MODELLING AND ANALYSISOF MITRAL VALVE IMPLANTATION USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Mitral valves is a part of heart where blood passes through leaflet from atrium to ventricle with function of two leaflets. The mechanics of mitral valve can be studied in systolic and diastolic phase of heart. Due to high impact loads in the form passing blood on the mitral valve leaflets causes stenosis, calcification, regurgitation and coaptation of blood. This paper is on materials which are tested to avoid mechanical failure in mitral valve leaflets. The static and dynamic loads on three mitral valve leaflet is used to investigate the strength of leaflet. Out of several materials three materials are taken i.e bovine pericardium, polylactic acid, and ultra high molecular weight polymer and the static loading on them is done. Various results are presented and discussed based on the present analysis.

Keywords: mitral valve, materials, modelling, finite element analysis,

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. Collier et al. specified that in present world people are suffering from heart valve diseases like mitral stenosis, aortic stenosis, mitral regurgitation, aortic regurgitation[1]. Approximately 2% of the population equally in males and females are suffering from mitral regurgitation. Stewart, et al. pointed that most common valvular heart disease occur in pregnancy [2]. Gelson et al. particularly said that 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]. Auricchio et al. presented that Bioprosthetic valves used in heart valve replacement generally offer functional properties (eg, hemodynamics, resistance to thrombosis) that are more similar to those of native valves [4]. Implantation of prosthetic cardiac valves to treat hemodynamically significant aortic or mitral valve disease has become increasingly common. 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. Haj-Ali et al. proposed a computational model 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 [5]. Kidane et al. used a new nano composite material POSS-PCU to make a synthetic heart valve and its mechanical properties are studied. Hart et al. developed fiber reinforced leaflets to avoid the tear and clacification due to use of synthetic heart valves and to reduce stresses in weak areas and the different orientations of the fibres is examined by preparing finite element models [6]. Weinberg, and Mofrad 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 [7]. Zhu et al. worked on Bio prosthetic heart valve using bovine pericardium, analysed using finite element method and the stresses are found using nonlinear anisotropic properties [8]. Hart et al. showed that collagen fibres will reduce in stresses during systole in aortic valves. Previous papers investigated that collagen fibres reduce in stresses during diastole [9]. Quosdorf et al. Coronary heart disease 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 [10]. Pielhop Time revolved particle image velocimetry is used to study the velocity distribution and wall shear stress of the stented vessel. 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 [11].Mohammadi 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 [12]. Mohammadi et al. used PVA-BC nano composite material to design and simulate a trileaflet aortic valve and the hyperelastic nonlinear mooney rivlin material model is used as a constitutive model and this model is used for any soft tissue like articular cartilage, tendon and ligament [13].Vottaet al. made research on different types of annular profile and leaflet profile are discussed and finite element analysis of ulatrasound data for mitral valve is done [14]. This work considers mitral valve leaflets of different materials used for pericardium, bioprosthetic and artificial valves to evaluate the deflections, stresses under static and dynamic loads to recognize the better functionality of mitral valve and with help of ANSYSAPDL 14.0 version

Table 1 Conventional and advanced materials used for different mechanical valve components

Conventional materials	Advanced materials		
	Matrix	Fibers	Particles
Titanium (or Ti-alloys) – Ti6A14V	Epoxy	Polylactide	Glass

		And its copolymers With Polyglycolides	
Cobalt based alloys- (Stelite-21, Haynes-25)	Polyolefins	Collagen	Alumina
Pyrolytic carbons (LTI carbon)		Hydroxylapatite	Silk
	Matrix	Fibers	Particles
Polyacaralyte			
Silicon rubbers		Polylactide	Glass
Polymethacrylate			
Polyacetate (Derlin)	Polycrylates	Tricalcium Phosphate	
Polyolefins (UHMWPE)	Glass ceramics	Polyesters	
Polypropylene	Polydiaxonone	PTFE	
Polytetrafluoroethylene (Teflon)	Alginate	Carbon	
Polyethylene terephthalate–PET -(Dacron)	Chitosan	Aramids	

II. MATERIALS AND METHOD

Conventional and advanced materials used for different mechanical heart valve implant and listed in Table 1[15]. Biomedical composites are the advanced materials which can be used in place of conventional materials out of these materials bovine pericardium is used for leaflets which allows good thrombogenic properties and it is analysed and compared with polylactic acid (PLA) and ultra high molecular weight polymer elastomer (UHMWPE).

III.GEOMETRIC MODELLING OF MITRAL VALVE

The natural mitral valve is formed with three layers with combination of collagen and elastin fibres. The three layers are named as fibrosa in atrium side, spongiosa in middle and ventricularis in ventricular side. The main parts of the mitral valve are anterior leaflet, posterior leaflet, chordae tendinae, papillary muscles. To avoid the complexity in analysing the mitral valve a leaflet of same size and single layer is taken into account to do the static and dynamic analysis of linear isotropic material. There are some assumptions taken in modelling the mitral valve. The leaflets are symmetric in nature in original there are two types of leaflets anterior and posterior leaflets and different regions which are discussed in literature. Thickness of leaflet is assumed as 4mm. Chordae tandinae support is neglected and the dimensions are shown in Figure 1.

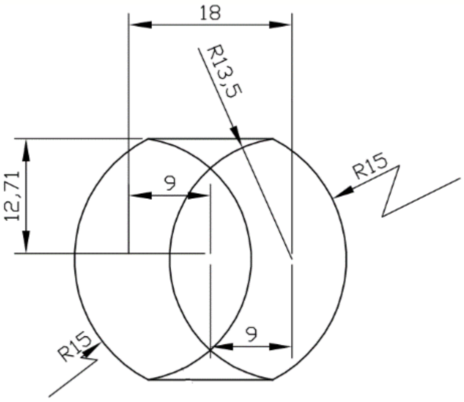


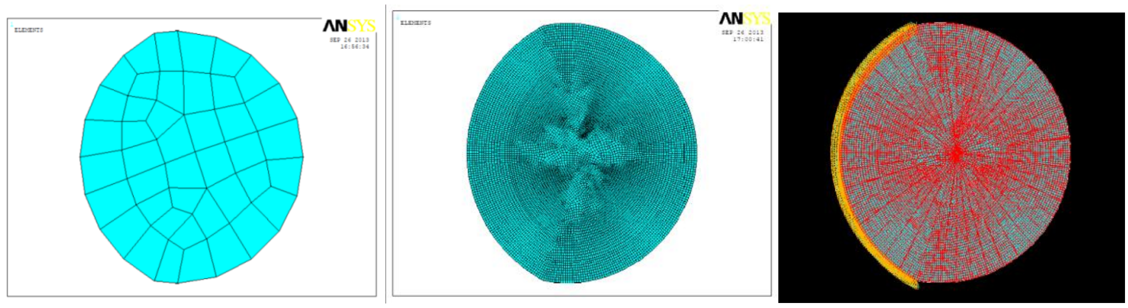
Fig 1 Artificial mitral valve leaflet for bio prosthetic valves

Table 2 mechanical properties of used materials

Material	Elasticity modulus	Density	Poisson's ratio
Bovine pericardium	5.4×10^{6}	1200	0.45
UHMWPE	9.65×10^{6}	945	0.42
PLA	5×10^{9}	1300	0.42

IV. FINITE ELEMENT MODEL OF MITRAL VALVE LEAFLET

For this work ANSYSAPDL 14.0 is used. The element used is shell 181. It has 4 nodes and 6 degrees of freedom. One of edges of the leaflet is constrained all degrees of freedom. Figure2(a) and Figure2(b) show the Meshing of mitral valve leaflet from 42 elements to 10982 elements. Figure2(c) shows the boundary conditions of single mitral valve leaflet. A load of 120mm of Hg is applied on the leaflet which is maximum pressure applied in systolic phase. The material used is bovine pericardium which is used for pericardium valves, polylactic acid material used for bioprosthetic valves and ultra high molecular weight(UHMWPE) used for mechanical mitral valves. On Table 2[16] materials for static and dynamic analysis is done.



(a) (b) (c)

Fig 2(a)Finite element mesh for 42 elements(b) finite element mesh for 1092 elements and(c)finite element model after giving boundary conditions and loads

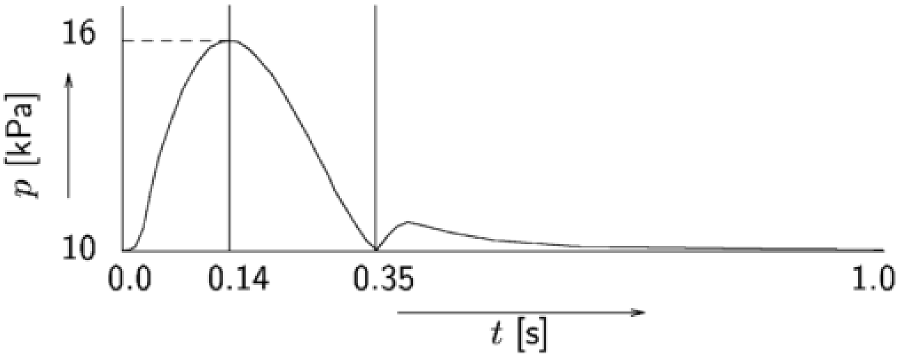


Fig 3 Transient loading on mitral valve in diastolic phase

V. RESULTS AND DISCUSSION

Three materials and their properties are shown in Table2. These are used in static and dynamic analysis of mitral valve leaflet. The transient load graph is shown in Figure 3 during diastolic phase. The static analysis of bovine, UHMWPE(ultra high molecular weight polymer elastomer) and PLA(poly lactic acid) material are converged using finite element analysis as shown in Figure 5(a),(b),(c) and tabulated in Table3. Bovine material has shown more flexibility in showing ultra high molecular weight polymers elastomers (UHMWPE) and poly lactic acid polymers (PLA). The failure due to stress is less using bovine pericardium. Bovine pericardium is used as percutaneous valves. UHMWPE (ultra high molecular weight polymer elastomers) is used for mechanical heart valves, PLA (Poly lactic acid polymers) is used for bioprosthetic heart valves. In Figure 7 the dynamic response of mitral valve leaflet using bovine is conducted upto 32 load steps. And the displacement of the leaflet is increased upto maximum loads and decreased to minimum loads similarly the stresses are given in Table 3and Table 4. Figure 4 shows the process of making analysis.

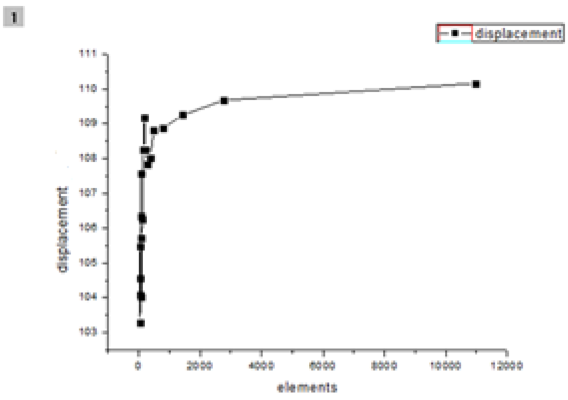
Table 3 Static analysis of mitral valve leaflets

	Static loading		
material	Min stress(MPa)	Max stress(MPa)	Displacement(m)
Bovine	0.453×10^{8}	0.111×10^{10}	110.164
UHMWPE	0.448×10^{8}	0.112×10^{10}	0.62328
Polylactic acid	0.448×10^{8}	0.112×10^{10}	0.120293

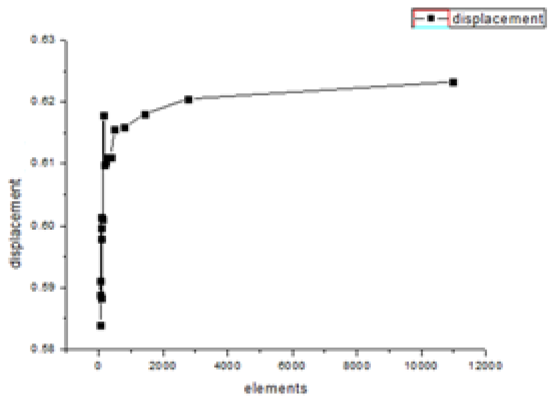
Table 4 Dynamic analysis of mitral valve leaflets

Dynamic loading			
Material	Min stress(MPa)	Max stress(MPa)	Displacement(m)
Bovine	0.668×10^{8}	0.146×10^{10}	161.633

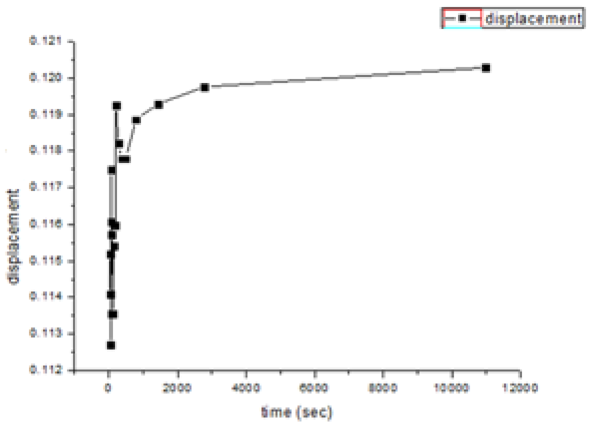
Fig 4. Block diagram of static and dynamic analysis of mitral valve leaflet



(a)



(b)



(c)

Fig 5(a) Displacement and convergense of bovine material, (b) Displacement and convergence of UHMWPE using static loads and (c) Displacement and convergence of PLA using static loads

Yes

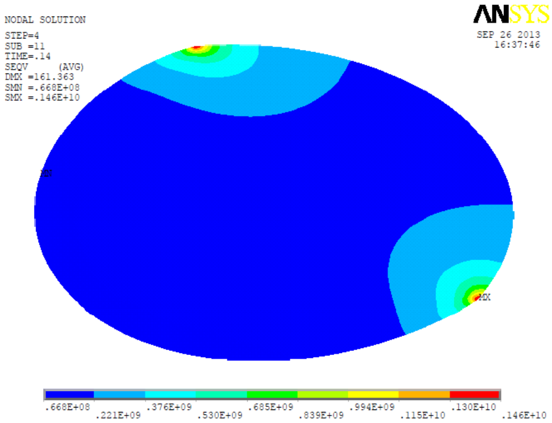


Fig 6 Dynamic model of mitral valve at step 4 with displacement and stress results

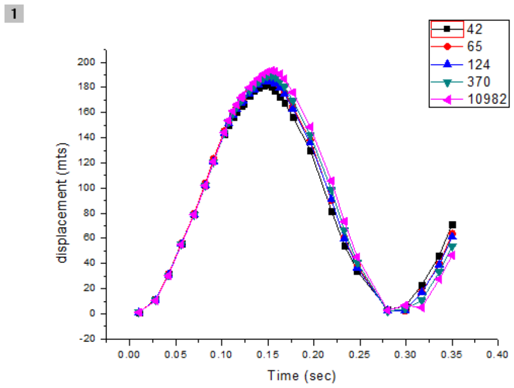


Fig 7 Dynamic response of mitral valve of bovine pericardium from 42 elements to 10982 elements for different time steps

VI.CONCLUSION

The material properties and the model of bioprosthetic valves is necessary to design in a way that they are long durable. In the present work static analysis on materials for different type of valve leaflets is done and dynamic analysis of bovine pericardium mitral valve leaflet is done. Bovine pericardium, UHMWPE and PLA material are used for leaflets and compared. In static analysis the results are converged. In dynamic analysis of bovine pericardium the displacement of the leaflet is shown.The stresses with in the leaflet with three materials bovine pericardium, UHMWPE, Polylactic acid polymers are similar in static load. Stress using bovine pericardium with dynamic loads are close to static load stresses. From deflection point of view bovine pericardium gives better functioning than other materials.

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