (2008)
8.	Magnetic resonance to assess the aortic valve area in aortic stenosis: how does it compare to current diagnostic standards?	John et al. (2003)
9.	Surgical mitral valve replacement using direct implantation of Sapien 3 valve in a patient with severe mitral annular calcification without adjunctive techniques, a case report.	Albacker TB et al. (2020)
10.	Valvular heart disease in women, differential remodeling, and response to new therapies.	Chandrasekhar, J. et al (2017).

3.1 evaluation of articles

To make it more understandable, articles are summarised and explained in more straightforward terms together to prevent the repetition of information and help group all information per item.

1 - Outcomes in Degenerative Mitral Regurgitation: Current State-of-the Art and Future Directions

This review study by MILYND Y et al. available in the full text was published in 2017. This state-of-the-art review discusses the latest knowledge in the natural history, imaging, surgical and percutaneous therapies in patients with degenerative MR in western countries.

Methods: This study is mainly for patients with degenerative MR. No age group was defined, but results were grouped on age average and gender. The study evaluates the severity and mortality of MR in all age groups and compares the possible diagnostic methods.

Results: degenerative MR has a 40% access mortality rate in people older than 64 years. It severely affects women more than men, and older women and have severe DMR and worse survival. MRI and echocardiography are the most widely used methods, but MRI is the most commonly used nowadays.

Conclusion: more diagnosis methods are being tried and becoming more precise, and health centres are trying to help patients choose the best therapy options, but more studies are still on ongoing.

Table 6: Milynd 2017

		results	comments
1.	Did treatment allocation blind participant?	Yes	
2.	Did the researcher blind the treatment allocation group	Yes	
3.	Was the output of the participants who withdrew from the research explained, and included in the analysis	no	A review was done on existing patient reports
4.	Were outputs evaluated blinded to the treatment allocation?	yes	
5.	Were control and experimental groups comparable in the beginning		No, because the
6.	Were groups treated the same without using another intervention for one of the groups?	no	Patients' other health conditions were considered
7.	Were the results/outputs measured in the same way in all groups?		
8.	Were the results/outputs measured reliably?	yes	
9.	Was statistical analysis used appropriately?	yes	

2 - The Evolving Role of Cardiac Imaging in Percutaneous Valvular Intervention

A nonrandomized study by Darryl P and others was published in 2013. It summarizes the goals of cardiovascular imaging in the work-up for, during, and in the follow-up of percutaneous valvular intervention.

Method: work from different authors was reviewed and analysed. No audiences were defined.

Results: Cardiovascular imaging plays a vital role in diagnosing VHD, singling out the mechanism of valvular dysfunction and quantifying its severity. Together with CT and percutaneous therapeutic options for VHD, MRI helps in patient selection and guides choice of prosthesis.

Conclusion: Cardiovascular imaging aids in patient screening for percutaneous valvular interventions. It is done during the procedure and as a follow-up to identify complications and monitor if the implantation was a success or failure.

Table 7: Darryl 2013

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group	no	Not possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis	yes	Due to geographical reasons
4	Were outputs evaluated blinded to the treatment allocation?	yes	Preliminary evaluation still ongoing
5	Were control and experimental groups comparable in the beginning	yes	MS, age
6	Were groups treated the same without using another intervention for one of the groups?	no	The severity of the disease
7	Were the results/outputs measured in the same way in all groups?	no	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?		Figures provided

3 - Cardiovascular Magnetic Resonance Imaging for Structural and Valvular Heart Disease Interventions

Joao L and others conducted this study and it, was published in 2016. It does not necessarily focus on individuals but rather on how CMRI works in general and points out its limitations.

Methods: Different valvular diseases were studied under MRI, and random patients scans were used to support the studies.

Results: CMRI is non-invasive and uses no radiations. It is a crucial part of the planning, procedural guidance, and follow-up of patients undergoing interventions for structural and valvular heart diseases. MRI shows better and more detailed scans than CT other imaging tools that make the diagnostic process better.

Conclusion: This result suggests that CMRI is the safest diagnosis method and not painful. Patients do not need hospitalization.

Table 8: Joao 2016

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group	no	Not possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis	no	Only participant Results are available
4	Were outputs evaluated blinded to the treatment allocation?	no	
5	Were control and experimental groups comparable in the beginning	yes	CMRI, VHD
6	Were groups treated the same without using another intervention for one of the groups?	yes	Different TAVR and valves
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?	yes	

4 - All you need to know about the tricuspid valve: Tricuspid valve imaging and tricuspid regurgitation.

Olivier Huttin and others conducted this study and it was published in 2016. This article does not necessarily focus on individuals but generally on tricuspid valve and tricuspid regurgitation and most importantly, its analysis.

Method: no defined method was used since it is a comprehensive study.

Results: The tricuspid valve is a complicated, dynamic, and changing structure which makes it challenging to analyse. 3D imaging, such as CT and MRI, are the best at analysing TR, and they provide the morphological description of the tricuspid valve complexity. However, the debate is still ongoing, and more imaging tools are being looked at.

Conclusion: tricuspid valve is one of the most common VHDs and it can lead tore cardiac complications.

Table 9: Olivie 2016

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group	no	Not possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis		Not specified
4	Were outputs evaluated blinded to the treatment allocation?	no	
5	Were control and experimental groups comparable in the beginning	no	The diagnosis was not applicable to all at the end
6	Were the group treated the same without using another intervention for one of the groups?	no	The diagnosis was not applicable to all at the end
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?	yes	

5 - Advanced cardiac MRI techniques for evaluation of left-sided valvular heart disease.

Carmen P.S. Blanken and others conducted this study and it was published in 2016. no defined group of people was mentioned and the authors showed no interest in conflict toward the publication of this study. It is entirely a study about CMRI techniques and its role in evaluating left-sided valvular heart disease compared to other imaging techniques.

Method: Works from different authors ware reviewed, analysed, and finally complied with by Carmen P.S. Blanken et al. and sent for printing.

Result: MRI is an accurate method for quantifying left-sided valvular heart disease as it provides increasingly excellent diagnosis and treatment selection for patients. Furthermore, more research aiming to explore quantitative MRI to its best potential needs to be done.

Conclusion: The most common types of VHD are aortic valve stenosis, aortic valve regurgitation, and mitral valve regurgitation. CMRI is a globally accepted diagnostic modality for the assessment of left-sided.

Table 10: Blanken 2016

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group		Not? possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis		Not specified
4	Were outputs evaluated blinded to the treatment allocation?	no	MRI, AS
5	Were control and experimental groups comparable in the beginning	no	
6	Were the group treated the same without using another intervention for one of the groups?		The severity of diseases differs
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?	yes	

6 - Cardiovascular magnetic resonance in the evaluation of heart valve disease.

The report by Glusin G. S and others was published in 2017, and it addresses the role and importance of CMR in the comprehensive evaluation of VHD

Method: GSG and GPM came up with the idea for the manuscript. GSG and AS constructed the initial draft. GPM gave gratitude to the manuscript and ensured the accuracy of its wholesome content. All authors showed no conflict with the final work. All clinical images used were granted permission from the hospital.

Result: CMR possesses the capability to measure cardiac volumes, function, mass, visualize and quantify cardiac motion and flow, and it uses only 2D accurately and reproducibly. The inability of CMR to use 3D and 4D velocity mapping makes it difficult to assess larger slices.

Conclusion: This article was the most accurate as it answers the aim of this thesis. It entails all the sequences, valvular heart diseases, limitations, and advantages of CMRI and it thoroughly states how it differs from other imaging tools. CMR is an essential tool for the assessment of cardiac diseases.

Table 11: Glusin 2017

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group		Not possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis		Not defined
4	Were outputs evaluated blinded to the treatment allocation?	no	
5	Were control and experimental groups comparable in the beginning		
6	Were the groups treated the same without using another intervention for one of the groups?	no	
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	Yes	
9	Was statistical analysis used appropriately?	Yes	

7 - Reviewing the process of preparing children for MRI

The report by Leanne M.H and others was published in 2008. This study explored the effectiveness of MRI intervention in children facilitated by educational play therapists.

Methods: The interference was directed in a practice MRI unit devoid of magnets. Data were obtained and analyzed according to age, gender, times of scans, position in bore, diagnostic scans, and movement artifacts.

Results: 291 children, ages ranging from 3 years seven months to 17 years, of which 48.8% were mal, d. 74.9% of the children were considered a pass at practice, 35 (12 %) were concluded as borderline pass, and statistically, 218 (96%) went onto a clinical MRI and diagnostic images were obtained from them.

Conclusion: In conclusion, MRI intervention facilitated by educational play therapists helps children cope with MRI without general anesthesia.

Table 12: Leanne 2008

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group	no	Not possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis	no	not stated
4	Were outputs evaluated blinded to the treatment allocation?	no	
5	Were control and experimental groups comparable in the beginning	no	The age group was well defined
6	Were groups treated the same without using another intervention for one of the groups?	yes	MRI, therapists
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?	yes	Epi data and Stata were used

8 - Magnetic resonance to assess the aortic valve area in aortic stenosis: how does it compare to current diagnostic standards?

This randomized study was compiled in 2003 by John S. L and others, and it is the oldest on the list. It is part of this thesis as it has information about the main topic of this work. It compares magnetic resonance to other diagnostic methods when it comes to the assessment of the severity of aortic stenosis.

Method: Forty patients underwent cardiac catheterization, TEE, and MR. The AVA was estimated by direct planimetry (MR, TEE) or calculated indirectly via the peak systolic transvalvular gradient (catheter). Pressure gradients from cardiac catheterization and Doppler echocardiography were compared too.

Results: from MR, the average AVA (max) calculated was 0.91 +/- 0.25 cm (2); by TEE, AVA (max) was 0.89 +/- 0.28 cm (2); and by catheter, the AVA was calculated as 0.64 +/- 0.26 cm (2). Mean absolute differences in AVA were 0.02 cm (2) for MR versus TEE, 0.27 cm (2) for MR versus catheter, and 0.25 cm (2) for TEE versus catheter. Correlations for AVA (max) were r = 0.96 between MR and TEE, r = 0.47 between TEE and catheter, and r = 0.44 between MR and catheter. The correlation between Doppler and catheter gradients happened to be r = 0.71.

Conclusion: MR planimetry of the AVA can provide a precise, non-invasive, well-endured alternative to invasive techniques and transthoracic echocardiography when it comes to the evaluation of aortic stenosis

Table 13: John 2003

		results	comments
1.	Did the treatment allocation blind participant?	yes	
2.	Did the researcher blind the treatment allocation group	no	
3	Was the output of the participants who withdrew from the research, explained, and included in the analysis		Not well defined
4	Were outputs evaluated blinded to the treatment allocation?	no	
5	Were control and experimental groups comparable in the beginning	no	
6	Were groups treated the same without using another intervention for one of the groups?	no	
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?	yes	

9 - Surgical mitral valve replacement using direct implantation of Sapien 3 valve in a patient with severe mitral annular calcification without adjunctive techniques, a case report.

This randomized study was compiled in 2020 by Albecker TB and others, and it is one of the latest studies on the list.

Method: An elderly female patient with multiple diseases who showed symptoms and signs of heart failure who happens to have a previous history of mechanical aortic valve replacement 15 years before the presentation was studied.

Results: the older woman had more health issues such as diabetes mellitus, hypertension, hypothyroidism, adrenal suppression, and a previous history of stroke. These health complications made it high risky for surgical intervention with a calculated STS risk score of (19.5%). Given her age health issues, it made no sense to decalcify the mitral annulus and reconstruct the annulus, leading to a high risk of atrioventricular groove disruption. Sapien 3 valve was implanted in the mitral position under direct vision after redo sternotomy. Mitral annular calcification (MAC) develops in 10% of the population with an alarming prevalence with advancing age (up to 40% above 80 years), and it is associated independently with all-cause mortality.

Conclusion: Direct open surgical implantation of Sapien 3 valve can be safely implanted in patients with severe MAC without complication and without other adjunctive techniques such as fixation sutures or patches.

Table 14: Albecker 2020

		results	comments
1	Did the treatment allocation blind participant?	yes	
2	Did the researcher blind the treatment allocation group	no	Not possible
3	Was the output of the participants who withdrew from the research explained, and included in the analysis		undefined
4	Were outputs evaluated blinded to the treatment allocation?	no	Not possible
5	Were control and experimental groups comparable in the beginning	no	The comparison was done later
6	Were the group treated the same without using another intervention for one of the groups?	yes	Severe MR and AS
7	Were the results/outputs measured in the same way in all groups?	yes	
8	Were the results/outputs measured reliably?	yes	
9	Was statistical analysis used appropriately?	yes	

10 - Valvular heart disease in women, differential remodeling, and response to new therapies.

This study was compiled in 2017 by Chandrasekhar and others. This review discusses the current evidence in the diagnosis and treatment of VHD in left-sided VHD and management in women.

Method: Patients with VHD, especially the most common AS and MR, were evaluated in this study. Women tend to be more prone to VHD; that is why the study focuses on women, and age was put in consideration. Different studies with a different number of patients were used for comparison.

Results: Aortic stenosis is the most common VHD, and it occurs in 2–9% of the population mainly in people older than 65 years of age. 50% of patients with severe AS may be asymptomatic, with a 1.0–1.5% yearly rate of sudden cardiac death. MR is the second most common VHD, and it has a prevalence of 2–3% in the general population. Calcification of the mitral valve mostly happens in women, and it increases with age. CHD (41.8%) and VHD (30.9%) are heart diseases present in pregnancy, and then cardiomyopathy (20%) and pulmonary hypertension (12%). Aortic and mitral valve diseases happen to be the most common.

Results: VHD, most specifically AS and MR, are increasingly observed to be of a degenerative etiology. Women tend to have latent symptoms, consequently it is relevant to consider both clinical symptoms and imaging findings for decision-making on treatment. In addition, almost 50% of patients undergoing transcatheter aortic valve replacement (TAVR) are women. Echo is still the standard diagnosis test while CT and MRI are being used to provide the valve classification and function. Relevantly, MRI allows recognition of different patterns of hypertrophy and remodeling, magnitude of LV fibrosis, and understanding into differential reverse remodeling and clinical outcomes in men and women.

Table 15: Chandrasekhar 2017

		results	comments
1	Were participant blinded by the treatment allocation?	yes	
2	Was the treatment allocation group blinded by the researcher	no	Not possible
3	Was the output of the participants who withdrew from the research, explained, and included in the analysis		undefined
4	Were outputs evaluated blinded to treatment allocation?	no	Not possible
5	Were control and experimental groups comparable in the beginning	no	Sex specific threshold
6	Were group treated the same without using another intervention for one of the groups?	no	Primarily focus on women but not limited to men
7	Were the results/outputs measured in the same way in all groups?	yes	AVA, AVC
8	Were the results/outputs measured in a reliable way?	yes	
9	Was statistical analysis used appropriately?	yes	

3.1.2 Diagnostic testing techniques

Magnetic resonance imaging (MRI) is a method that has evolved rapidly during the past 20 years, yielding MR systems with stronger static magnetic fields, faster and stronger gradient magnetic fields, and more powerful radiofrequency transmission coils (Dill, 2008). Cardiac magnetic resonance imaging (CMR) has become a crucial imaging technique for the diagnosis and treatment of patients with cardiovascular diseases (Hombach et al., 2010). The CMR has the capability of acquiring tomographic images of the hypertrophied LV chamber, with tissue contrast and border definition that are often superior to that achievable with echocardiography (Rickers et al., 2005).

Furthermore, CMR is vital for detecting and reliably measuring the anatomic valve area (Maganti et al., 2010). Technical advances in the past have rendered CMR unique in the evaluation of cardiovascular anatomy, physiology, and pathophysiology due to its unique ability to produce high resolution tomographic images of the human heart and vessels (Hombach et al., 2010) in any arbitrary orientation, with soft tissue contrast that is superior to competing imaging modalities without the use of ionizing radiation. Cardiac magnetic resonance imaging has the potential to detect segmental wall thickening in any area of the LV wall, even when these regions are quite limited in size, and therefore can provide critical supplemental morphological information beyond that obtained from conventional and clinically adequate echocardiographic studies (Maron et al., 2003).

In comparison to echocardiography, MRI is mainly user independent and does not substantially suffer from variations in image quality and poor patient-related echogenicity. The high blood-tissue contrast particularly when using the steady-state free precession (SSFP) techniques, and the capability of three-dimensional (3D) reconstruction of cardiac and vascular structures (Markl et al., 2004).

Velocity encoded CMR is currently being investigated for the assessment of velocity across the stenotic aortic valves. As with cardiac CT, the role of this modality in the management of AS is currently not well defined (Kilner et al., 1993) but it has an established role in evaluating aortic root and ascending aortic anatomy. Although cine CMR is not as well validated as echocardiography, it can be useful for detecting progressive left ventricular dilatation and for planning the timing of surgery for asymptomatic patients with severe aortic regurgitation. Cardiac magnetic resonance is used to obtain accurate information regarding regurgitant volumes and flow (Helbing and De Roos, 2000).

Velocity-encoded imaging is another useful technique that allows quantification of both forward and regurgitant flow (Roes et al., 2009). Maganti et al. (2010) postulates that exercise testing is useful as a measure of functional capacity when it is unclear whether symptoms are present. However, exercise left ventricular ejection fraction is often abnormal in asymptomatic patients with severe aortic regurgitation and has not been shown to provide additional prognostic information when resting left ventricular size and function are already known (Borer et al., 1998).

The use of standard imaging sequences, cardiac magnetic resonance allows identifying accurately serial changes in ventricular volumes, mass, and function reflecting the global burden of valvular disease and has, the potential to contribute to determining the optimal time for surgical or transcatheter valvular intervention (Cawley et al., 2009).

3.1.2 Safety issues surrounding the use MRI

MRI is often described as a ‘‘safe’’ modality due to the fact that, unlike x-ray-based systems, ionizing radiation is not involved. Despite prosthetic heart valves and annuloplasty rings are made from a variety of materials, numerous studies have demonstrated that MRI examinations can be carried out successfully without any concerns (Prasad and Pennell, 2004). However, hazards inherent such as strong static magnetic fields, pulsed gradient magnetic fields and pulsed radiofrequency fields to the MR environment must be acknowledged:

3.1.3 Accuracy and reproducibility

Ideally, for any diagnostic test to be clinically useful, it must be accurate and reproducible. Accuracy can be determined by matching measurements obtained by the technique or modality in question with those obtained by a reference standard. Accuracy determines how close to the truth a measurement is. Reproducibility addresses measurement variability, which can relate to the individuals performing the measurement (intra- and inter-observer variability) and the variability related to repeated measurements (test–retest or interstudy variability). Reproducibility is especially crucial for tests that are being used for clinical surveillance over a period of time, as is the case in serial follow-up of the RV in patients with CHD (Geva, 2014).

3.1.4 MRI in Pregnant women

During pregnancy, anatomical and physiological changes occur. Complications such as valvular heart disease, and pregnancy-associated cardiovascular changes can contribute to maternal, foetal, and neonatal complications in pregnant women (Stout and Otto, 2007). Imaging studies are important in diagnostic evaluations of acute and chronic conditions. For instance, according to Birchard et al. (2005) acute abdominal pain in pregnant patients presents a difficult diagnostic challenge. The differential diagnosis during pregnancy is extensive in that the abdominal pain may be obstetric in nature or may be caused by disease of other intraabdominal or intrapelvic structures. The use of X-ray, ultrasonography, CT, nuclear medicine, and MRI has become so embedded in the culture of medicine and their applications are so diverse, that women with recognized or unrecognized pregnancies are likely to be evaluated with any of these techniques (Kruskal, 2017). However, the use of conventional radiographic imaging is constrained because of the risk of harm to the foetus by ionizing radiation. Using CT is well recognized in the evaluation of acute abdominal pain. CT provides excellent anatomic detail; however, a considerable dose of ionizing radiation is conferred to the foetus, making this technique undesirable (Birchard et al., 2005).

MRI offers a good overall topographic display and high intrinsic soft-tissue contrast. MRI also benefits from the lack of ionizing radiation (Barber-Millet et al., 2016), making it safe to use in pregnant patients. Although several prior reports have shown the ability of MRI to evaluate the foetus using current short-duration sequences (Nguyen et al., 2016), there are fewer reports describing the investigation of maternal abdominal and pelvic disease on MRI. The main advantage of MRI over ultrasonography and computed tomography lies in the ability to image deep soft tissue structures in a manner that is not operator dependent and does not use ionizing radiation. Magnetic resonance imaging is like ultrasonography in the diagnosis of appendicitis, but when MRI is readily available, it is preferred because of its lower rates of non-visualization. Although there are theoretical concerns for the foetus, including teratogenesis, tissue heating, and acoustic damage, there exists no actual harm (Kruskal, 2017).

Unlike CT, MRI sufficiently images most soft tissue structures without the use of contrast. However, there are diagnostic situations in which contrast enhancement is of benefit. According to (Kruskal, 2017), there are two types of MRI available. Gadolinium-based agents and super magnetic iron oxide particles. Gadolinium-based agents are useful in imaging the nervous system because they cross the blood-brain barrier when this barrier has been disrupted, such as in the presence of a tumour and an abscess. Even though it can increase the specificity of MRI, the use of gadolinium-based contrast enhancement during pregnancy is controversial. Uncertainty surrounds the risk of possible effects because gadolinium is water-soluble and can cross the placenta into the foetal circulation and amniotic fluid.

A retrospective evaluation was made of 66 pregnancies in 64 women with VHD conducted by Hameed et al. (2001) revealed that women with VHD had a significantly higher incidence of congestive heart failure (38% vs. 0%; $p < 0.00001$), arrhythmias (15% vs. 0%, $p = 0.002$), initiation or increase of cardiac medications (41% vs. 2%, $p < 0.0001$), and hospitalizations (35% vs. 2%, $p < 0.0001$). Mortality, however, occurred in only one patient (2% vs. 0%, p = NS) with aortic stenosis (AS) and coarctation. Moreover, VHD also influenced foetal outcome, resulting in an increased preterm delivery (23% vs. 6%, $p = 0.03$), intrauterine growth retardation (21% vs. 0%, $p < 0.0001$), and a reduced birth weight (2897 ± 838 g vs. 3366 ± 515 g, $p = 0.0003$). Increased maternal morbidity and unfavourable foetal outcome were seen mostly in patients with moderate and severe mitral stenosis (MS) and AS.

The most common cause of mitral stenosis is rheumatic valvular disease, which is often first diagnosed during pregnancy. In pregnant women with mitral stenosis, the increase in cardiac output combined with a decrease in filling time due to increased heart rate can result in increased left atrial pressures and pulmonary oedema. Even in women who were previously asymptomatic, further shortening of the diastolic filling period owing to atrial fibrillation or comorbid conditions that further increase heart rate, such as anaemia or fever, often causes haemodynamic decompensation (Stout and Otto, 2007).

Severe aortic stenosis may be difficult to manage during pregnancy. Certainly, all women with symptomatic aortic stenosis should undergo prompt intervention before pregnancy. Most asymptomatic patients tolerate pregnancy well, but a minority develop symptoms of heart failure, angina or syncope.

Pulmonic stenosis may occur in isolation or as a part of other congenital abnormalities such as tetralogy of Fallot. Pulmonary stenosis is generally well-tolerated in the absence of other haemodynamically significant lesions. It is also amenable to percutaneous valvuloplasty if necessary.

Patients with chronic left-sided valve regurgitation often do well during pregnancy due to the decrease in afterload but have trouble during labor, delivery, and the early postpartum period due to the increase in both venous return and vascular resistance. In the peripartum period, diuresis may be needed, and afterload reduction may be helpful in the first 24–48 h post-partum (Stout and Otto, 2007).

3.1.5 Magnetic resonance imaging in children

Magnetic resonance imaging (MRI) is a common investigation used in medical imaging requiring patients, including young children, to keep still for up to 60 min for the study to be performed successfully. Children often find the confined space, the noise, the need to lie still, and the possibility of needle insertion for intravenous contrast agent administration anxiety-provoking and sometimes so distressing that they are unable to cope and require general anesthesia (Tyc et al., 1995).

General anesthesia or sedation is sometimes used in young children, often routinely in children younger than 6– 8 years old (Lawson, 2000) to manage the MRI procedure and enable MRI technicians to achieve diagnostic quality scans effectively. Sedation levels for MRI can put the child at risk of respiratory depression with over-sedation, potentially resulting in the loss of protective reflexes and the ability to maintain an airway (Malviya et al., 2000).

An ideal practice MRI intervention (PMRI) session conducted by an educational play therapist (EPT) gives children who are about to undergo MRI the opportunity to develop the skills required to complete a scan successfully. The practice unit is a full-scale 1.5-T MRI unit that is devoid of magnets. The child experiences the scanning environment with the help of an EPT. The child has the opportunity to enter the PMRI unit in the same way they will in the clinical MRI unit, to lie on the gantry, to see and use a coil that will be part of their scan, and to hear the sounds of the unit (Malviya et al., 2000). Specific skills to enhance coping can be practiced, such as relaxation, controlled breathing, and guided imagery. Furthermore, specific requirements for the MRI would be taught and rehearsed such as breath-holds. Coping strategies for intravenous cannulation and intravenous administration of contrast agents during the scan can also be developed (Hallowell et al., 2008).

Findings by Hallowell et al. (2008) illustrate that of the 291 children who underwent a PMRI, 218 (74.9%) passed, and 227 (78%) went on to clinical MRI without GA. Of these 227 children, 198 (87.2%) had passed a practice MRI, 1 (0.4%) had failed and 28 (12.3%) had bee

3.1.6 FETAL DIAGNOSIS

Ongoing developments in prenatal imaging include advances in echocardiography that have improved rates of foetal diagnosis of CHD. Quartermain et al. (2015) reported that the rate of foetal diagnosis has increased in neonates and infants, particularly less than 6 months who need to undergo surgical intervention (26% in 2006 to 42% in 2012). Moreover, children who require operative intervention as neonates have drastically increased rates of prenatal diagnosis compared with those who had operative interventions as infants, 43.2% versus 23.9%, respectively. Often, the view comprises atrioventricular septal defects, large ventricular septal defects, hypoplastic left heart syndrome (HLHS), critical aortic stenosis, severe coarctation of the aorta, tricuspid atresia, pulmonary atresia with intact ventricular septum, Ebstein anomaly of the tricuspid valve (TV), and double inlet left or right ventricle (Hunter and Simpson, 2014).

Foetal CHD diagnosis brings out the likelihood of foetal interventions, which could improve subsequent cardiac function. Moreover, lesions with the greatest potential benefit from foetal interventions are foetal arrhythmias, severe aortic or pulmonary stenosis (Holst et al., 2017). As observed the largest experience with foetal interventions is often the balloon dilation of the AV in foetuses, with critical aortic stenosis and additional features of left heart hypoplasia (Freud et al., 2014).

Findings by Freud et al. (2014) reported that the initial attempt at foetal aortic valvuloplasty in 100 patients with critical aortic stenosis was successful in 77 patients at a median gestational age of 23.8 weeks. However, of the 77 successful aortic valvuloplasty, 45% were able to undergo a biventricular repair rather than single ventricular pathway. Moreover, enhancements in survival in CHD and survival of 80-95% of children born with a congenital cardiac lesion surviving to adulthood have resulted in an increase in the incidence of reoperation in CHD and operation on adults with CHD (Fuller et al., 2015).

Computed tomography and MRI imaging are particularly valuable in the preoperative evaluation of patients with a previous cardiac operation because of the superior visualization of anatomic structures in proximity to the sternum (Said and Dearani, 2014). During reoperations for CHD, the aorta and extracardiac conduits are at the greatest risk of injury on re-entry. Moreover, other structures at risk could include the innominate vein, the right atrium, or RV depending on the primary diagnosis (Holst et al., 2011).

4 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Cardiovascular magnetic resonance (CMR) has become a valuable investigative tool in the field of cardiac medicine. Its value in heart valve disease is well appreciated, particularly as echocardiography is a powerful and widely available technique in valve disease. Studies report that CMR is presently the best diagnostic modality for the assessment of RV size and function in patients with CHD. Furthermore, an increase in literature informs clinicians on how to use CMR data to monitor patients in a manageable manner.

This thesis highlights the added value that CMR can bring in valve disease, complementing echocardiography in many areas, but it has also become the first-line investigation in some, such as pulmonary valve disease.

CMR has many advantages, including the ability to image in any plane, which allows full visualization of valves and their inflow or outflow tracts, direct measurement of valve area (particularly for stenotic valves), and characterization of the associated great vessel anatomy such as the aortic root and arch in aortic valve disease. Albeit, the increase of MRI uses as an imaging modality in many fields of medicine; careful patient screening before the examination and accurate evaluation of the individual risk is still cautioned. This enhances the success of the MRI technique, around the globe.

4.2 Recommendations

The current study recommends a field examination of patients living with heart valvular diseases to be used in studies in the future.

Moreover, a survey was implored to assess the aftereffects of the use of the MRI technique, several years later.

5. BIBLIOGRAPHY

5.1 Primary source

1. Columbia Doctors. (2018). Heart Valves, Anatomy and Function. Columbia Doctors - New York. [online]. [cit. 22 Apr. 2021]. Available from: https://www.columbiadoctors.org/condition/heart-valves-anatomy-and-function

2. GARCIA, J. et al. Cardiovascular magnetic resonance evaluation of aortic stenosis severity using single plane measurement of effective orifice area. Journal of Cardiovascular Magnetic Resonance. *Biomedcentral* [online]. 2012, 14(1), pp.1-12. [cit. 2022-02-20]. ISSN: 1532-429X. Available from: https://doi.org/10.1186/1532-429X-14-23

3. GIUNTA, C.J. and MAINZ, V.V. Discovery of nuclear magnetic resonance: Rabi, Purcell, and Bloch. STROM E-T a V-V MAINZ, *Pioneers of Magnetic Resonance* [online]. Washington: ACS Publishing Center, 2020, pp 3-20 [cit. 2022-02-20]. ISBN: 9780841237100. Available from: ACS Symposium Series (ACS Publications)

4. Gulsin, G.S. McCann, G.P. and Singh, A., (2017). Cardiovascular magnetic resonance in the evaluation of heart valve disease. BMC Med Imaging. [online]. London: BioMed Central, 17(1), 67 [cit 22 Apr. 2021]. ISSN: 1471-2342. doi: 10.1186/s12880-017-0238-0

5. LOPEZ-MATTEI C Juan, SHAH J Dipan (2013). The Role of Cardiac Magnetic Resonance in Valvular Heart Disease. Methodist DeBakey Cardiovascular Journal [online]. Houston, TX: Methodist DeBakey Heart & Vascular Center., 9(3), 142–148. [cit 22 Apr. 2021]. ISSN:1947-6108. DOI: 10.14797/mdcj-9-3-142a

5.2 Secondary source

6. BONOW, R.O., MANN, D.L., ZIPES, D.P. AND LIBBY, P, 2011. *Braunwald's heart disease e-book: A textbook of cardiovascular medicine*. Elsevier Health Sciences. Philadelphia, PA: Elsevier Saunders. 1961pp. ISBN 978-0-8089-2436-4

7. BRANT, W.E. and HELMS, C.A, 2012. *Fundamentals of diagnostic radiology*. Philadelphia: Lippincott Williams and Wilkins. 692pp. ISBN 978-1-60831-911-4.

8. Galderisi, M., Cardim, N., d'Andrea, A., Bruder, O., Cosyns, B., Davin, L., Donal, E., Edvardsen, T., Freitas, A., Habib, G. and Kitsiou, A., 2015. The multi-modality cardiac imaging approach to the Athlete's heart: an expert consensus of the European Association of Cardiovascular Imaging. *European Heart Journal-Cardiovascular Imaging*, *16*(4), pp.353-353r. [cit. 2022-02-22]. available at: https://doi.org/10.1093/ehjci/jeu323

9. Giunta, C.J. and Mainz, V.V., 2020. Discovery of nuclear magnetic resonance: Rabi, Purcell, and Bloch. In *Pioneers of Magnetic Resonance* (pp. 3-20). American Chemical Society. Available at: https://pubs.acs.org/doi/abs/10.1021/bk-2020-1349.ch001

10. Saikrishnan, N., Mirabella, L. and Yoganathan, A.P., 2015. Bicuspid aortic valves are associated with increased wall and turbulence shear stress levels compared to tri-leaflet aortic valves. *Biomechanics and modeling in mechanobiology*, *14*(3), pp.577-588. DOI 10.1007/s10237-014-0623-3

11. LILLY, L.S., 2020. *Pathophysiology of heart disease:* Philadelphia. Wolters Kluwer health. 420pp. ISBN 9781975152178.

12. Sommer, G., Bremerich, J., & Lund, G. (2012). Magnetic resonance imaging in valvular heart disease: clinical application and current role for patient management. *Journal of Magnetic Resonance Imaging*, *35*(6), 1241-1252. Available at: https://onlinelibrary.wiley.com/doi/pdf/10.1002/jmri.23544

5.3 Internet resource

13. AlGhatrif, M. and Lindsay, J. (2012). A brief review: history to understand fundamentals of electrocardiography. *Journal of community hospital internal medicine perspectives*, *2*(1), 14383. Available at: https://doi.org/10.3402/jchimp.v2i1.14383

14. Andell, P., Li, X., Martinsson, A., Andersson, C., Stagmo, M., Zöller, B., Sundquist, K. and Smith, J.G., 2017. Epidemiology of valvular heart disease in a Swedish nationwide hospital-based register study. *Heart*, *103*(21), pp.1696-1703. http://dx.doi.org/10.1136/heartjnl-2016-310894

15. Aurigemma, G.P., Zile, M.R. and Gaasch, W.H., 2006. Contractile behavior of the left ventricle in diastolic heart failure: with emphasis on regional systolic function. *Circulation*, *113*(2), pp.296-304. https://www.ahajournals.org/doi/full/10.1161/CIRCULATIONAHA.104.481465

16. Baumgartner, H., Hung, J., Bermejo, J., Chambers, J.B., Evangelista, A., Griffin, B.P., Iung, B., Otto, C.M., Pellikka, P.A. and Quiñones, M., 2009. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. *Journal of the American Society of Echocardiography*, *22*(1), pp.1-23.

17. Bekeredjian, R. and Grayburn, P.A., 2005. Valvular heart disease: aortic regurgitation. *Circulation*, *112*(1), pp.125-134. Available at: https://doi.org/10.1161/CIRCULATIONAHA.104.488825

18. Birchard, K. R., Brown, M. A., Hyslop, W. B., Firat, Z., & Semelka, R. C. (2005). MRI of acute abdominal and pelvic pain in pregnant patients. *AJR Am J Roentgenol*, *184*(2), 452-458. https://www.researchgate.net/profile/Jodi-Abbott/publication/8330277_MRI_of_Right-Sided_Abdominal_Pain_in_Pregnancy/links/5876dfa608ae329d62260faf/MRI-of-Right-Sided-Abdominal-Pain-in-Pregnancy.pdf

19. Borer, J.S., Hochreiter, C., Herrold, E.M., Supino, P., Aschermann, M., Wencker, D., Devereux, R.B., Roman, M.J., Szulc, M., Kligfield, P. and Isom, O.W., 1998. Prediction of indications for valve replacement among asymptomatic or minimally symptomatic patients

with chronic aortic regurgitation and normal left ventricular performance. *Circulation*, *97*(6), pp.525-534. https://www.ahajournals.org/doi/full/10.1161/01.CIR.97.6.525

20. Bosi, G.M., Capelli, C., Cheang, M.H., Delahunty, N., Mullen, M., Taylor, A.M. and Schievano, S., 2018. Population-specific material properties of the implantation site for transcatheter aortic valve replacement finite element simulations. *Journal of biomechanics*, *71*, pp.236-244. https://www.sciencedirect.com/science/article/pii/S0021929018301143

21. Brickner, M.E., 2014. Cardiovascular management in pregnancy: congenital heart disease. *Circulation*, *130*(3), pp.273-282. https://www.ahajournals.org/doi/full/10.1161/CIRCULATIONAHA.113.002105

22. Cantatore, A. and Müller, P. (2011). Introduction to computed tomography. *Kgs. Lyngby: DTU Mechanical Engineering*. Available at: https://backend.orbit.dtu.dk/ws/portalfiles/portal/51297792/Introduction_to_CT.pdf

23. Carapetis, J.R., Beaton, A., Cunningham, M.W., Guilherme, L., Karthikeyan, G., Mayosi, B.M., Sable, C., Steer, A., Wilson, N., Wyber, R. and Zühlke, L., 2016. Acute rheumatic fever and rheumatic heart disease. *Nature reviews Disease primers*, *2*(1), pp.1-24. Available at: https://www.nature.com/articles/nrdp201584

24. Cawley, P.J., Maki, J.H. and Otto, C.M., 2009. Cardiovascular magnetic resonance imaging for valvular heart disease: technique and validation. *Circulation*, *119*(3), pp.468-478.

25. Čelutkienė, J., Lainscak, M., Anderson, L., Gayat, E., Grapsa, J., Harjola, V.P., Manka, R., Nihoyannopoulos, P., Filardi, P.P., Vrettou, R. and Anker, S.D., 2020. Imaging in patients with suspected acute heart failure: timeline approach position statement on behalf of the Heart Failure Association of the European Society of Cardiology. *European journal of heart failure*, *22*(2), pp.181-195.

26. Chandrasekhar, J., Dangas, G. and Mehran, R., 2017. Valvular heart disease in women, differential remodeling, and response to new therapies. *Current Treatment Options in Cardiovascular Medicine*, *19*(9), pp.1-21. https://doi.org/10.1007/s11936-017-0573-z

27. Cheung, D.Y., Duan, B. and Butcher, J.T., 2015. Current progress in tissue engineering of heart valves: multiscale problems, multiscale solutions. *Expert opinion on biological*

therapy, *15*(8), pp.1155-1172. Available at: https://www.tandfonline.com/doi/abs/10.1517/14712598.2015.1051527

28. Dill, T., 2008. Contraindications to magnetic resonance imaging. *Heart*, *94*(7), pp.943-948. Doi: 10.1136/hrt.2005.067975 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1955531/

29. El-Shahed, M., 2003, January. Fractional calculus model of the semilunar heart valve vibrations. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 37033, pp. 711-714). Available at: https://doi.org/10.1115/DETC2003/VIB-48384

30. Frank, J.E. and Jacobe, K.M., 2011. Evaluation and management of heart murmurs in children. *American family physician*, *84*(7), pp.793-800.

31. Fujii, T., Hasegawa, M., Miyamoto, J. and Ikari, Y., 2019. Differences in initial electrocardiographic findings between ST-elevation myocardial infarction due to left main trunk and left anterior descending artery lesions. *International journal of emergency medicine*, *12*(1), pp.1-10.

32. Fuller, S.M., He, X., Jacobs, J.P., Pasquali, S.K., Gaynor, J.W., Mascio, C.E., Hill, K.D., Jacobs, M.L. and Kim, Y.Y., 2015. Estimating mortality risk for adult congenital heart surgery: an analysis of the society of thoracic surgeons congenital heart surgery database. *The Annals of Thoracic Surgery*, *100*(5), pp.1728-1736.

33. Garcia, J., Marrufo, O.R., Rodriguez, A.O., Larose, E., Pibarot, P. and Kadem, L., 2012. Cardiovascular magnetic resonance evaluation of aortic stenosis severity using single plane measurement of effective orifice area. *Journal of Cardiovascular Magnetic Resonance*, *14*(1), pp.1-12. Available at: https://jcmr-online.biomedcentral.com/articles/10.1186/1532-429X-14-23

34. Goldstein, S.A., Evangelista, A., Abbara, S., Arai, A., Asch, F.M., Badano, L.P., Bolen, M.A., Connolly, H.M., Cuéllar-Calàbria, H., Czerny, M. and Devereux, R.B., 2015. Multimodality imaging of diseases of the thoracic aorta in adults: from the American Society of Echocardiography and the European Association of Cardiovascular Imaging: endorsed by the Society of Cardiovascular Computed Tomography and Society for Cardiovascular Magnetic Resonance. *Journal of the American Society of Echocardiography*, *28*(2), pp.119-182. Available at: https://www.researchgate.net/publication/43183323_Validation_of_an_echo-

35. Gottdiener, J.S., Bednarz, J., Devereux, R., Gardin, J., Klein, A., Manning, W.J., Morehead, A., Kitzman, D., Oh, J., Quinones, M. and Schiller, N.B., 2004. American Society of Echocardiography recommendations for use of echocardiography in clinical trials: a report from the american society of echocardiography's guidelines and standards committee and the task force on echocardiography in clinical trials. *Journal of the American Society of Echocardiography*, *17*(10), pp.1086-1119. Available at: https://www.onlinejase.com/article/S0894-7317(04)00675-3/abstract

36. Govoni, A.F., 2003. Diagnostic Radiology; A Textbook of Medical Imaging-Donald G. Grainger, David Allison, Andreas Adam, Adrian D. Dixon (Editors), London, UK: Churchill Livingstone, imprint of Harcourt Publishers 2001, Vol. 1: 973 pages, 1145 illustrations; Vol. 2: 800 pages, 1044 illustrations; Vol. 3: 849 pages, 1317 illustrations. *Clinical Imaging*, *2*(27), pp.141-142. ISBN 978-0-7020-4295-9

37. Guy, T. S. and Hill, A. C., 2012. Mitral valve prolapse. *Annual review of medicine*, *63*, 277-292.available at: https://www.annualreviews.org/doi/abs/10.1146/annurev-med-022811-091602

38. Hallowell, L.M., Stewart, S.E., de Amorim e Silva, C.T. and Ditchfield, M.R., 2008. Reviewing the process of preparing children for MRI. *Pediatric radiology*, *38*(3), pp.271-279.

39. Hameed, A., Karaalp, I.S., Tummala, P.P., Wani, O.R., Canetti, M., Akhter, M.W., Goodwin, M., Zapadinsky, N. and Elkayam, U., 2001. The effect of valvular heart disease on maternal and fetal outcome of pregnancy. *Journal of the American College of Cardiology*, *37*(3), pp.893-899. https://doi.org/10.1016/S0735-1097(00)01198-0

40. Helbing, W.A. and De Roos, A., 2000. Clinical applications of cardiac magnetic resonance imaging after repair of tetralogy of Fallot. *Pediatric Cardiology*, *21*(1), pp.70-79.

41. Holst, K.A., Said, S.M., Nelson, T.J., Cannon, B.C. and Dearani, J.A., 2017. Current interventional and surgical management of congenital heart disease: specific focus on valvular disease and cardiac arrhythmias. *Circulation research*, *120*(6), pp.1027-1044.

42. Hombach, V., Merkle, N., Bernhardt, P., Rasche, V., and Rottbauer, W. 2010. Prognostic significance of cardiac magnetic resonance imaging: Update 2010. *Cardiology journal*, *17*(6), 549-557. https://journals.viamedica.pl/cardiology_journal/article/view/21302

43. Iung, B., Baron, G., Tornos, P., Gohlke-Bärwolf, C., Butchart, E.G. and Vahanian, A., 2007. Valvular heart disease in the community: a European experience. *Current problems in cardiology*, *32*(11), pp.609-661. https://doi.org/10.1016/j.cpcardiol.2007.07.002

44. Jassar, A.S., Levack, M.M., Solorzano, R.D., Pouch, A.M., Ferrari, G., Cheung, A.T., Ferrari, V.A., Gorman III, J.H., Gorman, R.C. and Jackson, B.M., 2014. Feasibility of in vivo human aortic valve modeling using real-time three-dimensional echocardiography. *The Annals of thoracic surgery*, *97*(4), pp.1255-1258. https://www.sciencedirect.com/science/article/abs/pii/S000349751302852X

45. John, A.S., Dill, T., Brandt, R.R., Rau, M., Ricken, W., Bachmann, G. and Hamm, C.W., 2003. Magnetic resonance to assess the aortic valve area in aortic stenosis: how does it compare to current diagnostic standards? *Journal of the American College of Cardiology*, *42*(3), pp.519-526. Available at: https://doi.org/10.1016/S0735-1097(03)00707-1

46. Kilner, P.J., Manzara, C.C., Mohiaddin, R.H., Pennell, D.J., Sutton, M.G., Firmin, D.N., Underwood, S.R. and Longmore, D.B., 1993. Magnetic resonance jet velocity mapping in mitral and aortic valve stenosis. *Circulation*, *87*(4), pp.1239-1248.

47. Kim, Y.S., Kim, E.H., Kim, H.G., Shim, E.B., Song, K.S. and Lim, K.M., 2016. Mathematical analysis of the effects of valvular regurgitation on the pumping efficacy of continuous and pulsatile left ventricular assist devices. *Integrative Medicine Research*, *5*(1), pp.22-29. Available at: https://doi.org/10.1016/j.imr.2016.01.001

48. Kolibash, A.J., 1988. Progression of mitral regurgitation in patients with mitral valve prolapse. *Herz*, *13*(5), pp.309-317. Available at: https://europepmc.org/article/med/3053383

49. Lee, R., Li, S., Rankin, J.S., O'brien, S.M., Gammie, J.S. and Peterson, E.D., 2011. Society of Thoracic Surgeons Adult Cardiac Surgical. *Database*, pp.677-684.

50. Leo, H.L., Dasi, L.P., Carberry, J., Simon, H.A. and Yoganathan, A.P., 2006. Fluid dynamic assessment of three polymeric heart valves using particle image velocimetry. *Annals of biomedical engineering*, *34*(6), pp.936-952.

51. Lilly, L.S., 2012. *Pathophysiology of heart disease: a collaborative project of medical students and faculty*. Lippincott Williams & Wilkins.

52. Ludman, P., Foale, R., Alexander, N. and Nihoyannopoulos, P., 1990. Cross sectional echocardiographic identification of hypoplastic left heart syndrome and differentiation from other causes of right ventricular overload. *Heart*, *63*(6), pp.355-361. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1024521/pdf/brheartj00054-0035.pdf

53. Lyen, S., Wijesuriya, S., Ngan-Soo, E., Mathias, H., Yeong, M., Hamilton, M. and Manghat, N., 2017. Anomalous pulmonary venous drainage: a pictorial essay with a CT focus. *Journal of Congenital Cardiology*, *1*(1), pp.1-13. Available at: https://jcongenitalcardiology.biomedcentral.com/articles/10.1186/s40949-017-0008-4

54. Maganti, K., Rigolin, V.H., Sarano, M.E. and Bonow, R.O., 2010, May. Valvular heart disease: diagnosis and management. In *Mayo Clinic Proceedings* (Vol. 85, No. 5, pp. 483-500). Elsevier. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2861980/

55. Malviya, S., Voepel-Lewis, T., Eldevik, O.P., Rockwell, D.T., Wong, J.H. and Tait, A.R., 2000. Sedation and general anaesthesia in children undergoing MRI and CT: adverse events and outcomes. *British journal of anaesthesia*, *84*(6), pp.743-748.

56. Marijon, E., Mirabel, M., Celermajer, D.S. and Jouven, X., 2012. Rheumatic heart disease. *The Lancet*, *379*(9819), pp.953-964. Available at:

https://eclass.uoa.gr/modules/document/file.php/BIOL231/Seminaria/Rheumatic%20heart%20disease_%CE%93%CE%B1%CF%8A%CF%84%CE%B1%CE%BD%CE%AC%CE%BA%CE%B7.pdf

57. Markl, M., Reeder, S.B., Chan, F.P., Alley, M.T., Herfkens, R.J. and Pelc, N.J., 2004. Steady-state free precession MR imaging: improved myocardial tag persistence and signal-to-noise ratio for analysis of myocardial motion. *Radiology*, *230*(3), pp.852-861.

58. Maron, M.S., Olivotto, I., Betocchi, S., Casey, S.A., Lesser, J.R., Losi, M.A., Cecchi, F. and Maron, B.J., 2003. Effect of left ventricular outflow tract obstruction on clinical outcome in hypertrophic cardiomyopathy. *New England Journal of Medicine*, *348*(4), pp.295-303. DOI: 10.1056/NEJMoa021332

59. McKay, R.G., Pfeffer, M.A., Pasternak, R.C., Markis, J.E., Come, P.C., Nakao, S.H.O.I.C.H.I.R.O., Alderman, J.D., Ferguson, J.J., Safian, R.D. and Grossman, W.I.L.L.I.A.M., 1986. Left ventricular remodeling after myocardial infarction: a corollary to infarct expansion. *Circulation*, *74*(4), pp.693-702. Available at: https://www.ahajournals.org/doi/pdf/10.1161/01.CIR.74.4.693

60. Messika-Zeitoun, D., Aubry, M.C., Detaint, D., Bielak, L.F., Peyser, P.A., Sheedy, P.F., Turner, S.T., Breen, J.F., Scott, C., Tajik, A.J. and Enriquez-Sarano, M., 2004. Evaluation and clinical implications of aortic valve calcification measured by electron-beam computed tomography. *Circulation*, *110*(3), pp.356-362.

61. Myerson, S.G., 2012. Heart valve disease: investigation by cardiovascular magnetic resonance. *Journal of Cardiovascular Magnetic Resonance*, *14*(1), pp.1-23. Available at: https://link.springer.com/article/10.1186/1532-429X-14-7

62. Otto, C.M., 2002. Calcification of bicuspid aortic valves. *Heart*, *88*(4), pp.321-322.

63. Otto, C.M., 2004. Aortic stenosis: even mild disease is significant. *European heart journal*, *25*(3), pp.185-187.

64. Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E. and Chou, R., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery*, *88*, p.105906. Doi: 10.1136/bmj.n71. http://www.prisma-statement.org/

65. Patton, K.T. and Thibodeau, G.A., 2014. *Anthony's Textbook of Anatomy & Physiology-E-Book*. Elsevier Health Sciences. ISBN 978-0-323-09600-3.

66. Peate, I., 2020. The circulatory system. *British Journal of Healthcare Assistants*, *14*(11), pp.548-553. Available at: https://swiflearn.com/wp-content/uploads/2021/01/circulatory-system-converted.pdf

67. Prasad, S.K. and Pennell, D.J., 2004. Safety of cardiovascular magnetic resonance in patients with cardiovascular implants and devices. *Heart*, *90*(11), pp.1241-1244.

68. Roes, S.D., Hammer, S., van der Geest, R.J., Marsan, N.A., Bax, J.J., Lamb, H.J., Reiber, J.H., de Roos, A. and Westenberg, J.J., 2009. Flow assessment through four heart valves simultaneously using 3-dimensional 3-directional velocity-encoded magnetic resonance imaging with retrospective valve tracking in healthy volunteers and patients with valvular regurgitation. *Investigative radiology*, *44*(10), pp.669-675.

69. Saikrishnan, N., Mirabella, L. and Yoganathan, A.P., 2015. Bicuspid aortic valves are associated with increased wall and turbulence shear stress levels compared to tri-leaflet aortic valves. *Biomechanics and modeling in mechanobiology*, *14*(3), pp.577-588.

70. Shellock, F.G. and Crues, J.V., 2004. MR procedures: biologic effects, safety, and patient care. *Radiology*, *232*(3), pp.635-652.

71. Sommer, G., Bremerich, J., & Lund, G. (2012). Magnetic resonance imaging in valvular heart disease: clinical application and current role for patient management. *Journal of*

Magnetic Resonance Imaging, *35*(6), 1241-1252. https://onlinelibrary.wiley.com/doi/pdf/10.1002/jmri.23544

72. Spouse, E. and Gedroyc, W.M., 2000. MRI of the claustrophobic patient: interventionally configured magnets. *The British Journal of Radiology*, *73*(866), pp.146-151.

73. Stewart, B.F., Siscovick, D., Lind, B.K., Gardin, J.M., Gottdiener, J.S., Smith, V.E., Kitzman, D.W., Otto, C.M. and Cardiovascular Health Study 1, 1997. Clinical factors associated with calcific aortic valve disease. *Journal of the American College of Cardiology*, *29*(3), pp.630-634. https://www.jacc.org/doi/abs/10.1016/S0735-1097(96)00563-3

74. Stout, K.K. and Otto, C.M., 2007. Pregnancy in women with valvular heart disease. *Heart*, *93*(5), pp.552-558.

75. Thanassoulis, G., Yip, J.W., Filion, K., Jamorski, M., Webb, G., Siu, S.C. and Therrien, J., 2008. Retrospective study to identify predictors of the presence and rapid progression of aortic dilatation in patients with bicuspid aortic valves. *Nature clinical practice Cardiovascular medicine*, *5*(12), pp.821-828.

76. Tyc, V.L., Fairclough, D., Fletcher, B., Leigh, L. and Mulhern, R.K., 1995. Children's distress during magnetic resonance imaging procedures. *Children's Health Care*, *24*(1), pp.5-19. https://doi.org/10.1207/s15326888chc2401_2

77. Unger, P., Pibarot, P., Tribouilloy, C., Lancellotti, P., Maisano, F., Iung, B., Piérard, L. and European Society of Cardiology Council on Valvular Heart Disease, 2018. Multiple and mixed valvular heart diseases: pathophysiology, imaging, and management. *Circulation: Cardiovascular Imaging*, *11*(8), p.e007862.

78. van den Bosch, H.C., 2018. *Clinical advances in cardiovascular magnetic resonance imaging and angiography* (Doctoral dissertation, Leiden University). Available at: https://scholarlypublications.universiteitleiden.nl/access/item%3A2952053/view

79. Vos, T., Barber, R.M., Bell, B., Bertozzi-Villa, A., Biryukov, S., Bolliger, I., Charlson, F., Davis, A., Degenhardt, L., Dicker, D. and Duan, L., 2015. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The lancet*, *386*(9995), pp.743-800. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4561509/

80. Walmsley, R.O.B.E.R.T. and Monkhouse, W.S., 1988. The heart of the newborn child: an anatomical study based upon transverse serial sections. *Journal of anatomy*, *159*, p.93. available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1262012/pdf/janat00173-0100.pdf

81. Weinhaus, A. J., & Roberts, K. P. (2005). Anatomy of the human heart. In *Handbook of cardiac anatomy, physiology, and devices* (pp. 51-79). Humana Press.https://www.hmmcollege.ac.in/uploads/Physiology_of_Heart_-1.pdf