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MECHANICAL PROPERTIES OF CORONARY VEINS

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Abstract: *There are several publications available and experiments were done regarding to the vessel biomechanical properties. In the range we could find in vitro and in vivo assessments data for elasticity properties. Even though we have many results in this topic we still don't have enough data for special veins. Three coronary veins were investigated from pig's heart. The aim of these experiments was to define and measure the longitudinal tensile stress and tensile strength of coronary veins. The tensile tests were done successfully and the tensile stress was defined in the range of 1.66-2.57 MPa.*

Keywords: *Coronary sinus, Longitudinal tensile stress, Longitudinal strength*

1. INTRODUCTION

In the last few years the Cardiac Resynchronization Therapy has became one of the most rapidly developing pacemaker therapy type. Those patients who need that kind of therapy already have mechanical and/or electrical delays between the two ventricles. With pacemaker leads placed in the right ventricle apex and coronary sinus, have the possibility to change the activation pattern and avoid the delay between the two chambers.

The most important to avoid is the intrinsic activation in the ventricles because in that case the delay still exist. Therefore necessary to achieve 100% pacing in the ventricles but the only chance to reach left side is the coronary sinus where the lead placement most of the cases not enough stabile. In recently several solutions were developed but there still don't exist a fixation mode which is stabile enough to maintain 100% pacing. To find a good fixation mechanism first we should define the mechanical and elastic properties of coronary vein.

There are lot of articles regarding to the vessel biomechanical load, but these are mainly investigate arteries from different part of the body. In our view the properties of coronary vessels are the most important. Coronary artery already evaluated due to the high number of patient suffering from cardiovascular disease. Number of studies have considered the artery to be a two layered structure theoretically and experimentally [1,2,3], also founded that blood vessels have incremental elastic modulus even if we investigate both for laws of elasticity and laws of viscoelasticity [4,5].

Data available for veins more or less concerning to saphenous veins, the breaking pressure [6], the mean tangential stress and elastic modulus was evaluated [7,8]. Also well known the fact whether the wall thickness and isobaric elastic properties of vein grafts increasing after a few days and rearrangement of the elastic structures occurs [9,10].

Even though several studies the elastic modulus and tensile strength of coronary sinus not defined until now. The aim of this investigation is to evaluate the tensile strength and tensile stress of coronary sinus with in vitro assessment.

2. MATERIALS AND METHODS

Fig.1: Coronary sinus preparation from pig heart

Three pig hearts were examined. All of was received from slaughterhouse and immediately after removal delivered within one hour, in a special Homograft solution (50ml Mycosyst, 50ml Dimetil-Szulfosid, 1. amp. Mandokef, 400ml Ringer solution) to the Semmelweis University, Cardiovascular Centre. With the support of Dr. Endre Zima, coronary sinus (CS) parts were prepared from the hearts (Fig.1,2).

Based on the structure and properties of coronary vein network really difficult to have more than 1 cm period of CS without any side branch. It is obvious if the side branches remain without any tying, during tensile test these are working as trouble spots and because of that all of it was tied.

Fig.2: Prepared and tied coronary sinus

All of CS parts were measured after preparation, length, diameter, wall thickness (Table 1) and cross section was calculated with the assumption that the vein part similar to a tube. The veins were stored in the same special solution until tensile tests were started at Budapest University of Technology and Economics, Department of Materials Science and Engineering.

	Average diameter [mm]	Wall thickness [mm]	Length [mm]	Cross section [mm^2]
1. vein	4.3	0.9	46	8.79
2. vein	3.9	0.7	57	6.21
3. vein	4.5	1	43	10.17

Table 1: Length, diameter and cross section of coronary sinus parts

First of all a fixation mode of coronary sinus was developed and tested on a plastic tube with similar diameter and length in order to avoid the damage of coronary sinus. The first examination was unsuccessful because the diameter of the shaft -what was used to keep the cylindric type- was lower. After that a new turned metal shaft (Fig.3) was used for keeping the cylindrical type and with it, the second test was successful and the fixation mode was ready for the real examination.

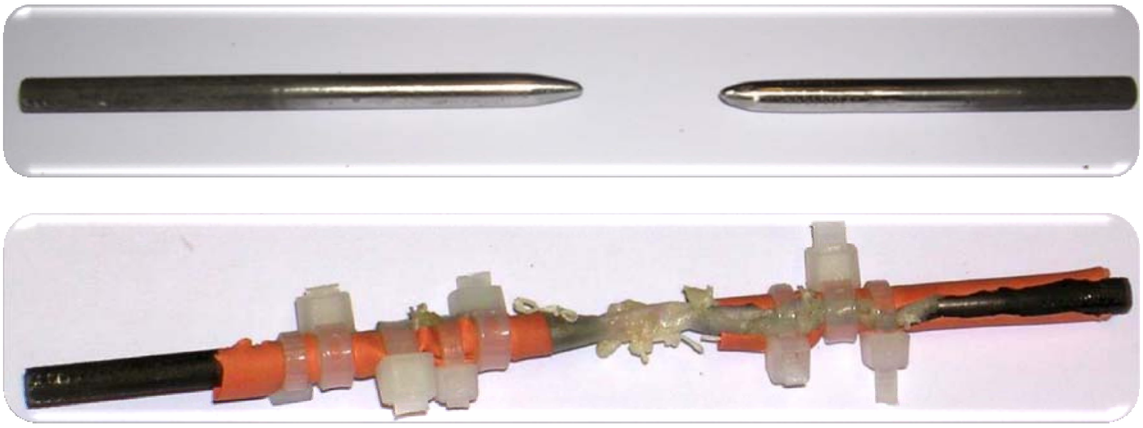

Fig. 3: Fixation mode with the new turned metal shaft

For tensile strength an Instron Hydraulic 8501 tensile test machine was used with a stretching speed about 20 mm/sec because the usual speed for metals is founded to slow for those veins which have the possibility to elongate.

3. RESULTS OF TENSILE TEST

All the three coronary sinus part was investigated. The fixation mode was founded to stabile during the first two tests, but the third vein displaced from the fixation and it is clearly seen in the graph. The shaft inside of the vein kept the cylindrical type of the CS until the tear. The force in function of displacement was recorded in all case (Fig.4-6.).

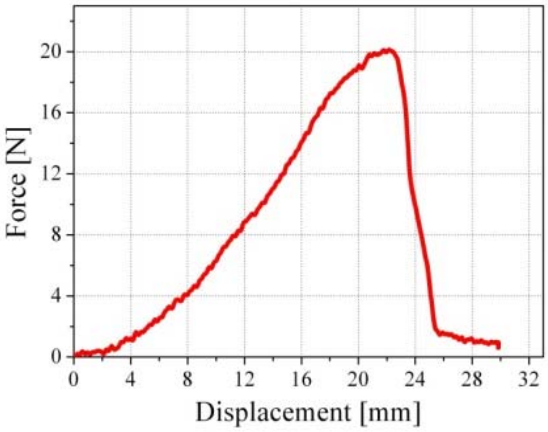

Fig. 4: Force [F] – Displacement [ΔL] curve of 1. vein

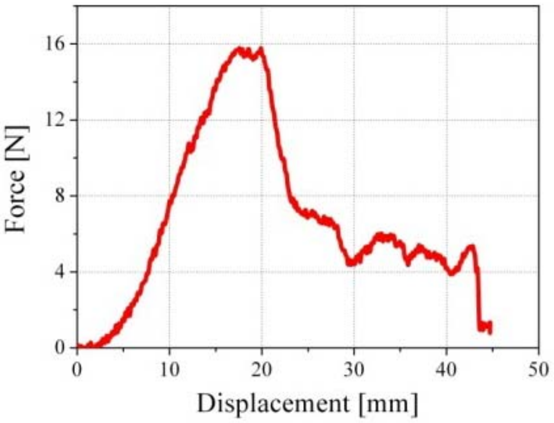

Fig. 5: Force [F] – Displacement [ΔL] curve of 2. vein

From the curves it is obvious that in the third case the fixation mode wasn't enough stabile keep the vein on the shaft and because of that we couldn't examined the real tension stress of the CS. Even though that the examination was failed it is known that the 16 N not enough high to tear the vein.

Prof Emil Monos and he's group investigated the elastic modulus of different veins based on the Laplace-Frank equation [11]. They used the intravascular pressure to measure the tangential elastic stress and the relative displacement. But in the view of pacemaker lead fixation mechanism more important to know a maximal force and stress what cause tearing in order to avoid the injury of coronary vein during and after implantation.

Based on that issue the force-displacement curves of vein tests were adapted to evaluate the tensile stress with equations (1) (Table 2).

$$\sigma = \frac{F}{A_0} \qquad (1)$$

$$\varepsilon = \frac{\Delta L}{L_0} \cdot 100\% \qquad (2)$$

$$E = \frac{\sigma}{\varepsilon} \qquad (3)$$

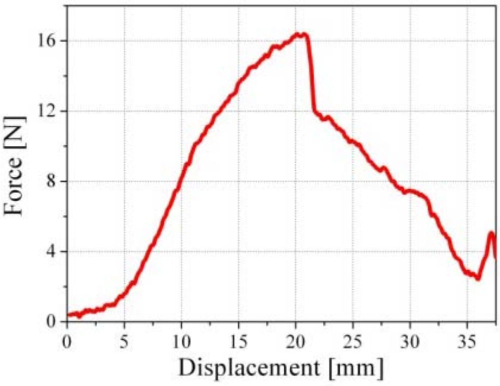

Fig. 6: Force [F] – Displacement [ΔL] curve of 3. vein

Where is σ - stress, ε - strain and E - Elastic modulus. For this calculation the starting cross-sections (A_0) and the starting length (L_0) of the veins was already known.

During the tests it was evident that the maximal force caused the tearing of the vein. Because of that the tensile stress was calculated with the measured maximal force from the different force-displacement curves of all the veins tested.

	Maximum force [N]	Tensile stress [MPa]	Relative extension [%]	Chord elastic modulus [MPa]
1. vein	20.6	2.34	49	4.78
2. vein	16	2.57	35	3.42
3. vein	16.92	1.66	47	3.52

Table 2: The tensile stress, relative extension and chord elastic modulus of coronary sinus parts

The relative extension was also calculated with the equation (2) (Table 2) for all the veins. The investigation of elastic modulus with this kind an investigation method wasn't aim of the study. Like the registered curves the tensile stress in function of relative extension is nonlinear. In spite of this, it is possible to define an approximate elastic curve to the coronary vein. As it used for polymers it is possible to define a chord elastic modulus which is a linear curve to one point of the tensile stress in function of relative extension curve. If the elastic modulus -based on Hook Law- evaluated with the tensile strength (3) an approximate elastic curve can be made with a chord elastic modulus (Table 2) connected to the tensile strength.

4. CONCLUSIONS

The tensile strength and tensile stress was evaluated successfully. Despite of that, it should be considered to repeat the in vitro tests with higher number of coronary veins to have statistic. Important to take into consideration the environment of the veins and do the test in special solution on a special temperature. It is also necessary to take into account the role of tied side branches during tests. To avoid it and define also the axial strength of the CS a rectangle coronary sinus samples should be prepared in order to evaluate the axial tensile stress and strength either. Also necessary to develop a new fixation mode for the vein what is more stabile during the tensile test.

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