ISSN No:-2456-2165

Expandable Polyurethane Stent Valve Physical, Hydrodynamic, Animal and Ultra Structural Studies - Expandable Polyurethane Stent Valve

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Abstract:-

Background: Patients with pediatric prostheses suffer from mismatch and early calcification, which causes a high number of reoperations

Methods: Expandable Polyurethane Stent Valve – EPSV, is composed by a flexible polyurethane (PU) leaflets is grown on the top of an expandable cobalt-chrome alloy stent, including the formation of three leaflets. Physical, Hydrodynamic, Animal studies, were performed following: ISO 5840-3,2015.

Results: Physical tests. Result of study of surface scanning of pre and post crimp stent, showed no structural modification of the PU. Hydrodynamic test showed a pressure gradient oscillation between 5 to 20mm, in basal or stress condition respectively. Experimental studies. Sheep were subjected to 3D echo-Doppler study, in 6th follow-up months, which showed satisfactory hemodynamic performance, with low transvalvular gradient (M = 6.60 mm Hg).
Ultrastructural Study: Six stents were explanted after 20 days to 21 months of follow-up to Ultrastructural analysis. All of which revealed no presence of calcium growth and prostheses structure was intact.

Conclusions: Association between: stent - design and PU-leaflets, allowed acceptable hemodynamic performance, regardless of the stent valve diameter. The resistance of polyurethane to crimping and the lack of calcification of leaflets, are advantages that will allow greater durability of the prosthesis. This new concept of synthetic expandable stent valve could be a viable option in growing patients

Keywords:- *Stent, Valve, Pulmonary, Synthetic, Catheter.*

- Presented at the Fifty, -second Annual Meeting of The Thoracic Surgeons, Phoenix- AZ., Jan. 23-27, 2016.
- EPSV was submitted to FDA evaluation and has Certification approved by the Humanitarian Use Device Program - DEV 2019 - 426
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I. INTRODUCTION

Two structural problems in pediatric prostheses have not yet been resolved:
1- Rigid support ring for leaflets, which do not allow to increase their diameter, following the child's development (mismatch), requiring frequent replacements.
2- Structure of biological tissue, treated with chemical solutions (glutaraldehyde - formaldehyde), which facilitate its mineralization (calcium deposit), especially in pediatric patients, causing valve dysfunction.[1]

The durability of biological heart prostheses in pediatric patients show that only 20%, Atik et al. [2] or 30%, Turrentine et al. [3], do not require replacement after 9 years of implantation. In exceptional and isolated cases, biological prostheses implanted in children may exceed 15 years of operational life (Maluf et al.) [4].

The first human transcatheter heart valve replacement was successfully reported in 2000 [5]. The Melody® valve was approved for use in the United States of America in 2010 [6]. Many clinical studies have reported early and mild-term outcome and more than 6,000 valves have been implanted worldwide [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17].

ISSN No:-2456-2165

The restrictions in the choice of pediatric groups [18], and observation of degradation of the biological tissue after crimping, indicate that the operational life for currently available prostheses is undesirably short [19]. A recent publication, [20] showed that it is possible to implant a valve stent in the pulmonary position in patients weighing less than 20 kg, but with the refusal of cases considered unfavorable or registering complications of the stent valve access route, it has to be considered in the indication,

While biological prostheses evolve to early mineralization (calcification), 5 to 6 years after implantation. On the other hand, PU leaflets, have been shown to be free of calcification. These are some of the reasons why PU is used for a variety of medical devices [21], [22], [23], [24], [25], [26], [27].

Recent evaluation, in our Institution, of 2 groups of patients, submitted to the tetralogy of Fallot, correction: one Group without pulmonary valve reconstruction (enlargement of the pulmonary ring with biological tissue) and another Group with reconstruction of the pulmonary ring (bicuspid prosthesis swine) , during a follow-up of 15 to 30 years, showed, in the study of Nuclear Magnetic Resonance: smaller diastolic and systolic diameters and preserved right ventricular ejection fraction, in patients with pulmonary valve reconstruction in childhood. The data collected in this study are being published and could mean a change in surgical conduct in the future.

The procedures of implant of prostheses by catheter, are indicated for the treatment of the pulmonary Insufficiency, with dysfunction of the right ventricle. This procedure in pediatric groups, finds the following difficulties or controversies:

Stent valve durability: Results show that the ultimate strength value of the implanted stents, with biological leaflets, decreases nearly by up to 50%. The modifications observed in the stent's material may jeopardize the long-term durability of the device

Calcification of biological tissue: The mineralization (calcification) of leaflets of prosthetic biological tissue in children, with an average durability of 9 years, is a known and documented phenomenon [2], [3].

Mismatch effect: There are no bibliographic references or prosthetic practices of stent valve implanted in childhood that can accompany the patient's growth, which requires reoperations until reaching adulthood. Isolated reports of implantation of prosthetic catheters in smaller patients have been reported [20], but they are not exempt from comorbidities at the vascular access site.

II. MATERIALS AND STENT MANUFACTURE

Methods

The original model presented here for the expandable polyurethane stent valve - EPSV, which tries to imitate the anatomy and functioning of a sigmoid human valve, involves a ring and three mobile stems, to reduce the mechanical fatigue of the leaflets, representing a key difference with respect to the stent valve models in the market today.

The expandable stent valve was fabricated, based on the design produced by computerized Angio Tomography of the aortic valve. These computerized 3-D images are imprinted onto the surface of a tube of cobalt-chromium (Co-Ch) material, which subsequently is exposed to a computer-controlled laser beam, cutting the tube along the imprinted pattern, to produce the stent with 8 to 10 mm diameter, subsequently expanded with a balloon up to 24 to 30 mm diameter, respectively. The fabricated stent is a low-profile prosthesis: 25 mm high.

The expandable valve stent (24 mm diameter) was inserted over the surface of stainless steel cylinder (22 mm diameter) terminated in a top patterned with leaflet shaped geometry, to induce the formation of a 3-D PU leaflets valve. The PU material (Carbothane PC 3585A, Lubrizol®) was applied using the dip coating® technique, to form membranes with same thicknesses in the range of 150 to 200 μ, without suture, such that the membrane performs as a valve. (Figure 1).

III. STENT PHYSICAL PERFORMANCE TESTS

3.1 Mechanical Stress Test

Mechanical stress test was performed via coupling of the polyurethane specimens to a mechanical stress testing machine where a 200 gr (2 N) load was applied for 30 seconds. After pre-loading, the test continued, on average, for 5 minutes, with a pre-set speed of 10 mm / min.

A study of polyurethane cusp membranes grown on the top of the stents, crimped for 30 minutes (Diameter = 5 mm) and another non-crimped, was performed on a small sample each membrane, prepared for insertion into an atomic force microscope (AFM), to perform atomic scale surface morphology studies. (Figure 2).

3.2 Hydrodynamic Test

Following the standards required by ISO 5840-3, 2015, hydrodynamic and fatigue tests studies were performed on stents with increasing diameters of 14 to 24 mm, using the Shelhigh Pulse Duplicator System Inc, model V. 4.0®. The hydrodynamic tests provided valuable information to evaluate the hemodynamic performance of the stents with the PU valves, simulating systemic pressure (120 x 80 mmHg) (Table 1).

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The stents with the PU valves were tested in aqueous solution (simulating blood) of 1% benzyl alcohol and pH 6.5 at room temperature (25°C), which has a viscosity of 4 cent Poise and a density of 1 g mL – 1.

Stents with diameters of 14 mm, 16 mm and 24 mm, were subjected to hemodynamic performance and durability tests in a fatigue simulation apparatus, employing 380 x 106 cycles, which is the expected value for mechanical prostheses (Figures 3A, 3B, and 3C). Parameters evaluated: transvalvular mean pressure gradient, mean effective orifice area, regurgitation fraction and their hydrodynamic equivalents. (Figure 3).

3.3 Animal Studies

Ten Dorper sheep, aged 3 to 4 months, weighing between 15 and 30 kg (median 24.45±6.45), all identified, were prepared for the implantation of an EPSV, in pulmonary valve. Due to the reduced diameter of vessels in the femoral and jugular region, due to the age and weight of the experimental animals, a surgical approach of the pulmonary valve, with a beating heart, was decided. The surgical approach was performed by 4th left intercostal space. Two pouch sutures were performed on the free wall of the right ventricle, through which a guide catheter was inserted through the pulmonary valve and positioned in the left pulmonary artery. The conditioning of the prosthesis along with the balloon was based on the preliminary measurements of the pulmonary ring, adding 2 to 4 mm of diameter. The conditioned stent in the balloon catheter was crimped, reducing its diameter from 24 mm to 5 mm. (13 FR)

Aided by radioscopic and transesophageal echocardiographic images, the crimp stent valve was directed to the pulmonary valve after passing through the wall and right ventricular cavity and when was considered in corrected position, in the pulmonary ring, the balloon was inflated, inducing opening of the stent to achieve its fixation onto the pulmonary ring (Figure 4). Measurements of flow velocity and transvalvular pressure gradients were performed. A barium solution was injection in the pulmonary trunk, to determine the presence of valve competence and the presence or absence of valve leak.

3.4 Ultrastructure Analysis of Explanted PU valves

The surface of six PU valves explanted between 20 days and 21 months of follow-up, were studied by Scanning Electron Microscopy (SEM) analysis, to characterize the surface morphology and by X-ray Photoelectron emission Spectroscopy (XPS) to characterize the surface chemistry of the PU after been exposed to the animal cardiovascular environment, with both analyses performed at the University of Texas-Dallas (Figure 5)

Removal of Ca atoms present on the surface of the PU valve, on the stent implanted for 21 months, was investigated, using an Argon Gas Cluster Ion Beam (ArGCIB), integrated in the XPS system, to bombard the surface of the PU with ionized Ar cluster beams, to sputter away the Ca atoms. This shows the weakness on the bond between the Ca atoms and the surface of the PU membrane, indicating that it cannot be from Ca growth inside the animal cardiovascular system. Analysis of more PU membranes are underway to confirm the analysis discussed in this paper.

IV. RESULTS

4.1 Physical Analysis of PU Valves

The mechanical test on PU membranes, crimped and non- crimped stent valves, showed, at the nano-scale, no significant difference between them. i.e., the structures were similar, demonstrating that there was no structural damage of the membrane (Figure 2)

The PU used for the stents integrated valves is a flexible and thermoplastic material with high deformation capability.

4.2 Hydrodynamic Performance Test for PU Valves

Prosthesis under systemic pressure (120 mmHg) and variation of prosthesis diameters (14, 16 and 24 mm), the pressure gradient oscillates between 5 mm Hg (diameter of 24 mm) and 20 mm Hg (diameter of 14 mm) (Figure 3)

The mean flow rate, at 60 beats per minute, was 4.2 L x min. The area of the real valve opening was 2.70 cm^2 or 70% of the area corresponding to the nominal diameter of the stent (24 mm).

4.3 Studies of Performance of PU-Based Stent Valves Implanted in Animals

The ten sheep survived the operation and recovered rapidly (Figure 4). All sheep received Acetyl Salicylic Acid daily. The pulmonary ring diameter, recorded by the transesophageal echo-Doppler cardiogram, was 18.20 ± 1.53 mm, while the mean value of the implanted stent diameter was 20.4 ± 2.07 mm. Before the implantation of the stent, the mean flow velocity of the pulmonary valve was 0.88 ±2.07 ms and the mean pressure gradient 2.98± 0.83 mm Hg, increasing slightly to mean flow velocity 1.36 ±0.21 ms and mean pressure gradient 6.92 ±1.5 mm Hg, after stent implantation (Table 2).

Eight (80%) sheep survived the 6 months follow-up; two died of non-cardiac causes. In the test follow-up period, the sheep exhibited an average weight gain of 20 kg. Eight sheep were subjected to 3D echocardiographic transesophageal study, under general anesthesia and controlled ventilation, after 6^{th} months of stent implantation follow-up. The mean of transvalvular flow velocity was 1.28 ±1.5 ms and the pressure gradients was 6.60 ±1.58 mm Hg. Discrete stent insufficiency, (4 cases), no PU visual calcification (8 cases) and no paravalvular leak was detected in any case (Table 4). Three sheep with 18 mm diameter PU stent valves and mean pressure gradient of 7.6 mm Hg, were submitted to expansion of the stent to 22 mm diameter, with success and a 30% (2.28 mm Hg) decrease in the transvalvular pressure gradient. (Table 3)

The PU stent valve were explanted from six (60%) sheep, (there were 2 dead and 2 out of the study due to pregnancy), between the 20th days to 21st month of follow-up, with the valves exhibiting the same structural dimensions as originally implanted.

4.4 Ultrastructure Analysis of Explanted PU valves

SEM analysis showed No evidence of Ca particles on the surface of the polymer valve exposed to animal cardiovascular environment, for 21 months.

Comments

Transcatheter pulmonary valve replacement (TPVR), represents the most significant change in heart valve disease; however, implantation in growing children, is the biggest challenge in relation minimally invasive implantation approach. At present, there is no on-the-market, an expandable stent valve, implanted by catheter, allowing for scheduled expansion in growing children, to avoid reoperations.

Since 1991, our group has used the pulmonary valve repair technique, with a swine bicuspid prosthesis, as part of the remodeling technique of the right ventricular outflow tract, in patients with tetralogy of Fallot, from 6 months of age [4]. This technique allowed to reduce pulmonary insufficiency and right ventricular dysfunction [21].

The demand for new materials and the manufacture of pediatric stent valves, by our Institution, was motivated by the performance observed for the biological prostheses, that are currently on the market [2], [3]. In addition, polymeric valves readily adjust to lower profile designs and are better suited for delivery and implantation into smaller caliber arteries [22], [23].

The design of EPSV is unique (no similar design was found in the literature). The Chr-Co-Mn alloy, It is a flexible material that showed resistance to wear, during fatigue tests, and PU is a biocompatible and biostable material, which is used to manufacture heart prosthesis, of the ventricular assist systems of Abiomed and Berlin Heart [24]. Valve durability was directly related to leaflet thickness, such that an approximate 150 to 200 µ. A recent in vitro fatigue testing showed that polycarbonate-urethane (PCU) valves with leaflet thickness ranging from 150 to 200 µ, were more durable, lasting between 600 million (15.8 years) and 1 billion cycles (26 years) of normal human body function [25].

A collaboration agreement between the University of Texas-Dallas-USA and the São Paulo Federal University-Brazil, focused on performing R&D, allowed the study of the ultrastructure of the explanted prostheses, in order to analyze the presence or not of wear of the stent and degree of mineralization of the polyurethane leaflets.

An initial XPS analysis, to be expanded in subsequent work, is presented here. Briefly, XPS is a surface-sensitive quantitative spectroscopic technique suitable for measuring the elemental composition of the surface of materials with a parts per thousand resolution to determine the chemical and electronic states of the elements in the near surface region (~ 20 nm depth) of materials, showing what elements exist and the chemical bonds between them [26], [27].

The XPs analysis shown above, is promising from the point of view that shows that the surface of PU stent valves, does not get calcified during extended time implantation in animals (Up to 21 months of follow-up) .

In a recent animal study, Kiefer et al. [28] examined the effect of Sapiens valve (Edwards®) crimping on valve calcification and durability. Their conclusion was that pre-crimping of the valve for less than one day will result in no significant change in the structural integrity of valve tissue compared to crimping for more than one day. However, Khoffi and Heim [19] show the mechanical degradation of biological heart valve tissue induced by low diameter crimping. The authors suggest the use of synthetic tissue for the manufacture of stent-valves, with the purpose of increasing durability. Polyurethane is a flexible thermoplastic material with high deformation, which resists the clipping procedure during stenting in the catheter, hence projecting a longer durability of the stent after implantation. The results of the analysis of the physical tests, performed by the engineers of our group using a scanning electron microscopy study, showed that there is no mechanical injury to the PU, confirming the integrity of the valve cusp after crimping, computing a long durability of the implanted prosthesis.

In the hydrodynamic tests, characteristics that Co-Chr material, design with mobile rods (which reduce wear of leaflets) and PU leaflets (150 to 200u) (applied to the stent without suture), allowed for better hemodynamic performance and long durability,

Experimental studies with follow-up, as in our study (21 months), were not found in the literature. Kiefer et al. [28]. Two similar experimental studies using a surgical approach (right thoracotomy) for transcatheter implantation of a polyurethane stent-valve, pulmonary position was published [29], [30]. Unfortunately, both studies had 30 days of follow-up.

The main objective of this study was:

- Assess the intraoperative hemodynamic behavior and during the late follow-up of an Expandable polyurethane stent valve
- Analyze the conditioning process in the catheter, after climping.
- Implant in the pulmonary ring of sheep, up to 3 months old, with a mini-thoracotomy approach.
- Prosthesis expansion, after 6 months of follow-up, using a balloon catheter, by approaching femoral vessels.

The purpose of this experiment was not to evaluate the transcutaneous approach to valve stent implantation, due to the small size of the animals used, with femoral vessels of inadequate caliber for catheter implantation

The hemodynamic performance of the EPSV, showed low transvalvular pressure gradients (M = 6.92 ± 1.5 mm Hg) and unrestricted blood flow with low velocity (1.36 ± 0.14 ms). After 6 months of follow-up, these parameters remained stable: low transvalvular pressure gradients (M = 6.60 ± 1.58 mm Hg) and unrestricted blood flow with low velocity (M = 1.28 ± 0.15 ms).

The occurrence of intrinsic calcification can be attributed to biological material. The study conducted by Alferiev et al [31], demonstrated that bisphosphonate derived polyurethane, improve resistance to calcification in polymeric heart valves.

The manufacture of 3 PU leaflets without sutures, reducing the chance of rupture. However, in case of rupture, another stent with PU valve with smaller diameter, can be easily inserted inside the ruptured stent [32] (Valve in valve procedure).

A clinical trial is being scheduled, through a multicentric study, with the EPSV implant, in a group of patients with pulmonary insufficiency, with right ventricular dysfunction, after correction of tetralogy of Fallot.

V. CONCLUSIONS

Association between: stent - design and PU – leaflets, had reduction of prosthesis wear in vitro and in vivo tests, regardless of the stent valve diameter. The resistance of polyurethane to crimping and the lack of calcification of leaflets, are advantages that will allow greater durability of the prosthesis. This new concept of synthetic expandable stent valve could be a viable option in growing patients

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Table 1 - Variables imposed by the Cardiac Simulator

Cardiac rate	**60 bpm**
Systolic volume (SV)	**70 ml**
Final diastolic volume (FDV)	**120 ml**
Final systolic volume (FSV)	**50 ml**
Left ventricle cardiac output (LVCO)	**4.2 L**
Duration of ejection	**250 m/s**
Aortic pressure	**80-120 mmHg**
Left ventricular diastolic pressure (LVDP)	**4-10 mmHg**
Left ventricular systolic pressure (LVSP)	**4-125 mmHg**
Approximate arterial compliance	**2,2 ml/mmHg**
Duration of systole	**360 m/s**
Dynamic viscosity of fluid analogous to blood	**4 mPa**
Fluid temperature	**20-25°C**

Bpm= Bit per minute, L= liters, m/s= meters / second, mPa= micropascal

ISSN No:-2456-2165

Table 2. Immediate Results of Expandable Polyurethane Stent Valve, Implanted in Pulmonary Artery.

	Date	***Sex***	***Identif.***	***Weight Kg***	***Pulmonary Valve mm***	***Prost. mm***	***PFR pre m/s***	***PFR post m/s***	***RV-PA pre mmHg***	***RV-PA post mmHg***
1	*26/08/2016*	*Female*	*373*	*28.5*	*19.5*	*22*	*1.10*	***1.80***	*3.10*	***6.40***
2	*13/09/2016*	*Male*	*375*	*28*	*19.6*	*22*	*1.04*	***1.27***	*4.30*	***6.50***
3	*13/09/2016*	*Male*	*369*	*18.5*	*18.5*	*18*	*1.00*	***1.20***	*4.00*	***5.80***
4	*20/09/2016*	*Male*	*374*	*22*	*18.8*	*18*	*0.87*	***1.53***	*3.00*	***9.40***
5	*20/09/2016*	*Female*	*305*	*18*	*16.3*	*18*	*0.90*	***1.63***	*3.20*	***10.00***
6	*23/09/2016*	*Female*	*365*	*31.5*	*18.5*	*22*	*0.79*	***1.28***	*2.50*	***6.50***
7	*11/10/2016*	*Female*	*366*	*21*	*16.2*	*18*	*0.91*	***1.28***	*3.30*	***6.50***
8	*18/10/2018*	*Female*	*301*	*28*	*17*	*22*	*0.68*	***1.18***	*1.90*	***5.60***
9	*18/10/2018*	*Female*	*333*	*31*	*20.7*	*22*	*0.71*	***1.25***	*2.00*	***6.30***
10	*18/10/2018*	*Female*	*372*	*18*	*16.9*	*22*	*0.80*	***1.25***	*2.50*	***6.20***
	Total			*244.5*	*182.0*	*204.0*	*8.80*	*13.6*	*29.8*	*69.2*
	Mean			***24.45 ± 6.25***	***18.20 ±1.53***	***20.4 ±2.07***	***0.88 ±0.14***	***1.36 ±0.21***	***2.98 ±0.78***	***6.92 ±1.5***

RV- PA G= Right ventricle – Pulmonary artery gradient, PFR= pulmonary flow rate, Pre= Preimplant; Post:= Postimplant, m/s= meters / second,

Table 2. Immediate Results of Expandable Polyurethane Stent Valve, Implanted in Pulmonary Artery.

	Date	***Sex***	***Identif.***	***Weight Kg***	***Pulmonary Valve mm***	***Prost. mm***	***PFR pre m/s***	***PFR post m/s***	***RV-PA pre mmHg***	***RV-PA post mmHg***
	26/08/2016	*Female*	*373*	*28.5*	*19.5*	*22*	*1.10*	***1.80***	*3.10*	***6.40***
2	*13/09/2016*	*Male*	*375*	*28*	*19.6*	*22*	*1.04*	***1.27***	*4.30*	***6.50***
3	*13/09/2016*	*Male*	*369*	*18.5*	*18.5*	*18*	*1.00*	***1.20***	*4.00*	***5.80***
4	*20/09/2016*	*Male*	*374*	*22*	*18.8*	*18*	*0.87*	***1.53***	*3.00*	***9.40***
5	*20/09/2016*	*Female*	*305*	*18*	*16.3*	*18*	*0.90*	***1.63***	*3.20*	***10.00***
6	*23/09/2016*	*Female*	*365*	*31.5*	*18.5*	*22*	*0.79*	***1.28***	*2.50*	***6.50***
7	*11/10/2016*	*Female*	*366*	*21*	*16.2*	*18*	*0.91*	***1.28***	*3.30*	***6.50***
8	*18/10/2018*	*Female*	*301*	*28*	*17*	*22*	*0.68*	***1.18***	*1.90*	***5.60***
9	*18/10/2018*	*Female*	*333*	*31*	*20.7*	*22*	*0.71*	***1.25***	*2.00*	***6.30***
10	*18/10/2018*	*Female*	*372*	*18*	*16.9*	*22*	*0.80*	***1.25***	*2.50*	***6.20***
	Total			*244.5*	*182.0*	*204.0*	*8.80*	*13.6*	*29.8*	*69.2*
	Mean			***24.45 ± 6.25***	***18.20 ±1.53***	***20.4 ±2.07***	***0.88 ±0.14***	***1.36 ±0.21***	***2.98 ±0.78***	***6.92 ±1.5***

RV- PA G= Right ventricle – Pulmonary artery gradient, PFR= pulmonary flow rate, Pre= Preimplant; Post:= Postimplant, m/s= meters / second,

ISSN No:-2456-2165

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Table 3- Transesophageal 3D Echo – study

	Results			***Follow-up = 6 months***					
N	**Ident**	**Weight**	**Prosthesis**	**Follow-up**	**Grad RV-PA**	**Valvar**	**Prost.**	**Calcific**	**Stent**
	(Kg)	**Diameter (mm)**		**(days)**	**(mmHg)**	**Insuf.**	**Leak**	**Position**	
1	375	34	22	180	8.0	Discret	Absent	Absent	PR
2	369	27.5	18	180	6.0	Discret	Absent	Absent	PA
3	374	32	18	160	5.0	Discret	Absent	Absent	PA
4	365	35	22	160	5.0	Absent	Absent	Absent	PR
5	366	25	18	160	12.0	Discret	Absent	Absent	PA
6	301	30	22	150	6.0	Absent	Absent	Absent	PR
7	333	36	22	150	5.0	Absent	Absent	Absent	PR
8	372	24	22	150	6.0	Absent	Absent	Absent	PR
		Mean 36.25			**163.75**		**6.6**		

PR= pulmonary ring - PA= pulmonary artery

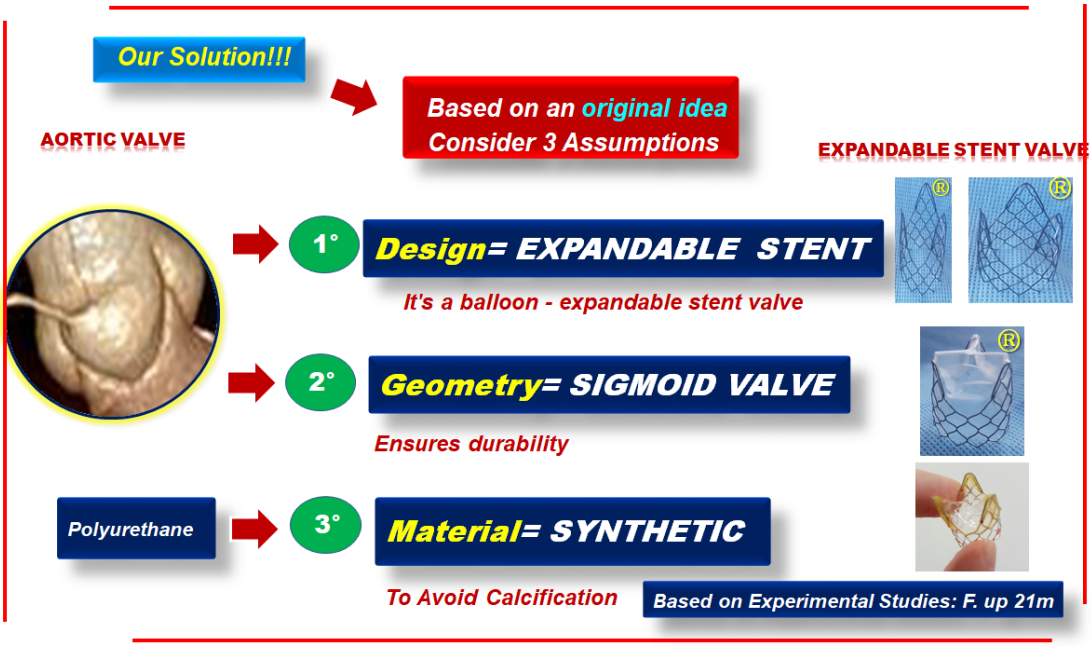

Figure 1. Concepts, Criteria and Solutions, for the manufacture of a new synthetic prosthesis.

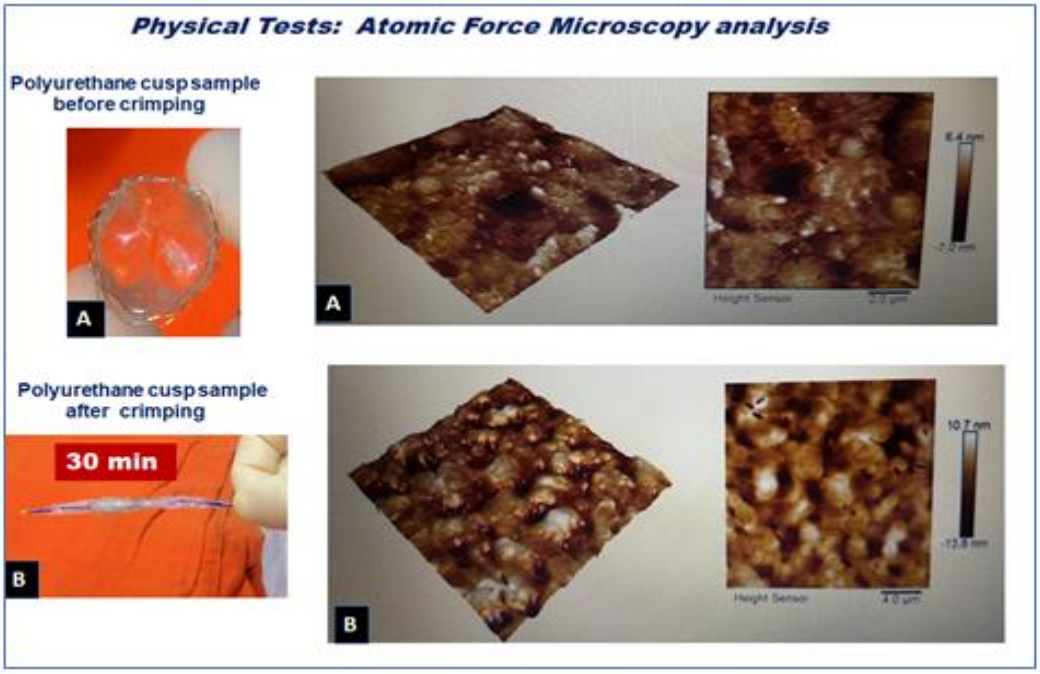

Figure 2. Photography of Images of 20 x 20 µ. A - Height variations in the order of 25 nm, non-crimped prosthesis and B-Crimped prosthesis. There was no difference in the PU structure.

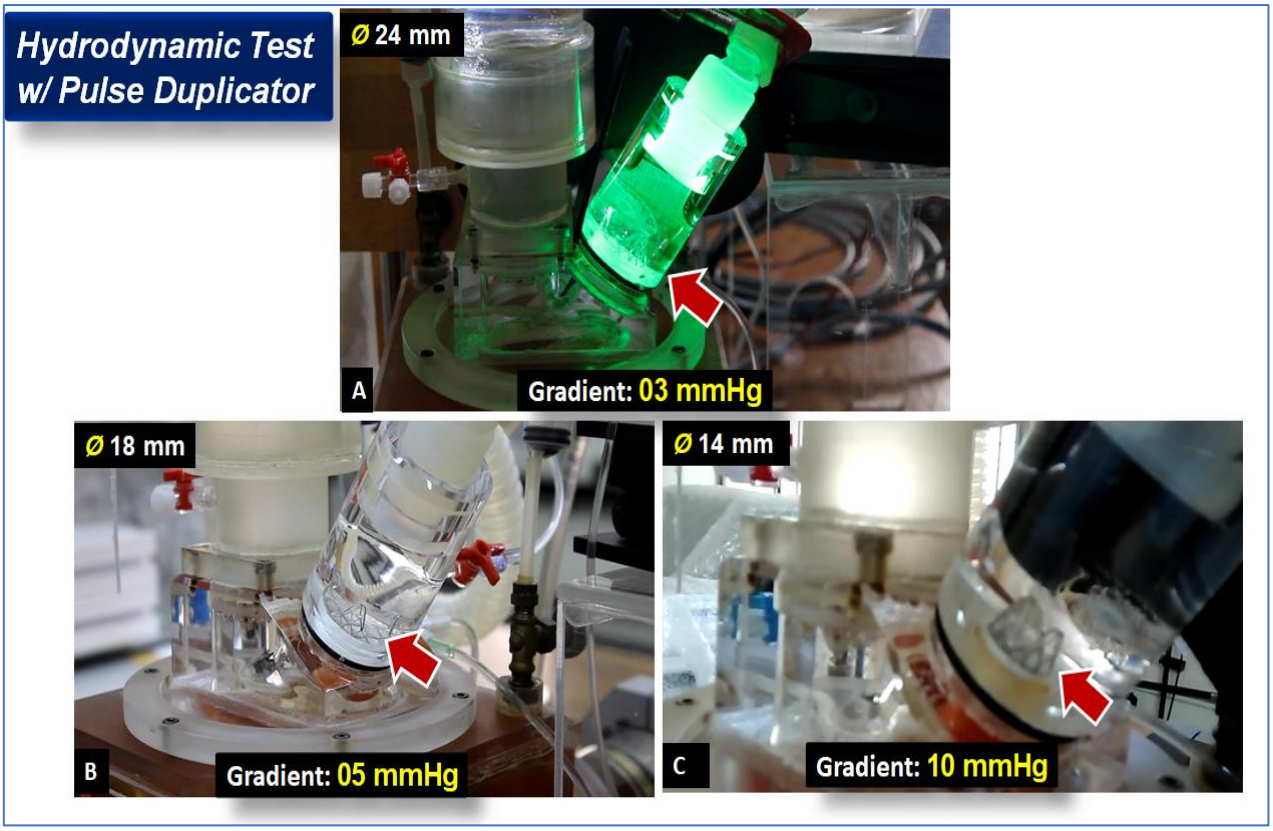

Figure 3. Hemodynamic performance of Expandable Polyurethane Stent Valve (arrows), employing pulse duplicator, with Systemic Pressure, (mmHg). A: Stent valve with a diameter of 24 mm, obtaining a gradient average = 3mmHg, B: diameter of 18 mm, mean gradient = 5 mmHg and C: diameter 14 mm, mean gradient = 10 mmHg.

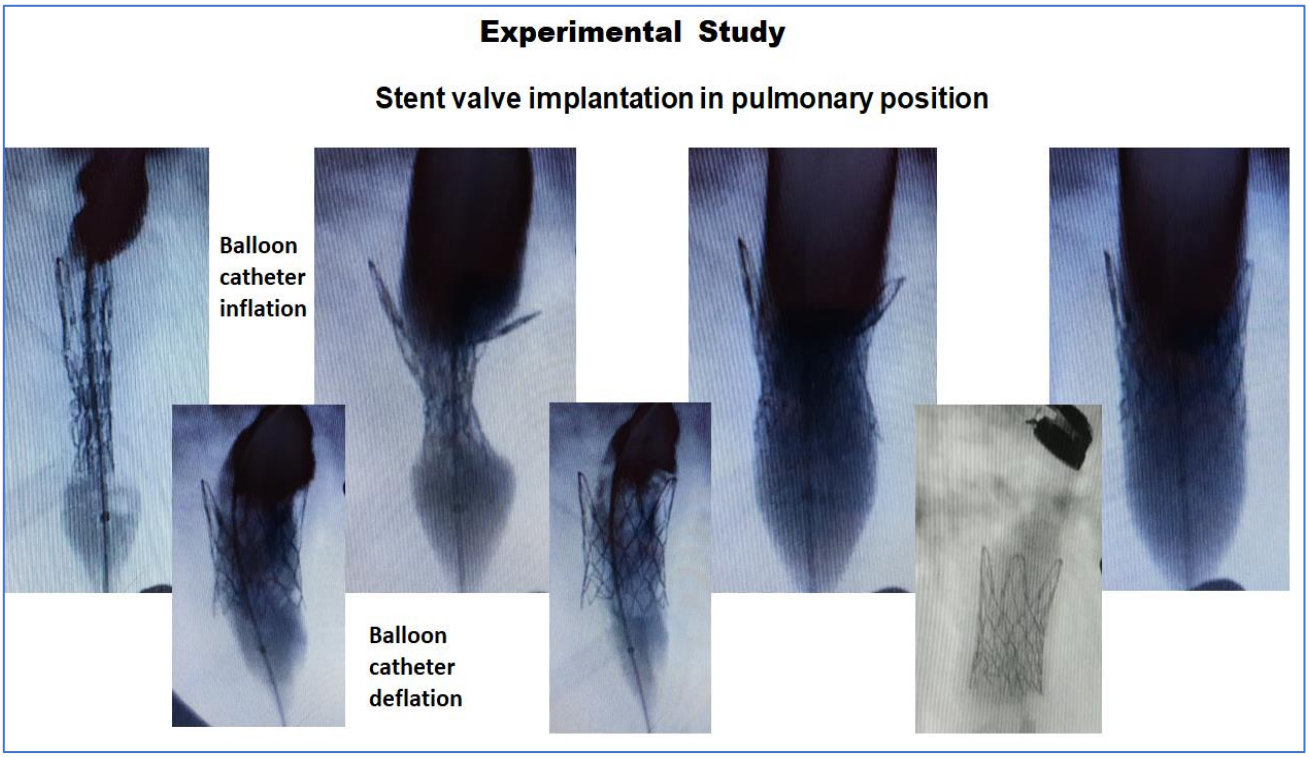

Figure 4. Photography of Radiological images of experimental procedure (sheep) of implantation of the prosthesis by catheter, in pulmonary position. Inflation of the balloon, with expansion of the stent valve; deflation of the balloon and finally injection of Iodized solution, for testing the prosthesis performance.

ISSN No:-2456-2165

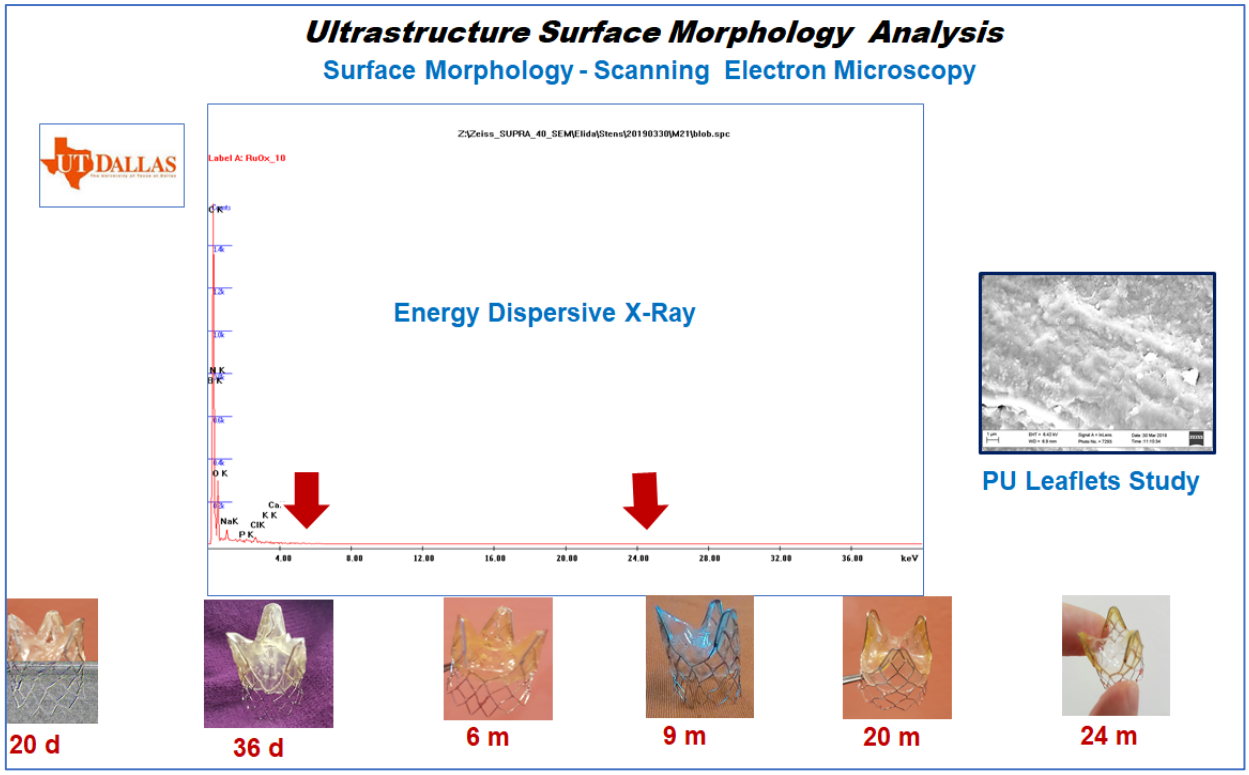

Figure 5. The surface of six stent valves explanted between 6 and 21 months were submitted to study by Scanning Electron Microscopy (SEM) by analysis of polyurethane (PU) leaflets morphology and by X-ray Photoelectron emission Spectroscopy (XPS) to characterize the surface chemistry of the PU, without signs of mineralization (arrows), after exposure to pulmonary circulation of sheep. Analyses performed at the *University of Texas- Dallas.*