Is the Heart a Suction Pump?

Agonist

JORGE C. TRAININI[MTSAC, 1]

BACKGROUND

Francisco Torrent Guasp never believed that the blood could enter the left ventricle if it was not by a suction device. He considered that the difference of the peripheral pressure with the heart is small and it cannot do it *vis a tergo*. The slop that returns it, is the ventricular aspiration. The heart is a structure formed by a muscular band that begins in the insertion of the pulmonary artery and ends at the level of the aorta, forming a double helix, which limits the ventricles. The two chambers that surround the muscular band are the left of ellipsoid shaping and the right of crescentic structure.Well, the contraction of this band not only explains the systole of the heart, but also suction blood (1) (Figure 1).

The inevitable question that arises is what, wherefore they can wring the bundles that surround the ventricles, they should do it on a rigid fulcrum just as a tendon does it, having a bony insertion lever: Are there in the heart? The heart does not need this support. When the heart fills with blood, this behaves as a bony insertion. The muscular band is a double helix suspended from the aorta and pulmonary artery that uses as buttress the hemoskeleton, that is to say, the cardiac filling. On this point, by rotating the base and apex of the left ventricle in opposite directions, a muscle twist is produced. This counterclockwise movement of the apex allows it to generate high pressure reducing deformation. Just like if you twist a towel. (2, 3)

SUCTION PUMP

> *"The cardiac mechanics is homologous to that of the circular fibers of blood vessels, which carry out their fuction without fixed fulcrums."*
>
> Francisco Torrent Guasp (4)

In classical models, after each systole, the heart remains passive filling with blood as a result of venous pressure. (5) By contrast, in the current development, a ***quantum*** of energy from each systole is stored in the same heart and activates the next stage of relaxation. (6) The physiological validity of the former model is endorsed by the Frank-Starling law, but actually this: a) does not reflect the interaction between systole and diastole and b) that law was enunciated with hearts removed.

In the current model, the relationship between both cardiac phases is critical for the proper functioning of the heart. Now, the energy stored in systole, **How is it spent in diastole?**

1. For the movement that gets in systole, the heart is pushed down and the blood in reverse direction (action-reaction principle of Newton). In diastole, however, the heart is projected upwards against the blood flow that enters. The latter increases the speed of the blood and helps to impulse the filling.
2. Systole compresses both the elastic elements of the heart as its muscular fibers to the point that even the natural tendency of ventricles is toward the expansion without any external filling. In this way it is generated a negative intraventricular pressure or suction. Tyberg, (7) occluding the mitral valve in the dog with a balloon, has shown that in diastole the left ventricle produces a decrease of pressure below zero. This makes the heart to be a dynamic suction pump, but for this pump has effectiveness, the dynamics of elastic recoil must have a limitation that allows an effective later systole. (2)

Let's recall that in the traditional model the output is only determined by the venous filling pressure on the right side. Atrial pressure is too low to explain the filling of the heart. On this ***key question*** in relation to the classical explanation, Francisco Torrent Guasp developed the concept of active suction pump buttressed by physiomuscle structure that he described. The last compressed areas of the ascending segment of apical myocardial loop produce suction blood from the atrium into the left ventricle. (6) This situation would bring unexplained situations in electrophysiology, because the T wave would coincide with the contraction of the septum, which makes essential investigations about the matter. (8)

Heart movements during systole and diastole respond to phenomena of inertia and elastic recoil, not to static filling pressures. The hearts of mammals persist in their emptying and filling after being removed and placed in buffered solution. The length that the cardiac muscle fibers reach, it is not determined only by the position of cardiac filling: suction mechanism is also involved.

On the other hand, if there is failure in systolic contraction, as it occurs in heart failure, it is possible

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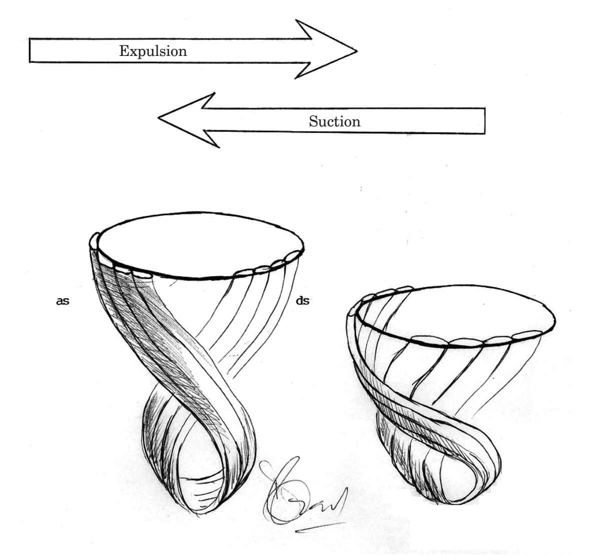

Fig 1. aca falta la traduccion

to think that there will not be enough energy release in the relaxation phase. The role of venous filling pressure, in these hearts, is here more relevant according to the Frank-Starling law.

HOW IS PRODUCED THE DIASTOLIC SUCTION?

The evidences are present from the current functional anatomy to the microscopy one. The anatomical description in double helix of The Torrent Guasp great myocardial band mimics in its torsion the microscopic connective structure of heart support, situation that reinforces this investigation. The lengthenings reside both in the own structure of the sarcomere as in the components of the muscle cell that makeup the cytoskeleton. (7) The sarcomere is expanded laterally and increases its diameter. This lateral expansion extends the Z discs. Thus, it becomes the storage mechanism of part of the energy of contraction that could be used as energy of expansion. (9)

In this participates the connective tissue. The outer surface of muscle cells is covered with connective fibers of collagen and elastin with stress-strain properties arranged in network in a helical way. This network structure returns to the muscle cells its original configuration by preventing the occurrence of an excessive stretching of the sarcomeres in order to get a good suction during the relaxation phase.

The fibrous cytoskeleton should be understood as the sum of the fibrous interlaced components, essential for the preservation of ventricular geometry. The scaffolding composed by collagen coordinates the muscle fibers to collect them in packs of growing structures, having as a goal to maintain an optimal stretch to obtain an effective posterior contraction. This cytoskeleton is composed by a grid-shaped mesh that individually endfolds the sarcomeres, which are gathered in bundles by connective structures called helical-shaped straps or twisted moorings on its own axis (Figure 2). (9)

Myocardial sarcomeres, in normal conditions, suffer a lengthering ranging from 1.85 micrometres in the period of contraction up to 2.05 micrometres in the resting state. In systole, the sarcomere contraction is only 12%, but with this little figure the left ventricle empties by a 70%. This effectiveness gets that the ejection takes place at a speed of 300cm /sec and at a pressure of 120/80 mmHg, allowing a three-dimensional left ventricular reduction of 15%. (2) The helical disposition of muscle fibers (macroscopic and microscopic) allows this efficiency to obtain a contraction that starts at the outflow tract of right ventricle and ends at the left apex, in the words of Torrent Guasp, a cardiac piston.

These straps of connective tissue, which have a disposition similar to the guy cables of helical twisted suspension bridges, has suggested the idea of a systolic energy storage, which liberated in the process would allow the effect of diastolic suction pump. The twisting motion of the fibers would cause recovery forces that start diastole contributing to diastolic suction.

Mammalian hearts placed in a buffered solution self-impulsed by having the structure of straps. In contrast, in the frog heart there is no such drive because it lacks of these moorings as elements of interfibrillar fixing. Paradoxically, an invertebrate such as squid sucks water through the hollow chamber surrounded by a muscle structure getting with expulsion the effect of jet propulsion. This can be done because that musculature has straps.

The decline of the left ventricle produces the lifting of the right ventricle favouring its rapid and accelerating filling. Whole heart motion contributes to the filling.By the effect of this mechanism, increased contractility of the left side increments the efficiency of the right side.

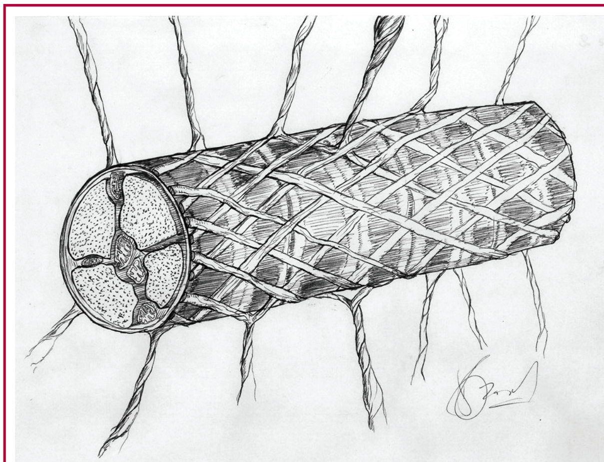

Fig 2. Microscopic structure of cardiac fibers with straps in space-helical disposition.

In short, the suction mechanism of the helical ventricular elastic recoil is an active ventricular process. During the period of isovolumic relxation of the left ventricular there is a contraction of ascending segment of apical loop. The initial suction with closed chamber would be explained by this mechanism. (7, 10) The brought up situation we could resemble it to a "plunger mechanism."

Likewise, mitral valve to be opened and increased wall stress with a decrease in the thickness of the wall, the fibers lengthen allowing the ventricle to fill up quickly. The high rate of filling at low pressures would be demonstrated by the suction phenomenon. This active mechanism of the Torrent Guaspo great myocardial band on the diastolic effect opens a wide view of the surgical restoration techniques, both in form as in volumen and the consequent left ventricular function.(11-15)

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Declaration of conflict of interests
The author declares he does not have a conflict of interests.

Antagonist

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The mechanical action of the heart is complex because it is the result of the integration of intrinsic properties of the myocardium under numerous extrinsic influences: resistance to the blood expulsion, vegetative nervous system and catecholamines, heart rate and exercise, venous return and blood volume. Anatomy texts describe the heart, but pay little attention to the disposition adopted by the myocardial fibers. Physiologists often not even mention the problem, as if the mechanical heart was not related to scaffolding design developed by the muscle fibers in the wall of the ventricles, it is impossible to interpret the measurements of cardiac function for diagnostic purposes if it is not taking into account the morphological structure. Cardiologists and clinical researchers have focused their attention on the molecular aspects and attempt to explain heart failure following neurohormonal models. However, pharmacological treatments that act on neurohormonal activation slow down but do not stop heart failure otherwise they are ineffective. The size and geometry changes are responsible for structural anomalies of myocytes and myocardium that make worse cardiac function, increase neurohormonal activity and reduce cardiovascular system response. The prognosis of patients with heart failure, that is to say, mortality and morbidity, is directly related to ventricular dilation.

The myocardial ability is related to the orientation of myocardial fibers and the conical heart has helical and circumferential circular myocardial fibers. The track of orientation of fibers determine the function and, thus, the ejection fraction is 60% when the normal helical fibers contract and fall to 30% if the transverse fibers are shortened. (1) The development of a spherical configuration changes the helical fiber orientation to a transverse configuration and decreases contractile force. (2)

Ventricular restoration surgery includes techniques that reconstruct the ventricle to its normal elliptical anatomic position, and change transverse fibers to their natural helical oblique orientation. (3) Its development has updated the legendary contribution of Torrent Guasp and his hypothesis of the myocardial band. (4, 5)

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HYPOTHESIS OF THE GUASP TORRENT MYOCARDIAL BAND

The dissection works developed by Torrent Guasp had as goal to confirm that the ventricular myocardial mass is constituted by a single and large muscular band that, originated in the pulmonary artery root, after describing two spiral turns (resulting in a helix), ends at the aorta root. These works of Torrent Guasp take to review some classic concepts:

- The fibrous skeleton of the heart. According to Torrent Guasp, the ventricular myocardial band does not require fixed fulcrums. It rests on two points, the pulmonary artery and aorta on one side and the ventricular blood sacks for another (hemoskeleton). This hypothesis represents a model that may satisfactorily explain the mechanics of cardiac contraction. The ejection is carried out by shortening the three axes 15%: longitudinal, anteroposterior and transverse. This is obtained by the peculiar contraction of the muscular band that shrinks into itself, based on hematic content, shortening and narrowing the helix with a twist movement, which explains the tthree-dimensional reduction of the heart.
- In this three-dimensional reduction there are three components: a) an annular component of the basal and apical loops leading to myocardial constriction movement in the transverse plane, b) a longitudinal motion of secondary shortening to contraction of the helical element that acts as if it were a spring c) a movement of expression of the helical component, counterclockwise in the left ventricle and clockwise in the right ventricle
- The two atria on one side and the two ventricles, on the other, form two morphological units, but the right and left heart are not a unit. This interpretation contrasts with the classical interpretation of the heart that considers a vertical functional unit composed of the atrium above and the ventricle below.
- New concept of the ventricle and the heart. The atria, with their mission of deposit, are cavities, while the ventricles with their propelling mission are sacks.

VENTRICULAR DIASTOLIC FILLING. ARGUMENTS FOR AND AGAINST THE SUCTION MECHANISM

Arguments in favour

The mechanism of ventricular filling has generated several hypotheses that can be summarized in two:

- The ventricle is a suction pump during diastole. This hypothesis was proposed by Erasistratus in the fourth century B.C. and later by Galen and Vesalius.
- Ventricular filling is performed by the beating of the atria, according to Harvey, or by the pressure gradient. This hypothesis was proposed in the twenties by Wiggers. (6)

Diastolic filling by a suction device is supported by the Torrent Guasp hypothesis (7) and by experimental and clinical studies. The three components of three-dimensional reduction of the heart interact synergistically through the muscular band that folds on itself and twist, to be hung the ventricles of the pulmonary artery and the aorta, moves them caudally and ventrally. In systole there is a tridimensional reorientation of the cardiac architecture with the helix that shortens in the longitudinal, transverse and torsional direction. Atrioventricular ring shrinks, the aortic annulus slightly expands, mitral and aortic levels descend and the outflow tract of the left ventricle remains open. The decline in base acts as a suction piston that increases venous return.

The suction occurs in early diastole, since the end of the isovolumic-opening relaxation phase of the mitral valve to the point F simultaneously with the third sound. During this period it has documented the presence of negative intraventricular pressure, both in human clinical (8, 9) and in animals with occlusion of the mitral valve with a balloon. (10, 11) During systole is stored a mechanical energy that is released in favour of a rapid dilatation during cardiac relaxation, causing the phenomenon of suction, which explains the high rate of filling with very low pressure gradients. This suction is favoured by several mechanisms (12):

- The Torrent Guasp hypothesis. Diastolic suction is secondary to passive elastic recoil of the ventricular helix, as if it were a spring with elastic properties. The relaxation is almost explosive and the sarcomere jumps as a spring to regain its original length. If the end-systolic volume is reduced, restoring expansive forces are greater, whereas pressure or volume overloads, hypertrophic cardiomyopathy or large volumes in heart failure slow the relaxation and reduce suction.
- The tension of the ventricular wall after mitral valve opening increments rapidly by increasing the intracavitary radius and the reducing wall thickness, according to the Laplace law. This expansive force acts at the end of the relaxation phase lengthening the fibers and allowing the ventricle to fill up quickly, despite a low filling pressure. Changes in wall thickness precede the changes in the radius of the cavity, that is to say, wall thinning precedes and conditions ventricular filling.
- The diastolic filling of coronary cunning may actively participate in myocardial expansion. The filling of the reservoir during diastole may stretch coronary myocardial mass as if the ventricle were a cavernous body and it is generated an erectile mechanism that prolongs the ventricular cavity. The coronary circulation becomes a protection of ischemic ventricular muscle during systole and it expands in diastole with the filling of the coronary bed. On the based of this principle, it has developed a cardiac model compound by a double elastic sac, whose hydraulic increase of the intramural pressure

generates a ventricular diastolic expansion, and which has been applied in devices of circulatory paracorporeal assistance.

The right ventricle is designed to drive large volumes of blood against low resistance, thanks to its crescentic shape of large surface area and low volume. Unlike the left ventricle, in which filling occurs bidirectionally and the blood is transferred from the mitral orifice to the apex before being directed to the aorta, in the right ventricle, blood is sent directly from the tricuspid orifice to the pulmonary artery following a central line of washing that constitutes 90 º.

Arguments against

In the classic model of cardiac function, the atria have two main functions: a function of transport or pump and reservoir function for rapid ventricular filling. As the ventricles, the atria respond to an increase in fiber length with an increase of contraction force and at rest, atrial contraction contributes 20% to ventricular filling. The increase in atrial contractility and a shift to the left of the function curves of the atrium or a rightward shift of the force-velocity curves may be produced by sympathetic stimulation, vasovagal inhibition or inotropic agents. In atrial fibrillation, circulatory reserve mechanisms may maintain resting cardiac output or else the loss of atrial contraction may produce serious consequences for ventricular filling and function of the heart.

There are contrasting results of the study phases of the cardiac cycle with sufficient weight to support the curves-gradient pressure to explain the ventricular filling:

- During the early phase of isovolumic relaxation, left ventricular pressure falls below the pressure of the left atrium shortly after the apex of the left atrial V wave.
- The rapid ventricular filling phase at the end of the isovolumic relaxation phase coincides with a continuing decline in atrial pressure that began during isovolumic relaxation. The end of rapid ventricular filling phase and the beginning of slow ventricular filling phase is characterized by a change of inclination in the curve of ventricular volume.
- During the slow ventricular filling phase, the pressures of the atrium and left ventricle increase slowly until the next atrial systole. Atrial contraction and the increase of the ventricular filling that it produces is manifested by an increase of pressure and of ventricular volume.

CONCLUSION

This discussion expresses two points of view, the classic model of cardiac function and the Torrent Guasp hypothesis. Its capacity for innovation was updated with the development of ventricular restoration techniques, applied to the surgical treatment of heart failure. However, the genius and work ability of Torrent Guasp, with over a thousand dissected hearts, and endorsed by some outliers is limited by: a) the huge but individual work of a genius without a real multidisciplinary team behind him, as it is shown to be single signatory of most published works, b) his hypothesis may be questioned if we confront it with the results of the classical model of cardiac function, less attractive but backed by solid scientific results, c) his hypothesis, of an overwhelming originality and logic, may raise doubts about the validity of the applied methodology: the technique of dissection has devices and to surgeons it is not possible for us to identify the band described by Torrent Guasp and there is not an integration of morphological study with ultrastructural and physiological study.

These issues cannot be resolved if the physiologist allows the anatomist performs his structural analysis alone and if the clinician does not accept that it must make a special effort to apply the diagnostic methods. Our group is focusing its efforts on cardiovascular modeling studies of the left ventricle through an original developed by the University Paul Sabatier, Next Limit and the Canal of Hydrodynamic Experiments of El Prado, in order to analyze the computational biomechanics of the left ventricle. (13) These tools will provide us important information on cardiovascular physiology and allow us to confirm the Torrent Guasp hypothesis and the model validity of ventricular suction filling.

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Declaration of conflict of interests

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AGONIST'S REPLY

The "key question" of Torrent Guasp on the return of blood to the heart leads to the concept of suction pump. This situatuion creates opportunities for research and physiotherapeutical consequences of relevance. It must be established from the basic that the isovolumic relaxation phase, during which intraventricular pressure falls at constant speed and gives place to gradients of transparietal and transvalvular pressures into the inside of the camera, is an active process of contraction upstream segment of the apical loop. This statement would implicate the understanding that a loss of ventricular suction would cause diastolic dysfunction. Inevitably, the dynamics of elastic recoil should have a constraint to be effective systole.

Another important consideration is based on the electrophysiological aspect, -in relation to T-wave-, as well as in the therapeutic level. Ventricular reduction techniques would find physiological dimensions and technically amazing on the suction base, given that the dynamics would be based on surgeries that make the conservation of shape, size and elasticity of the ventricular walls. At level of phasic history of cardiac knowledge, diastolic phase of isovolumic relaxation, which could be active (muscle contraction) and not passive, will it happen to be considered systolic?, "And would the T wave coincide with the contraction of septum? *Rigor mortis*.

Dr. Jorge C. Trainini

ANTAGONIST'S REPLY

The classic model of cardiac function has been sustained for decades.As Jorge Trainini explains, this model, which does not reflect the interaction between systole and diastole, is based on the Frank-Starling law, set with removed hearts. The Torrent Guasp hypothesis has obtained that the study of the cardiac mechanical action recovers the importance that it deserves. This hypothesis has led to revise classical concepts: ventricular myocardial band without fixed fulcrums generating a three-dimensional reduction; the morphological unit of the atria and ventricles in contrast to the functional vertical atrium- ventricle unit, the new concept of ventricle and heart.

As to the question " Is the heart a suction pump?", according to Torrent-Guasp, the energy stored in systole is released in favour for a rapid dilation during relaxation, originating the diastolic suction as a secondary phenomenon to the passive elastic recoil of ventricular helix. There are arguments against it: the rapid increase of tension in ventricular wall after the mitral opening, according to the Laplace law, "Is it not sufficiently explained in the classical model?", "Do the atria have a pumping function and their contraction contribute 20% to ventricular filling?". There are study results of cardiac cycle that support gradients of pressure to explain the filling and support the classical model.

The Torrent Guasp hypothesis, original and with an overwhelming logic, is not supported by solid results. Its importance requires a priority confirmation, integrated by cardiologists, anatomists, physiologists, researchers and surgeons. Studies of computational mechanics (speed vectors, moving geometry, shear stress, high diastolic vortex and its role as a store of energy, counterclockwise vortexes), let us know if the cardiac suction and the Torrent Guasp hypothesis is confirmed or if his greatest contribution has been the questioning of the classical model.

Dr. Jesús Herreros