11th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

SOME CONSIDERATIONS ON OPTIMAL DIAMETER OF A MECHANICAL VALVE PROSTHESIS AND ITS QUALITY EVALUATION PARAMETERS"

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ABSTRACT
Cardiovascular illness treatment constitutes a vast market, the demand being extremely various from simple drugs till supporting circulation temporary devices for implanted artificial hearts. Concerning different "philosophical" considerations from the argument point of view, it must be mentioned that treatment is rarely resolving, more often a life quality improvement is obtained. The problem of valve prosthesis diameter is a very sensitive one, because its quality must ensure not only dimensional but also physiological parameters. In this paper we propose to present the dependence between valve's diameter and its type, patient's homodynamic characteristics and its physical activity. Also, in order to choose the appropriate diameter of a valve prosthesis one must take into account the relationship between pressure passing through valve, the temporary evolution of the blood volume and the cardiac frequency. Further, some dimensional and non-dimensional parameters that estimate the valve's quality function are presented: the effective passing section, the effective free section, and reflux.

1. ELEMENTS OF HEART'S PHYSIOLOGY AND PATHOLOGY
Many ill human parts need mechanical or electric devices: kidney, blood and vessels, valves, heart's muscle etc. Cholesterol particles and grease deposed internally to thicken blood vessels drive flow reduction, reduced oxygenation till occlusion. If the plates are deposed on valves (Figure 1), they can produce heart attack. Growing of cholesterol plates is foreseeing by angiographies, and other tests.

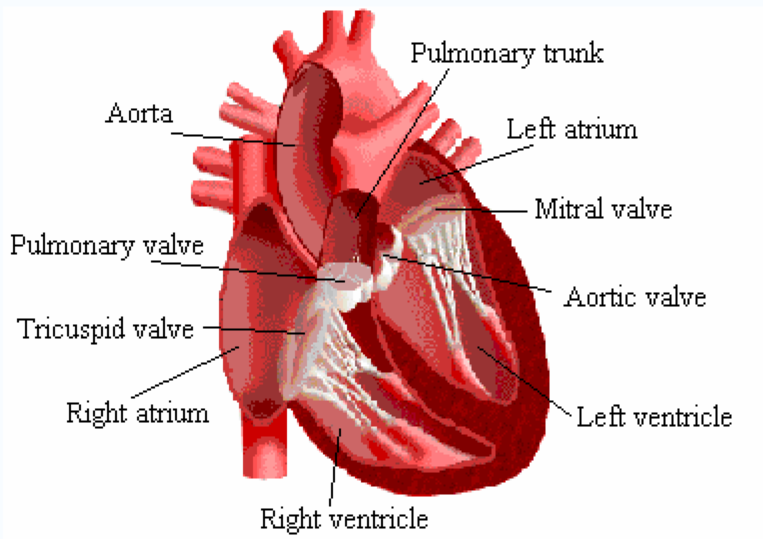

Figure 1. Heart's valves.

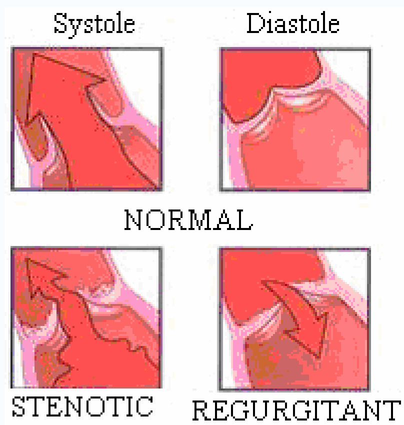

Figure 2. Valvular functions.

Generally the drugs are not sufficient and their mechanical removal or vessel's enlargement by graft or by-pass is imposed (even relapses are often reported).
Valve's principal illnesses (Figure 2)are insufficiency (regurgitant - incapacity to stop retrogressive flow during closing phase) and incapacity to open enough (stenotic - due to partial welding of valve's boards). Both illnesses can coexist and diagnosis is quite rapid and simple through specific symptoms, utilized intervention being plastic valves' surgery or, in grave cases, replacement of valves with mechanical or biological devices.

2. TYPES OF VALVE PROSTHESIS

Valve prosthesis are of two types: biologic and mechanic. Mechanic valves are done from materials having a higher strength than the natural ones tissues (figure 3) as special steels and are doing themselves the guidance of blood flow. But regularity in flow running is not always ensured (and also coagulation), with great deviations, turbulent and slow zones, presenting great danger for blood as thrombosis. This last mentioned phenomenon is aggravated by closing mechanism of valve leafs which have the tendency to crush red blood cells. In any case, mechanical valve prosthesis a much long life lasting, effort resistant and can be used for all types of replacement (aortic, mitral, tricuspid).

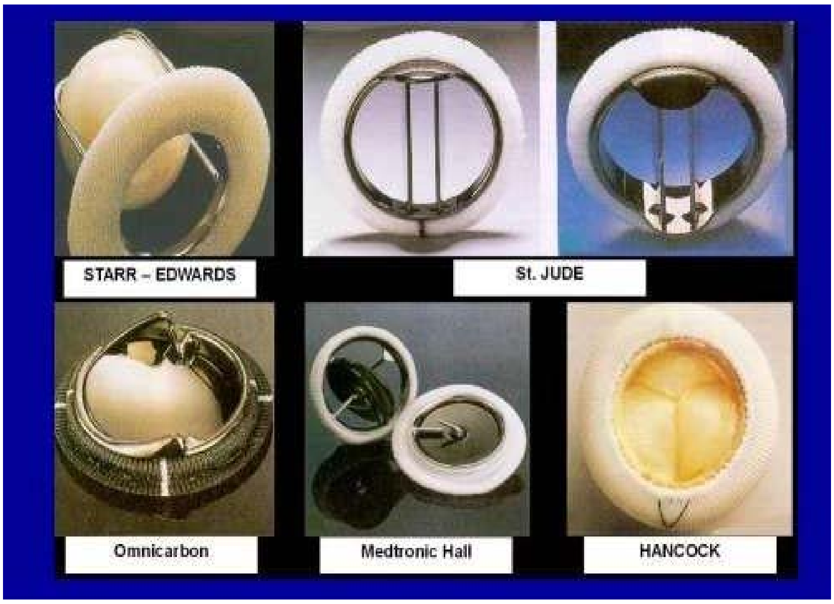

Figure 3. Mechanic valves

Figure 4. Biologic valve.

Biologic valves are composed from three parts: biologic tissue, tissue for fixation and support ring (stent) and made by cutting leafs from animal tissues: pig valve, bovine pericardial, and human tissue, mounted on metallic, polymeric or biologic support. Preparing biologic valves supposes many phases and preliminary treatment to reduce rejection process and, consequently, they are very expansive. This valve type rarely present rapid and fatal damage – it appears gradually and provoke specific symptoms.

3. CALCULUS OF VALVE PROSTHESIS OPTIMAL DIAMETER

Calculus of optimal diameter of valve prosthesis to be implanted is done in accord with valve type (aortic or mitral), patient hemodynamic characteristics and physical activity usually performed (repose or effort). For a correct choice of valve, it is necessary to take into account the connections between pressure drop at its end, temporally evolution of the volume and cardiac frequency.
Valves can be considered as zones with dimensional variation producing instantaneous energy loss, illustrated by pressure variation, given by the next equation:

$$\Delta P = \frac{8 \cdot \alpha \cdot \rho \cdot q^2}{\pi^2 \cdot D^4} = k \cdot \frac{q^2}{D_4}, \text{ with } k = \frac{8 \cdot \alpha \cdot \rho}{\pi^2}, \tag{1}$$

where: α is energetic loss coefficient, q is blood flow, ρ the blood density, D the passing diameter in valve and k is defined as a constant proportional with energy loss at the end of the prosthesis.
Average energetic loss during the period T (ventricular systole or diastole) is given by the integral of instantaneous energetic losses and this drives us to the conclusion that it is necessary to know the temporary evolution of volume. For the aortic valve blood volume (cardiac discharges) the Swanson and Clark (1977) equation is representative (eq. 2) and for volume evolution through mitral valve, the Talukder and Reul (1978) equation (eq. 3).

$$q_s = Q_s \cdot \left[0{,}924 \cdot \boldsymbol{sin}\left(\frac{\pi \cdot t}{T_s}\right) + 0{,}23 \cdot \boldsymbol{sin}\left(\frac{2 \cdot \pi \cdot t}{T_s}\right) + 0{,}092 \cdot \boldsymbol{sin}\left(\frac{3 \cdot \pi \cdot t}{T_s}\right)\right], \tag{2}$$

$$q_m = Q_m \cdot \left[0{,}52 \cdot \boldsymbol{sin}\left(\frac{\pi \cdot t}{T_d}\right) + 0{,}257 \cdot \boldsymbol{sin}\left(\frac{2 \cdot \pi \cdot t}{T_d}\right) + 0{,}479 \cdot \boldsymbol{sin}\left(\frac{3 \cdot \pi \cdot t}{T_d}\right)\right], \tag{3}$$

where: T_s indicates the duration of ejection phase (ventricular systole), T_d is the duration of ventricular diastole, Q_s is the maximal value of instantaneous aortic volume and Q_m the same value for mitral volume (recharge or ventricular diastole).
If the duration of the whole cardiac cycle is defined as: $T_c = T_d + T_s = f^{-1}$ the average volume will be given by:

$$\overline{Q} = \frac{1}{T_c} \int_{T_s} q_s dt = \frac{1}{T_c} \int_{T_d} q_m dt = f \cdot \int_{T_s} q_s dt = f \cdot \int_{T_d} q_m dt \tag{4}$$

After transformations in equation (2), (3) and (4), the instantaneous systolic and diastolic maxim volume is:

$$Q_s = 1{,}65 \cdot \overline{Q} \frac{T_c}{T_s} \quad \text{and, respectively,} \quad Q_m = 2{,}32 \cdot \overline{Q} \frac{T_c}{T_d}, \tag{5}$$

with a relationship between T_d and T_s calculated by Katz and Feil (1923): $T_s = \sqrt{0{,}096 \cdot T_c}$, the constant 0,096 being measured in seconds. To augment cardiac frequency, the systolic phase is quite constant and diastole is reduced.
Using previous equations, average pressure variation (energetic loss) in aortic valve is determined as function of frequency f average volume, passing blood diameter D and the constant k of energetic loss. Analogous, the same calculus will be performed for mitral valve, obtaining the next two equations:

$$\overline{\Delta P_a} = 12{,}88 \cdot k_a \cdot \frac{\overline{Q}^2}{D_a^4} \cdot \frac{1}{f} \quad \text{and respectively} \quad \overline{\Delta P_m} = 1{,}51 \cdot k_a \cdot \frac{\overline{Q}^2}{D_m^4} \cdot \frac{1}{\left(1 - \sqrt{0{,}096 \cdot f}\right)}, \tag{6}$$

with the values: 12,88 expressed in seconds^{-1} and 1,51, non dimensional. Logically, the above equations (6) allow to obtain the inner diameters of valves:

$$D_a = D_a = \sqrt[4]{\frac{12{,}88 \cdot k_a \cdot \overline{Q}^2}{\Delta P_a \cdot f}} \quad \text{and respectively,} \quad D_m = \sqrt[4]{\frac{1{,}51 \cdot k_m \cdot \overline{Q}^2}{\Delta P_m \cdot \left(1 - \sqrt{0{,}096 \cdot f}\right)^2}} \tag{7}$$

Using previous relations, abacus allowing the rapid choose of the inner diameter of the prosthesis to be implanted are done, in accord with the patient characteristics (average volume, frequency, transvalvular pressure variation) and valve type (mitral or aortic), indicated by *k*parameter (Fumero, Pietrabissa, 1986).

4. VALVULAR MECHANIC PROSTHESIS EVALUATION PARAMETERS

In order to evaluate the quality of functional behavior, several parameters are more often used, as:

- ***EOA* (effective orifice area),** used by cardiologist as to know the efficient passing section:

$$EOA = \frac{Q}{C \cdot \sqrt{\Delta P_{PF}}} = \frac{Q}{3{,}1 \cdot \sqrt{\Delta_{PF}}} \ [\text{cm}^2], \qquad (8)$$

with Q [l/min] – blood volume and ΔP_{PF} [mm·Hg] – maximal transvalvular pressure variation.

- ***DC* (discharging coefficient),** is a non dimensional coefficient expressing the ratio between *EOA* (an equivalent section) and inner area of the prosthesis (a measured area, representing the effective free area for blood pass)**:**

$$DC = \frac{EOA}{A_I} \qquad (9)$$

- ***PI* (performance index)** is still a non dimensional parameter given by the ration between *EOA* and mounting surface A_m of the prosthesis, meaning that it shows the effect of joint (welding):

$$PI = \frac{EOA}{A_m}. \qquad (10)$$

If *DC* is kept constant, a greater *PI* indicates a greater reduction of the diameter due to the valve's joint and, reciprocally, if *PI* is constant, a greater *DC* allows a better blood flow (bigger section) and les ΔP.

- ***RF* (ebbing percentage)** represents the percentage of volume passing through the closed valve (regurgitant working):

$$RF = \frac{ebb\ volume}{principal\ volume} \cdot 100\ [\%]. \qquad (11)$$

5. CONCLUSIONS

In vascular pathology, valvular illnesses still present a great incidence. In their treatment, especially for advanced valvular damages, it is strongly necessary to replace the natural one with an artificial valve. From the hydraulic point of view, a heart valve is a mono directional one that guides the blood flow by opening and closing itself and by producing pressure gradients. Apparently, very simple in fact it has a complex structure and a correlated function with other functions of intra cardiac structures. Mechanisms of valves' damaging by different pathologic process are still not completely known and also, details that confer to it the mechanical durability as alive structure.

6. REFERENCES

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