TRENDS IN MITRAL VALVE IMPLANTATION – A BIO MECHANICAL APPLICATION

Golive. MahendraNath[1], Mallikarjun makana[2], Kuna. Eswararao[3]

[1,2,3]*Mechanical Engineering Department,*

Sri Venkateswara College of Engineering and Technology(India)

ABSTRACT

This paper is related to biomechanical application. Where the solution of the problem deals with subjects like finite difference method, finite element method, computational fluid dynamics and fluid structure interaction using computers. This paper gives the biology, mechanics of mitral valve and various methods and materials used to design for mitral valve implantation. In beginning period of artificial mitral valve implantation is done by keeping mechanical heart valves. In this paper latest materials that can used to improve the efficiency and function of artificial mitral valves from mechanical heart valves to tissue engineered heart valves. Analysis of mitral valve implantation can be done by assuming simple shape linear isotropic material subjected to static loads and the degree of accuracy can be improved by complicating the mathematical model using nonlinear isotropic and nonlinear anisotropic material.

Keywords: Bio materials, finite element method, Mitral valves,

I.INTRODUCTION

Heart acts like a mechanical pump in the body. It receives deoxygenated, impure blood from the body pumps to liver. There it oxidises blood and transfers to heart and finally it pumps the oxidized, pure blood to body. Inside the heart transfer of blood takes place between four chambers they are left atrium, left ventricle, right atrium, right ventricle, and passes outside through arteries and veins. The movement of blood in between the chambers and in between heart and outside body parts synchronously facilitated by valves. There are four types of heart valves mainly classified as three tricuspid valve and one bicuspid valve. The bicuspid valve is named as mitral valve. The present work is going to be on mitral valves. In diastolic phase mitral valve opens and blood moves from left atrium to left ventricle, during systolic phase mitral valve closes and the blood pass from ventricle to arota through arotic valve. The natural heart valves fail due to calcification, regurgitation, cavitation and coaptation. When the heart valves are damaged they are generally repaired using angioplasty rings otherwise the replacement of heart valve with mechanical heart valves(MHV) or bio prosthetic heart valves (BHV) is advised. The mechanical heart valve is mainly classified as two types' ball and cage valves and tilting disc valves. MHV's are long durable than BHV's but it causes blood coaptation, regurgitation and cavitation problems. Ball and cage valves are fail due to coaptation and the design of structure. It is in such a way that there is no central flow of blood is allowed which is not a solution. The tilting disc valves are two types and classified as single leaflet and double leaflet valves. Although tilting disc MHV's have better haemodynamic properties than ball and cage ones but it has some disadvantages and advantages. These are long durable and have wear resistant leaflets. There are chances of cavitation, coaptation of blood and main disadvantage is regurgitation of blood. So, for better haemodynamic Properties BHV's are used. BHV's are less durable. The different materials used for bioprosthetic heart valves are discussed in this paper. These materials are assumed as hyperelastic and viscoelastic materials. The recent developments in design and manufacturing of heart valves where using pericardium heartvalves, transcatheter heart valves and tissue engineered heart valves. In this paper a staticand dynamic linear analysis of mitral valve leaflet using ultra high molecular weight polymer (UHMWPE), Poly lactic acid (PLA) a synthetic polymer and bovine pericardium is used on assuming a approximate mitral leaflet model, and a model of a mechanical heart valve to avoid regurgitation, cavitation and coaptation is presented and discussed. Various bio-composite materials for the tilting disc in mechanical heart valve leaflets to obtain better haemodynamic properties in these types of valves are included in this paper.

II. REVIEW ON MITRAL VALVES

2.1 Natural heart valves

In the present world people are suffering from heart valve deseases like mitral stenosis, aortic stenosis, mitral regurgitation, aortic regurgitation. Approximately 2% of the population equally in males and females are suffering from mitral regurgitation [1]. Most common valvular heart disease occur in pregnancy[2]. Approximately 2% of people over the age of 65, 3% of people over age 75, and 4 percent of people over age 85 suffer from aortic stenosis [3]. These heart valve disease mainly cause due to rheumatic fever, calcification of valves, regurgitation of blood and other heart deseases like hypertension,Marfan's syndrome, Cardiomyopathy, endo- carditisetc [4]. This paper states that there are mechanical, bioprosthetic, tissue engineered, and percutaneous heart valves as recent development for implantation. The mechanical valves should be designed to satisfy the thrombogenic properties. Bioprosthetic valves have a drawback of giving less durability but new polymer groups like poly urethane is used for better durability and tissue engineered heart valves doesn't have better source cells to implant[5]. Mechanism of aortic and mitral valve and its various parts are discussed and presented [6]. The topic gives the details of naturally engineered heart valve and biology of aortic valve. The function of valvular endothelial cells and valve interstitial cells are discussed. The main problems of valve calcification like Marfan syndrome, Williams's syndrome, Holt–Oran syndrome, Noonan syndrome etc and other causes for aortic valve diseases are discussed. The six main approaches of tissue engineered aortic valve those are decellularization of aortic valve scaffolds, shaping and seeding of scaffolds made of biodegradable polymers, shaping biological protein hydrogels that have encapsulated cells, hybrid or layered decellularized tissue/polymer scaffolds, in vivo engineered valve shaped tissues, and 3D printing of valves are discussed. Each approach has advantages and limitations which are provided here [7]. New computational models to predict the architecture of the cardiovascular tissue and its reconstitution due to mechanical stimuli is proposed. Remodelling rules using fibre volume fraction, fibre reorientation are discussed. For example the collagens at heart valve tissues and artery tissues are studied [8]. Mechanical behaviours of the extracellular matrix structural proteins, underlying cellular function and their integrated relation to the major aspects of valvular hemodynamic function are discussed [9].

2.2 Finite element modelling of artificial heart valves:

Bioprosthetic valves used in heart valve replacement generally offer functional properties (eg, hemodynamics, resistance to thrombosisthrombosis) that are more similar to those of native valves. Implantation of prosthetic cardiac valves to treat hemodynamically significant aortic or mitral valve disease has become increasingly common [10]. The tissue level mechanism of arotic valves discussed and strain energy functions in terms of invariants are given and the parameters are optimized using experimental data [11]. Finite element models have been proposed using bio-medical images of different patients to observe the mitral valve function and to repair [12].An edge-edge technique is employed to know the structural effects of human mitral valve leaflet. A comparison of structural effects of surgical repair parameters are done [13]. Quasi static leaflet deformations under 40, 80,120mm Hg quasi static pressures are simulated and the results are validated with experimentation [14]. The various geometrical dimensions of aortic valve are given, taking it's functional characteristics as limitation like coaptation area, coaptation height, angle of closed leaflet, height of the commissures, and the angle of leaflet free edge in the open position the valves are designed and 3d model presented. Even though the finite element analysis results are not shown in paper and it mentioned the results are shown in subsequent work [15]. The displacements of Anterior mitral leaflet of a sheep is measured using radiopaque markers and these where used as boundary conditions in a simulated AML finite element model. The resultant stresses and displacements are found to be similar to natural AML of sheep [16].

2.3 Bio-materials used for making mitral valves:

The computational model created using finite element methods is compared with experimental approach of prosthetic tri-leaflet aortic heart valves and polyurethane polymeric leaflets are used in a constitutive material model and fit the experimental data [17]. A new nano composite material POSS-PCU is used to make a synthetic heart valve and its mechanical properties are studied [18]. To avoid the tear and clacification due to use of synthetic heart valves and to reduce stresses in weak areas a fibre reinforced leaflets are developed and the different orientations of the fibres is examined by preparing finite element models[19]. A PVA-BC Nanobiocomposite which mimics with the mechanical properties of a porcine heart valve is introduced. This reduces the tearing and calcification of leaflets and gives better thrombogenic properties [20]. A PVA-BC nano composite material is used to design and simulate a trileaflet aortic valve and the hyper elastic nonlinear mooneyrivlin material model is used as a constitutive model and this model is used for any soft tissue like articular cartilage, tendon and ligament [21].

2.4 Finite element analysis of heart valve leaflets:

A new shell element which extends the modelling capibilities to handle large deformations and anisotropic behaviour is formulated for simulating heart valve leaflet mechanics. A 4 node mixed interpolation shell is used in getting three dimensional stress and strain effects[22]. As the degree of anisotropy and constitutive material model is complex in nature for a heart valve leaflet a new high-order element using p-type finite element formulation is used. Anisotropic material properties of heart valve leaflets are incorporated in the one single element[23]. An incompressible transversely isotropic hyperelastic material is used in solid finite element anlaysis of porcine mitral valve. The results are compared with echocardiographic measurements and with simulated membrane finite element models[24]. Four dilation models of 5%,15%,30%,50% dilation in aortic root, aortic valve are observed. The effect of the dilation in stress, strain and coaptation is stated and concluded that the dilation increases the stress and strain in the leaflet[25].

2.5 Percutaneous, tissue engineered and transcatheter heart valves:

Bioprosthetic heart valve using bovine pericardium is analysed using finite element method and the stresses are found using nonlinear anisotropic properties [26]. This paper showed that collagen fibres will reduce in stresses during systole in aortic valves. Previous papers investigated that collagen fibres reduce in stresses during diastole [27]. This paper shows the results came from dynamic analysis of aortic valve at organ level, the finite element analysis of simplified versions of aortic valve i.e at tissue level and finally at organ level taking different referenced configurations of leaflet. Where these are useful for further understanding of aortic valve mechanics under multi scale approach [28]. Hydrodynamic and fatigue testing of polymer trileaflet valves is done using different stress-cycle curves the trileaflet valve is analysed using fiite element method[29]. A bileaflet valve is tested for both thrombogenic and cavitation potential during fluid flow. The properties are analysed by coupling left ventricular contraction and the computational fluid dynamics representation of fluid structure interaction. Platelet reactions considering the wall shear stress is also studied [30]. Tissue engineering and regeneration of cells are important in tissue engineering and latest enhanced cellular/tissue functions and regenerative outcomes are discussed[31]

2.6 Fluid structure interaction applied for cardiovascular systems:

Coronary heart desease is a problem caused due to atheroma build up in the inner vessel of artery and cause narrowing of blood flow. When normal stents are used they cause in-stent-restenosis. To avoid this drug eluting stent is used and analysed the flow of blood, wall shear stresses using micro-particle-image-velocimetry. Blood analogue fluid is used to represent non Newtonian fluids [32]. Time revolved particle image velocimetry is used to study the velocity distribution and wall shear stress of the stented vessel [33]. Fluid flow field in the ascending aorta is investigated using particle tracking velocimetry and found that parabolic distribution in systole and chaotic flow in diastole [34]. This paper deals with the bio-fluid mechanics. Planar particle image velocimetry is used to study the flow in straight, tapered and bifurcating pipes. For steady flows in complex geometry greatly depends on the Reynolds number. In unsteady flow field is not only time-dependent, but also differs at the same phase when the geometry differs[35]. Ultra sound image processing is used to study the flow field. The topic shows the accurate readings of flow without any biased results [36]. The fluid flow in left and right side of the heart is studied and concluded that a swirling like flow is observed. Flow in Right ventricular pattern is studied using non-invasive 3D echoechocardiac device. Flow in left ventricle is observed using the exact solution of unsteady state navier stokes and continuity equations [37][38].

2.7 Biomaterials and Biomedical composites materials:

2.7.1 Material and methods:

There are also some biopolymers used for making leaflets. At present collagen fibres, elastin, polyurethane family is used in making the leaflets. natural polymers like collagens, glycosaminoglycan, starch, chilin, chitosan and Synthetic polymers like PLA, PGA,PLGA,PCU, POSS-PCU are also can be used. A new nano composite material POSS-PCU is used to make a synthetic heart valve and its mechanical properties are studied [39]. To avoid the tear and calcification due to use of synthetic heart valves and to reduce stresses in weak areas a fibre reinforced leaflets are developed and the different orientations of the fibers is examined by preparing finite element models [40]. A PVA-BC nanobiocomposite which mimics with the mechanical properties of a porcine heart valve is introduced. This reduces the tearing and calcification of leaflets and gives better thrombogenicproperties[41]. A PVA-BC nano composite material is used to design and simulate a trileaflet aortic valve and the hyperelastic nonlinear mooneyrivlin material model is used as a constitutive model and this model is used for any soft tissue like articular cartilage, tendon and ligament[42].

Biomaterials used for different mechanical valve components table: 1

TABLE 1

Component	**Material used**
Cage, housing or hinge design	Titanium (or Ti-alloys) – Ti6A14V
	Cobalt based alloys (Stelite-21, Haynes-25)
	Pyrolytic carbons (LTI carbon)
Leaflet, disc, or ball	Pyrolytic carbons (LTI carbon)
	Silicon rubbers
	Polyacetate (Derlin)
	Polyolefins (UHMWPE)
Sewing ring	Polypropylene
	Polytetrafluoroethylene (Teflon)
	Polyethylene terephthalate–PET (Dacron)

2.7.2 BIOMEDICAL COMPOSITES:

These are some bio medical composites which are not used for artificial heart valves i.ebioprosthetic and mechanical heart valves. Resorbable polymers can be used for bioprosthetic valves.

TABLE 2

Thermosets Polymers Inorganic		
MATRIX	**FIBERS**	**PARTICLES**

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Polyacrylates Polymethacrylates Polyesters Polyesters Silicones Polymethacrylate	(Aramids) UHMWPE Polyesters Polyesters Polyesters PTFE	Alumina **Organic** Polyacrylate
Thermoplastics Polyolefins(PP,PE) UHMWPE Polycarbonate Polysulfones Poly (ether ketones Polyesters	**Resorbable Polymers** Polylactide, and itsCopolymers with Polyglycolide Collagen Silk	
Inorganic Hydroxyapatite Glass ceramics Calcium carbonate Ceramics Calcium Phosphate Ceramics Carbon Steel, Titanium	carbon glass Hydroxyapetite Tricalcium Phosphate	

Resorbable Polymers Polylactide Polyglycolide and their Copolymers Polydioxanone Poly(hydroxyl butyrate) Aliginate Chitosan Collagen		

III. CONCLUSION

The anatomy, mechanics of miral valve leaflet is discussed. In this paper the different bio prosthetic heart valves, mechanical heart valves, pericardium heart valves, tissue engineered heart valves are discussed. The different materials used for bio prosthetic heart valves are given and recent materials like Nano polymers are used for bio prosthetic heart valves. The material properties and the model of bioprosthetic valves is necessary to design in a way that they are long durable. The Various biomedical composites materials which are not tested for present mechanical heart valve plates to increase the haemodynamic and thrombogenic properties, long durability and reduced cavitation is given. Different mechanical models and materials can be designed based on the draw backs of present mechanical heart valves. Natural mitral valve is complex in shape and has material nonlinearity through out the shape. The stiffness varies for different bioprosthetic valve shapes, materials and boundary conditions at different regions of leaflet will differs, further the stresses will differ. The new model of mitral valve is to be developed and finite element analysis and computational fluid dynamic analysis and fluid structure interaction analysis has to be done. The applicability of stiffness is in such a way that it should match with long durability and it is tested using fatigue analysis. An in vitro or in vivo experimental setup to be made based on optimum stress values. The relation between the stiffness and pressures on leaflets are to be studied to avoid the cavitation problems in bio prosthetic valves. The research on Bio prosthetic valves can be done assuming the material as hyper elastic and visco elastic in nature and finite element analysis of bio prosthetic leaflets of super elastic nature is useful and to be tested to get heart valve properties like thrombogenic, avoiding cavitation, calcification and regurgitation, and it is to be tested using fatigue and high impact loads so that the stiffness of leaflet and stresses in leaflet should leads to good working condition. In mechanical heart valve the regurgitation can be avoided by changing the stiffness ie changing the model or by changing the contact joints and by changing the materials. The different kinds of biomedical composites which are not tested and tested for mechanical heart valves are presented and a suitable material for this application can be illustrated with profound work using finite element analysis. Tissue engineered heart valves doesn't have better source cells. It gives good thrombogenic and durability but the regeneration of cells on the scaffold after the damage due to high impact loads and other fluid flow properties like shear, cavitation etc, it gives moderate results and research is going on bone marrow cells the papers are presented in review. In percutaneous heart valves papers are presented here that bovine pericardium more functional than kangaroo and porcine pericardium. Transcatheter heart valves are new types of artificial heart valves which are very easy to install in humans and other suitable living beings like sheeps etc. and further work to be done considering the physics in fluid flow where the interaction between fluid and solid comes into account i.e a fluid structure interaction problem. Application of nano coatings on the leaflet to be conducted to get the results in such a way to avoid breakage of blood platelets during the impact of fluid flow on the structure of heart valves.

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