ISSN 2320-5407 International Journal of Advanced Research (2015), Volume 3, Issue 5, 491-499

ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

DESIGN AND EVALUATION OF INFLOW CANNULAE FOR LEFT VENTRICULAR ASSIST DEVICE

Pratima Saravanan, M. Alagappan*

Department of Biomedical Engineering, PSG College of Technology, Coimbatore, Tamil Nadu 641 004, India

Manuscript Info

Manuscript History:

Received: 11 March 2015
Final Accepted: 22 April 2015
Published Online: May 2015

Key words:

Thrombus, LVAD, Inflow cannula, Blood, Heart

Corresponding Author

M. Alagappan

Abstract

Left Ventricular Assist Device (LVAD) is a mechanical circulatory device used to support failed hearts. Due to the scarcity of donor hearts, patients depend on LVADs which pushes blood from left ventricle to the aorta. The inflow cannula is the connection between the apex of left ventricle and the pump of LVAD. The tip structure of the inflow cannula is responsible for many adverse events like obstruction of blood flow and suction of left ventricle, which later leads to device failure. In this paper, study is made on the blood flow characteristics in the inflow cannulae of LVAD using COMSOL Multiphysics simulation software. Four types of inflow cannulae, namely blunt tip, beveled tip, caged tip and trumpet tip were designed and their performances were compared. Their velocity and pressure profiles proved that the trumpet tip cannula is the best of all the other cannulae for uninterrupted blood flow, and hence overcoming thrombus formation and obstruction.

INTRODUCTION

In recent years, heart failure has become a major threat to mankind. Heart transplantation was the only way for sure survival. To reduce the days waiting for heart transplantation and due to the increased mortality rate, people prefer mechanical circulatory devices like Left Ventricular Assist Device (LVAD). LVADs are life saving modules for patients who need temporary cardiac assistance and for those waiting for heart transplantation. Hence LVADs are being used as both, bridge to recovery and bridge to transplantation[1,2]. Many studies are being done on LVADs to make them as destination therapy and the patients no longer need to wait for donor heart transplantation. LVAD has a mechanical pump which pushes blood from left ventricle to the aorta. The inflow cannula is the connection between the apex of left ventricle and the pump of LVAD. They are made of biocompatible titanium alloy, polythene, or silicon rubber. The structure of inflow cannulae include blunt tip, beveled tip, caged tip and trumpet tip. The tip structure of the inflow cannula is responsible for velocity and pressure distribution in the cannula and in the left ventricle. The tip structure also leads to many adverse events like obstruction of blood flow and suction of left ventricle, which later leads to device failure. Obstruction of blood flow caused by thrombus formation is due to slow flow of blood and the suction of left ventricle is caused by a large pressure drop in the left ventricle due to the insertion of the inflow cannula[3]. The longer inflow cannula had less thromboembolic events and other neurologic complications than shorter inflow cannula[4]. Hence the size of the inflow cannula is an essential part of designing. The positioning and geometry of the ventricular cannula can also influence the performance of the device[5]. In our study we have focused on four types of inflow cannulae namely, blunt tip, beveled tip, caged tip and trumpet tip. Simulation of left ventricle and inflow cannulae were done using COMSOL Multiphysics software. Their flow speed and pressure distribution were assessed to study the extent of clot formation and ventricular suction.

MATERIALS AND METHODS

The inflow cannulae were taken as straight pipes with 12 mm diameter and 50 mm length. Blood was taken as an incompressible Newtonian fluid and the left ventricle was designed as a severely dilated ventricle with a diastolic volume of 205 mL. Simulation of blood flow through the inflow cannulae was done using COMSOL Multiphysics simulation software. The flow characteristics of blood were studied in the inflow cannulae alone with a blood inflow velocity of 0.15 m/s. It is the velocity at which blood flows from left atrium to the left ventricle[6]. Later, the blood was made to flow from the mitral valve through the left ventricle to the inflow cannula with a flow rate of 5 L/min[3]. The flow rates are usually set by an external controller in LVAD[7]. The static outlet pressure was maintained at 0 Pa to study the pressure changes caused by blood flow. The velocity of blood flow was directly related to the occurrence of thrombus formation and the pressure related the possibilities for ventricular suction. In order to simulate with the real characteristic nature of blood and left ventricle, the parameters mentioned in table I were considered. The structure of the four types of inflow cannulae is shown in figure1.

RESULTS AND DISCUSSION

A. Velocity profile of blood flowing through the inflow cannulae

Figure 2 shows the velocity profile of each type of cannula without considering left ventricle. The velocity of caged tip cannula was very low when compared to other types with a maximum value of 0.1462 m/s. Therefore, the blood will get stagnated leading to clot formation. The velocities of blunt tip and beveled tip were 0.2135 m/s and 0.3205 m/s respectively. The blunt tip also has higher possibilities for thrombus formation but their smooth interior surface prevents such occurrence. The beveled tip has a good velocity which indicates that the clot formation is less. The trumpet tip has the best velocity of 0.5815 m/s which is better than all other inflow cannulae, concluding that no thrombus formation can occur.

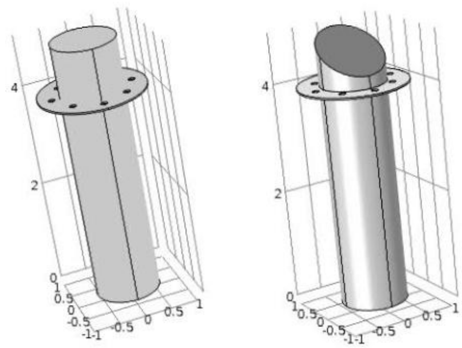
Figure 3 shows the velocity profile of blood flow from the mitral valve through the left ventricle into the inflow cannula. In all the cannulae the maximum outflow velocity was approximately 1 m/s, but their velocities differed at the apex of left ventricle since it is the place where the inflow cannula is sutured. Hence, any obstruction in that area may either reduce the flow rate of blood or stops the blood flow completely. The caged tip cannula had a very low velocity of 0.8935 m/s at the apex, proving high possibilities of clot formation and obstruction. The trumpet tip cannula showed good velocity of 1.0539 m/s at the apex than other cannula, resulting in a high flow rate with no clot formation and obstruction. The values of velocity at different cases are given in table II and their comparisons are depicted in the figure 4.

B. Pressure profile of blood flowing through the inflow cannulae

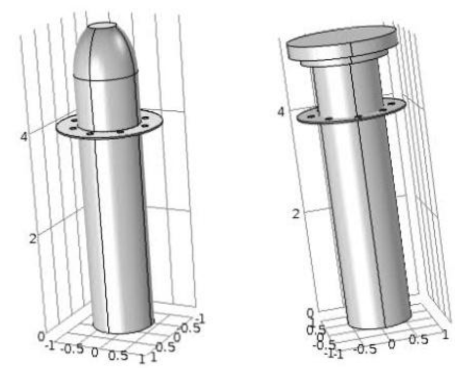
Whenever low pressure field occurs, left ventricle collapses and suction takes place. Hence the pressure profile of the inflow cannulae must be high to prevent ventricular collapsing[3,10]. The systolic left ventricular pressure is nearly equal to the maximum value of the inflow cannula pressure. But the minimum pressure value of the inflow cannula does not relate the diastolic left ventricular pressure[11]. Figure 5 shows the pressure distribution of the four cannulae and table III shows the values of the pressure distributed in the inflow cannulae. The pressure distribution has difference in the range of 16 to 18 Pa which proves that the pressure is evenly distributed in the inflow cannulae. Negative pressure prevails in the trumpet tip cannula showing the occurrence of ventricular suction, but trumpet tip can resist ventricular collapse and obstruction[3.] Trumpet tip has a maximum pressure of 697.69 Pa. Blunt tip does not create any low pressure field hence there is no occurrence of ventricular suction. Beveled tip's pressure values conclude that it is likely to cause ventricular collapse. The caged tip cannula has a serious low pressure field, so it has high possibilities for ventricular collapse.

CONCLUSION

The design and simulation of blunt tip, beveled tip, caged tip and trumpet tip inflow cannulae of Left Ventricular Assist Device (LVAD) was done using COMSOL Multiphysics simulation software. Their velocity and pressure profiles were analysed and their results concluded that the caged tip had a very low velocity and pressure profiles leading to high possibilities for adverse events. But the trumpet tip cannula has better biocompatible fluid dynamic property and has a good flow velocity and pressure profile. Therefore, it has negligible possibilities of clot formation, obstruction and ventricular suction.

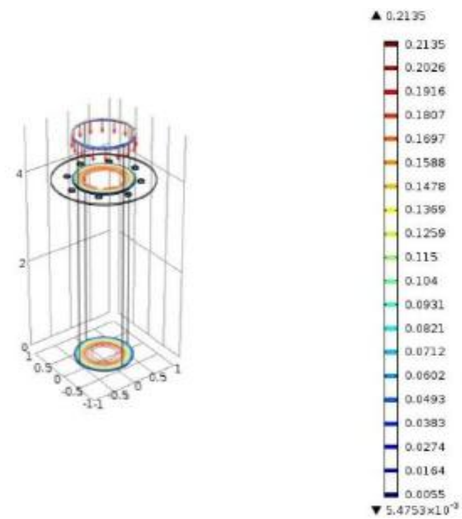


1a. Blunt tip 1b. Beveled tip

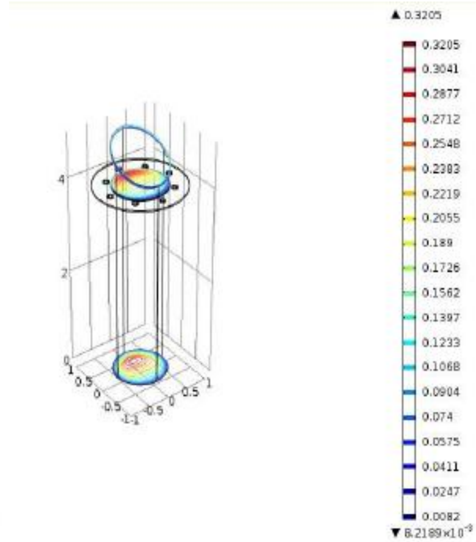


1c. Caged tip 1d. Trumpet tip

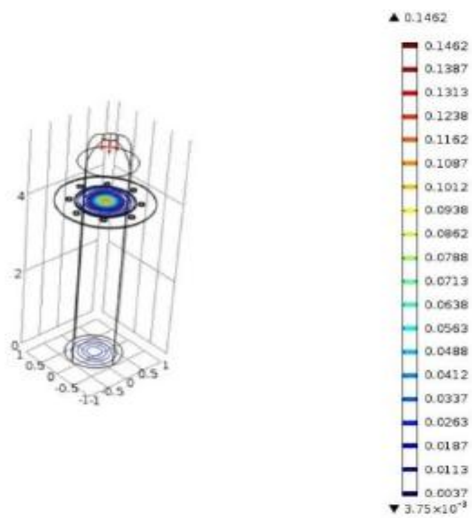
Figure 1: Structure of the four inflow cannulae



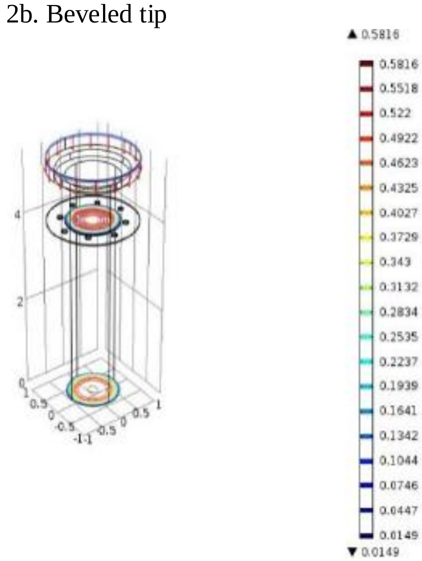
2a. Blunt tip



2b. Beveled tip

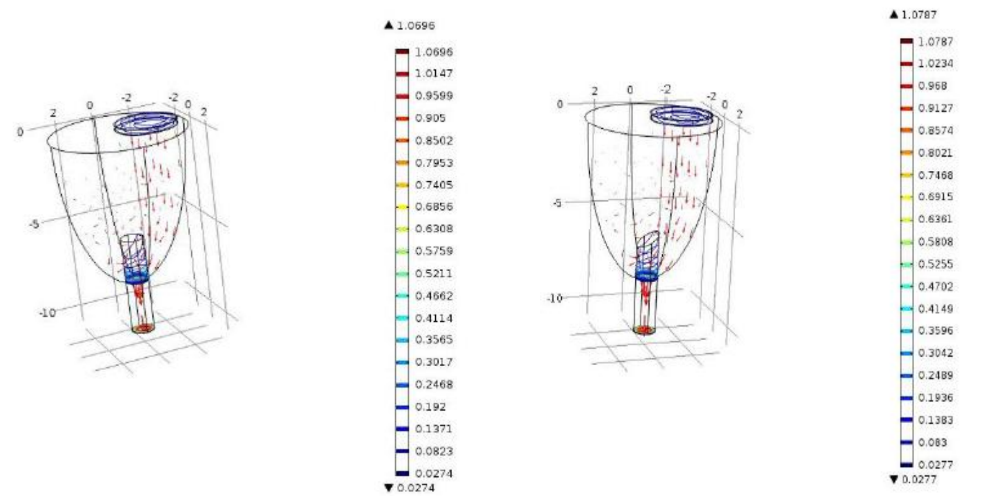


2c. Caged tip

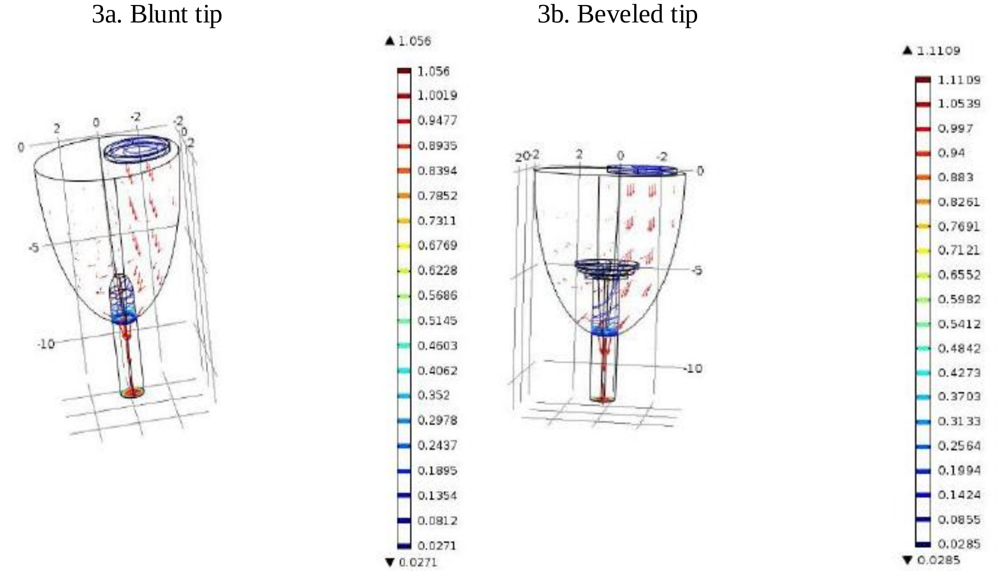


2d. Trumpet tip

Figure 2: Velocity profile for blood flowing through the inflow cannulae- without considering left ventricle



3a. Blunt tip 3b. Beveled tip



3c. Caged tip 3d. Trumpet tip

Figure 3: Velocity profile for blood flowing through the inflow cannulae- considering left ventricle

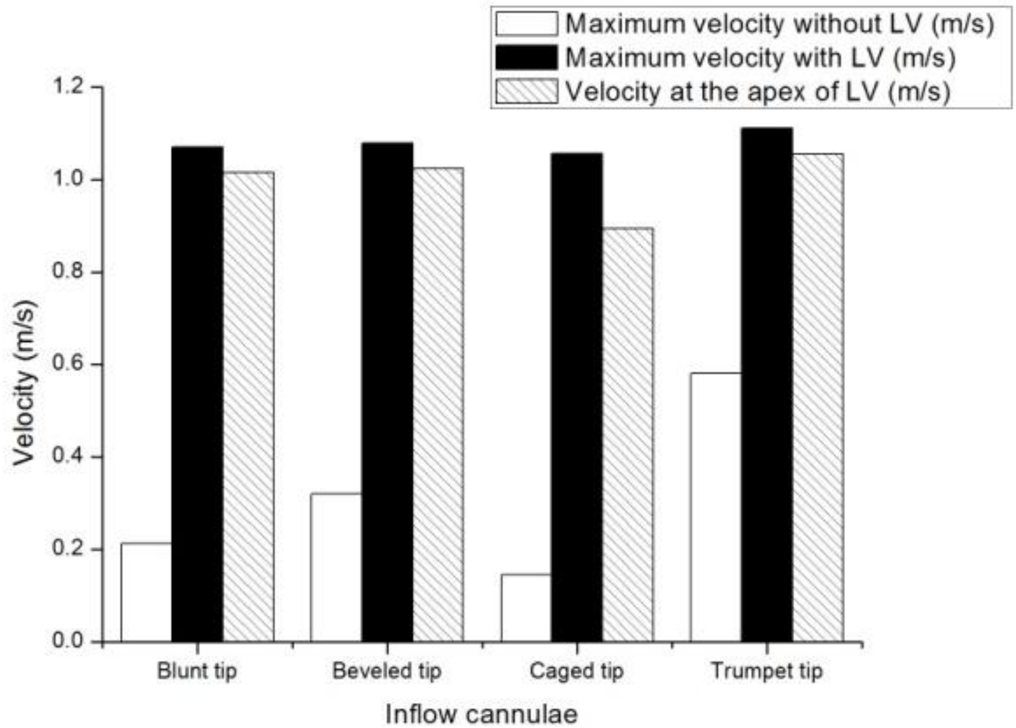
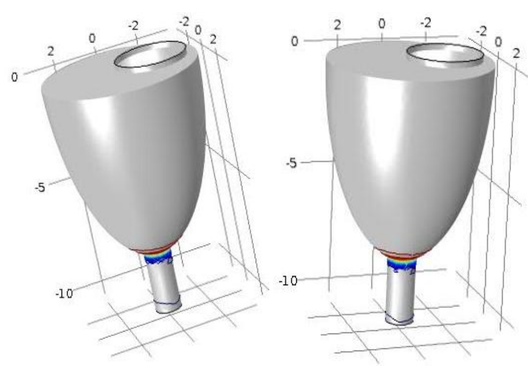
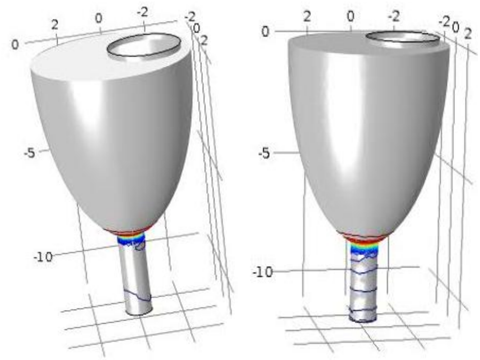


Figure 4: Comparison chart for velocity profile of blood flow through the inflow cannulae



5a. Blunt tip 5b. Beveled tip



5c. Caged tip 5d. Trumpet tip

Figure 5: Pressure distribution in the inflow cannulae due to blood flow

Table I: Parametric values of blood and left ventricle[8,9]

Parameters	Values
Young’s modulus of left ventricle	700000 Pa
Poisson’s ratio of left ventricle	0.40
Density of blood	1060 kg/m^3
Dynamic viscosity of blood	0.00270 Pa. s

Table II: Comparison of velocity profile of blood flow through the inflow cannulae

Type of cannulae	Maximum velocity without LV (m/s)	Maximum velocity with LV (m/s)	Velocity at the apex of LV (m/s)
Blunt tip	0.2135	1.0696	1.0147
Beveled tip	0.3205	1.0787	1.0234
Caged tip	0.1462	1.0560	0.8935
Trumpet tip	0.5816	1.1109	1.0539

Table III: Pressure distribution in the inflow cannulae

Pressure (Pa)			
Blunt Cannula	Beveled Cannula	Caged Cannula	Trumpet Cannula
634.54	634.30	630.28	697.69
618.37	618.13	614.20	679.77
602.21	601.96	598.12	661.85
586.04	585.79	582.04	643.93
569.88	569.63	565.96	626.02
553.72	553.46	549.88	608.10
537.55	537.29	533.80	590.18
521.39	521.13	517.72	572.27
505.22	504.96	501.64	554.35
489.06	488.79	485.56	536.43
472.90	472.62	469.48	518.51
456.73	456.46	453.40	500.60
440.57	440.29	437.32	482.68
424.40	424.12	421.24	464.76
408.24	407.96	405.16	446.85
392.08	391.79	389.08	428.93
375.91	375.62	373.00	411.01
359.75	359.45	356.92	393.09
343.58	343.29	340.84	375.18
327.42	327.12	324.76	357.26
311.26	310.95	308.69	339.34
295.06	289.79	292.61	321.43
278.93	278.62	276.53	303.51
262.76	262.45	260.45	285.58
246.60	246.28	244.37	267.68
230.44	230.12	228.29	249.76
214.27	213.95	212.21	231.84
198.11	197.78	196.13	213.92
181.94	181.61	180.05	196.01
165.78	165.45	163.97	178.09
149.62	149.28	147.89	160.17
133.45	133.11	131.81	142.26
117.29	116.95	115.73	124.34
101.12	100.78	99.651	106.42
84.959	84.612	83.572	88.504
68.795	68.445	69.492	70.587
52.631	52.278	51.412	52.670
36.467	36.110	35.333	34.753
20.303	19.943	19.253	16.836
4.1395	3.7760	3.1739	-1.0813

REFERENCES

1) Louis E. Samuels (2013). The Implantable Left Ventricular Assist Device: A Bridge to a Destination. *Journal of Clinical & Experimental Cardiology*; DOI:10.4172/2155-9880.1000267.
2) Jens Garbade, Hartmuth B. Bittner, Markus J. Barten, and Friedrich-Wilhelm Mohr (2011). Current Trends in Implantable Left Ventricular Assist Devices. *Cardiology Research and Practice*; DOI:10.4061/2011/290561.
3) Guang-Mao Liu, Hai-Bo Chen, Fu-Liang Luo, Yan Zhang, Han-Song Sun, Jian-Ye Zhou, and Sheng-Shou Hu (2012). Numerical Simulation of LVAD Inflow Cannulas with Different Tip. *International Journal of Chemical Engineering.*; DOI:10.1155/2012/596960.
4) Christof Schmid et al (2008) Influence of Inflow Cannula Length in Axial-flow Pumps on Neurologic Adverse Event Rate: Results from a Multi- center Analysis. *International Society for Heart and Lung Transplantation*; DOI:10.1016/j.healun.2007.12.007.
5) Timothy N Bachman, Jay K Bhama, Josiah Verkaik, Stijn Vandenberghe, Robert L Kormos, and James F Antaki (2011). In-vitro Evaluation of Ventricular Cannulation for Rotodynamic Cardiac Assist Devices. *Cardiovasc Eng Technol*; pp.203–211, DOI:10.1007/s13239-011-0050-x.
6) Carla Contaldi, Lubna Choudhury, Bradley Allen, Daniel C. Lee, Nick Furiasse, Jyothy Puthumana, James Carr, Michael Markl, Robert O. Bonow (2014). Core 5. Myocardium: Function and Failure, Session Title: Novel Diagnostic Modalities in Heart Failure. Abstract 19491: Left Atrial Blood Flow Velocity Distribution in Hypertrophic Cardiomyopathy: Association with Left Ventricular Diastolic Function and Interstitial Fibrosis. *Circulation-American Heart Association.*
7) Christopher A. Thunberg, Brantley Dollar Gaitan, Francisco A. Arabia, Daniel J. Cole, and Alina M. Grigore (2010); Ventricular Assist Devices Today and Tomorrow. *Journal of Cardiothoracic and Vascular Anesthesia; Vol 24, No 4; pp 656-680.* DOI:10.1053/j.jvca.2009.11.011.
8) Daniel M. Espino, Michael A. Watkins, Duncan E.T. Shepherd, David W.L. Hukins and Keith G. Buchan (2006). Simulation of Blood Flow through the Mitral Valve of the Heart: A Fluid Structure Interaction Model. *Excerpt from the Proceedings of the COMSOL Users Conference Birmingham*.
9) Toni Lassila, A. Cristiano I. Malossi, Marco Stevanella, Emiliano Votta, Alberto Redaelli, Simone Deparis (2012). Multiscale fluid-structure interaction simulation of anatomically correct left ventricle fluid dynamics with fictitious elastic structure regularization. *International Journal for Numerical Methods in Biomedical Engineering*; pp. 1-23. DOI: 10.1002/cnm.
10) Saito, T. Isoyama, H. Miura, H. Nakagawa, A. Kouno, T. Ono, W. Shi, Y. Inoue, A. Kishi, Y. Abe (2010). Development of the Natural heartbeat synchronize control method for the Undulation pump Ventricular Assist Device using inflow pressure. *World Congress on Medical Physics and Biomedical Engineering.*
11) I. Saito, T. Chinzei, T. Isoyama, H. Miura, H. Nakagawa, A. Kouno, T. Ono, W. Shi, Y. Inoue, A. Kishi, Y. Abe, S. Yamaguchi-Sekine (2008). Implementation of the Natural heartbeat synchronize control for the Undulation pump Ventricular Assist Device using inflow pressure. *7th Asian-Pacific Conference on Medical and Biological Engineering- APCMBE, IFMBE Proceedings 19; pp. 62-65.*