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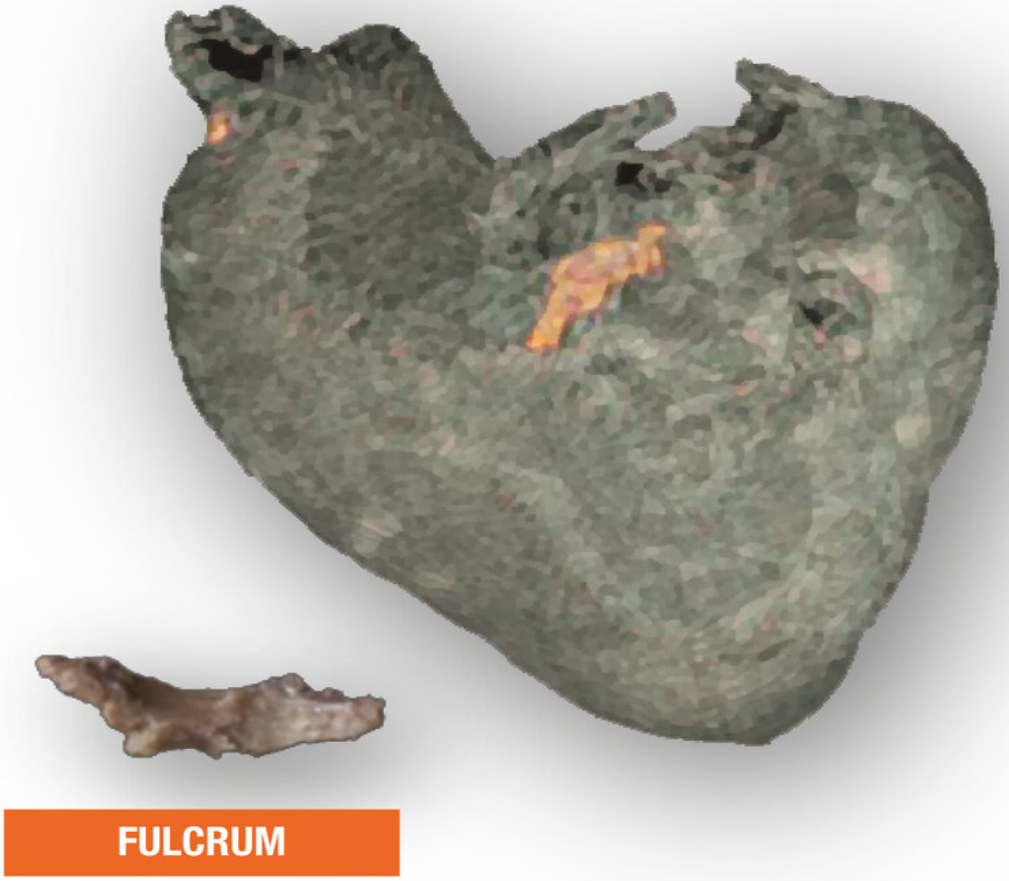
FULCRUM AND TORSION OF THE HELICAL MYOCARDIUM



Editorial Biblos

Fulcrum and Torsion of the Helical Myocardium

In this new book, Trainini and his team attempt a step forward and make a series of proposals that come to complete cardiac anatomy, physiology and mechanics. Reading this new investigation is a pleasure that demands continuous attention, so that our “neuronal boxes” do not rebel against the effort it means to sometimes destroy what we have firmly installed in them. The text should be read slowly, as it was never easy to tread in swamp-limited grounds and, as in the ascent to the summit of a difficult mountain, stop now and then to take a breath and enjoy the view as we get near the peak, where we will see the final landscape of the new vision. Then we will be conscious that the effort was worthwhile.

In the first proposition of the research the authors study the anatomical and histological study of the myocardium, which defines a continuous, spiraling muscle, an integral piece that in order to fulfill its muscle function needs a supporting point, the *cardiac fulcrum*. The myocardium is inserted at its origin and end into this nucleus with tendinous, cartilaginous and even osseus structure,

according to the specimen analyzed, located below and in front of the aorta. In this first proposition, splendidly documented, there is also an important contribution regarding the friction generated between the muscle layers in the mechanism of cardiac contraction

Afterward, the authors analyze the left ventricular endocardial and epicardial electrical activation sequence with three-dimensional electroanatomical mapping using a Carto navigation and mapping system, which allows a three-dimensional anatomical representation with electrical activation and propagation maps. Later on, the authors focus in the physiology and understanding of the suction mechanism that is explained about the persistent contraction of the ascending segment during the onset of the active protodiastolic phase. The authors describe a series of personal studies and investigations which define and clarify the three-stage cardiac mechanics with the concept of the scientifically-based suction phase, an active process that the authors explain as never before, integrating hydraulics and physics, disciplines not usually adequately incorporated to evaluate cardiac mechanics and the definition of mechanical suction pump.

Undoubtedly, the fast changes produced in cardiac imaging techniques will allow their use to understand the myocardial three-dimensional structure and its coupling with the new physiological concepts of cardiac mechanics.

We are facing a unique text, different, provocative. It is a creation that will demand a hundred percent of your

attention, to sort out the new pathways that open before our eyes with original investigations and proposals in the limits of the unknown.

—Miguel Angel García Fernández
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The true secret of cardiac mechanics is found deep inside the myocardium. At a glance, the cardiac muscle does not show its most hidden treasure. Only with an adequate dissection the mystery is unraveled and the cardiac fulcrum emerges between the muscle fibers. A chondroid anatomical structure that attaches the continuous myocardium at its ends. A support that allows torsion/detorsion motions. A supporting point working as the lever any muscle needs. This myocardium with helical structure explains a large part of cardiac pathophysiology. The beginning of this mystery led to explore along more complex pathwaysand evaluate a three-stage heart with an intermediate stage between systole and diastole, the suction phase.

Hidden mysteries, intrigues revealed after so many years of a classical cardiac anatomy, possible hypotheses and new concepts to ponder, are under the magnifying glass of this scientific study. Along these pages, the questions presented in this investigation were solved and explained in detail with the different studies performed. Other enigmas were

jointly and interdisciplinary clarified from different perspectives. It was necessary to incorporate not strictly medical knowledge for the complex understanding of the involved mechanisms, which could not be revealed through a single discipline.

We never imagined that the beginning of this investigation would cause uncertainty and curiosity. Nothing more thrilling than submitting works to be evaluated and discussed collectively. New thoughts emerge from the critical and complementary view, from the possible to the real. Often something is built from simplicity, but the responsibility lies in sharing it to allow a common growth. This investigation has had a main objective, that of regarding a hypothesis with a new look that might contribute to the cardiac structure-function and solve pathologies. *Fulcrum and Torsion of the Helical Myocardium* invites to consider the cardiac organ as a true hydraulic pump.

Jorge C. Trainini - Jorge A. Lowenstein - Mario Beraudo - Vicente Mora Llabata - Francesc Carreras-Costa - Jesús Valle Cabezas - Mario Wernicke - Benjamín D. Elencwajg - Alejandro Trainini - Diego Lowenstein - María Elena Bastarrica

FULCRUM AND TORSION OF THE HELICAL MYOCARDIUM

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Abbreviations

3D-EAM: Three-dimensional electroanatomic mapping
APDSP: Active protodiastolic suction phase
CI: Cardiac index
CMR: Cardiac magnetic resonance
CO: Cardiac output
DCMP: Dynamic cardiomyoplasty
HDF: Hemodynamic forces
HR: Heart rate
LV: Left ventricle
LVEF: Left ventricular ejection fraction
LVSWI: Left ventricular systolic work index
MAP: Mean arterial pressure
NS: Not significant
PAP: Pulmonary artery pressure
PCP: Pulmonary capillary pressure
PVR: Pulmonary vascular resistance
RAP: Right atrial pressure
RV: Right ventricle
RVSWI: Right ventricular systolic work index
SI: Systolic index
SVR: Systemic vascular resistance

Prologue

Miguel Angel García Fernández
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Professor Tainini takes a step forward and again surprises us with his book *Fulcrum and Torsion of the Helical Myocardium*, which the reader has now in his hands and that could easily have the subtitle: "*Beyond the master Torrent*"..... and that is not a small thing.

As is well-known, Torrent Guasp with his mythical and original heart dissections, revolutionized the classical cardiac anatomy and mechanics found in our books for over 250 years. In a simple definition of his gigantic work, the ventricular myocardium was formed by a group of muscle fibers spatially arranged as a laterally flattened cord similar to a band that limited the two ventricular chambers and defined their functionality. All his studies converged in a radical contribution*: diastolic suction as an active process, by the contraction off the myocardial band ascending segment*.

Undoubtedly, one of the most outstanding experts in Master Torrent Guasp's theory is also Master Trainini, who had already delighted us with a splendid book written three years ago and leading a group of specialists: *Myocardial torsion. Anatomo-functional investigation*", achieving the most complete text created so far on cardiac anatomy and function under the "*lights of Torrent*". This previous text came to respond and organize the answers of a long series of questions that emerged when physiology was approached with the master´s anatomy. The book, fitted as a magic puzzle, a large assortment of loose pieces that together provided solidity to Torrent's theories.

In this new book, Trainini and his team attempt a step forward and make a series of proposals that come to complete Torrent's cardiac anatomy, physiology and mechanics. Reading this new investigation is a pleasure that demands continuous attention, so that our "neuronal boxes" do not rebel against the effort it means to sometimes destroy what we have firmly installed in them. Concentration in its reading to start linking the pieces of this puzzle, which at the end of the book shows to be simple, clear and demonstrative. The text should be read slowly, as it was never easy to tread in swamp-limited grounds and, as in the ascent to the summit of a difficult mountain, stop now and then to take a breath and enjoy the view as we get near the peak, where we will see the final landscape of the new vision. Then we will be conscious that the effort was worthwhile.

The book is arranged into four great sections or *Propositions*, outlining the contributions of Dr Trainini and collaborators, and linking them like the pieces of a puzzle to shape the final idea.

In the first place, *Proposition I "Support and functional anatomy of the heart. The helical myocardium*" constitutes for me the fundamental part of this book. The anatomical and histological study of the myocardium defines a continuous, spiraling muscle, an integral piece that in order to fulfill its muscle function needs a supporting point, the *cardiac fulcrum*. The myocardium is inserted at its origin and end into this nucleus with tendinous, cartilaginous and even osseus structure, according to the specimen analyzed, located below and in front of the aorta. Although this "os cordis" had been mentioned in veterinary studies, this is the first description not only of its presence in the human heart, but what is more relevant, by assigning it a physiological function that means an important change in the understanding of the anatomo-physiology of Torrent, justifies in itself the creation of this book. A *cardiac fulcrum*, a supporting point, a meeting point between the ascending segment and the right segment of this cardiac muscle, which are the origin and end of the myocardial structure. The importance of this idea is to supplement that of master Torrent, who considered that the myocardium did not have a supporting point as adopted by other muscular systems for their contraction and force function. In this first *Proposition*, splendidly documented, there is also an

important contribution regarding the friction generated between the muscle layers in the mechanism of cardiac contraction. This friction produced by the opposing motion of the ascending and descending segments, as well as of the latter segment against the septal area of the myocardial band, demands a lubricating antifriction system that the author places in the lacunar structures between the muscle bundles, together with the Thebesian and Langer venous conduits. Thus, the discovery of intramyocardial hyaluronic acid as a "lubricating oil" is reached. Without this new antifriction mechanism, myocardial contraction would be impossible due to great energy dissipation.

Personally, I think that this first *Proposition* is the real *Gordian knot* of the scientific proposal and the progress in the puzzle of cardiac functioning postulated by Trainini, a continuous muscle that needs a supporting point and an antifriction mechanism: a revolutionary conceptual triad.

Secondly, in *Proposition II*, "*Research on cardiac electrical propagation",* the authors analyze the left ventricular endocardial and epicardial electrical activation sequence with three-dimensional electroanatomical mapping using a Carto navigation and mapping system, which allows a three-dimensional anatomical representation with electrical activation and propagation maps. Myocardial stimuli diffusion has a pattern that corresponds to the topographic arrangement of muscle bundles, the direction of their muscle fibers and the motion

mechanism that allows a correlation with electrical propagation and the corresponding function.

In *Proposition III*, "*Helical cardiodynamics. Suction pump*", the authors focus in the physiology and understanding of the suction mechanism that is explained by master Torrent's proposal about the persistent contraction of the ascending segment during the onset of the active protodiastolic phase. The authors describe a series of personal studies and investigations which define and clarify the three-stage cardiac mechanics with the concept of the scientifically-based suction phase, an active process that the authors explain as never before, integrating hydraulics and physics, disciplines not usually adequately incorporated to evaluate cardiac mechanics and the definition of mechanical suction pump.

The authors insist on a fundamental topic, as the importance of understanding that this active suction mechanism and its integrity with systole/diastole mechanics can be the basis to approach new surgical techniques and therapeutic options.

The last part of the book is *Proposition IV*, "*Contributions of Echocardiography and Cardiac Magnetic Resonance to the study of the helical heart".* Undoubtedly, the fast changes produced in cardiac imaging techniques will allow their use to understand the myocardial three-dimensional structure and its coupling with the new physiological concepts of cardiac mechanics. Deformation studies using *speckle-tracking* as a support of anatomical arrangement,

the increasing incorporation of new techniques to the medical practice, though still with doubts about their operation, such as feature-tracking and fast SENC, and the use of cardiac magnetic resonance by diffusion tensor with tractography analysis of cardiac fibers, constitute a clear progress to understand heart motions and its pathology.

All these tools, and to my understanding mainly the analysis of myocardial torsion-detorsion deformation, are provided as a scientific support of the “new cardiac mechanics” to visualize, complement and verify with another more dynamic approach, the innovative interpretation changes proposed and unraveled along the *Propositions* of this text.

Have no doubt, you are again before a different book, unusual in its presentation and the manner of implementing the information collected through the investigation. We are facing a unique text, different, provocative. It is a creation that will demand a hundred percent of your attention, to sort out the new pathways that open before our eyes with original investigations and proposals in the limits of the unknown. Its reading will leave nobody indifferent and that is something that few books can achieve.

Do not precipitate, sit down with an open mind, enter the maze and enjoy a new world of cardiac mechanics and physiology vision.

Madrid, January 2022.

Preface

We leave the stillness of the shore to enter the whirlwind of the river of knowledge. We join in the efforts of those who during four centuries have longed to see beyond the established structure and function of the heart. Some have passed through those waters many years ago; others more recently, but certainly all remained in the uncertainty. The old dogma of the heart that “closes and opens like a fist” endured without allowing fissures. We belonged to another era. As we arrived later, we had other tools, but above all we had the religious faith of science, the doubts of the skeptic, the tenacity of the needy and the strength to find out where that flood that had carried away the old ideas on the structure and organization of the heart was heading.

We met from different places guided by the strange ritual that science has, that of going from mystery to understanding, which is never total or infallible, but which leaves knowledge clearer and more possible. Open to certainty and imagination, to a new level of abstraction. We entered the hypothesis of “Fulcrum and Helical Myocardial Torsion”, some of us earlier, others later. It was not mere chance. It was the need to complete the knowledge from all the necessary angles. We tried to advance in worldwide

communion with all who accepted the challenge. This ambition never ceased. The first entry into its waters seemed reckless. Parked in that endless stream of Heraclitus river, we did not allow ourselves to be overwhelmed by the persistence of its waters or by despair. We were afraid of not facing the challenge of understanding how it was structured and what were the motions of that organ that three weeks after conception begins its endless heart beat until returning the being to mystery. Investigations and years followed. We always appealed to effort; science does not conceive primeval ideas without boldness. It must be submitted to tests of loyalty and honesty, of falsifiability. The scientist who cheats commits suicide. Impulses followed, then communications to the centers of knowledge. We often returned to the review, the step forward and the doubts. We have wept too many times. Nature does not reveal its intelligibility spontaneously. At first it seems complex, but it becomes simple by its logic, as long as soul and time devote to it. Thus, knowledge evolves.

Too much time passed in our lives but not for the indifferent river flow that carried us pretending to be the same one that had picked us up. We changed the primitive ideas, discovering them as overlapping sheets, one after the other. Time passed ruthlessly. We often did not notice that drainage in our lives when we were in the middle of the river. We persistently called on another batch of younger scientists to join the task. We never gave up

because we never finished the work. Today we can offer what we have achieved, always to the limit reached, since everything keeps on flowing. The hypothesis of the cardiac structure-function achieved through the access to its myocardial intimacy enriches the passion of each of us and also, of those who were before in this river. At one point we established: “The heart is a majestic city/of well-known frontiers/ with its hidden, mysterious/ and unexplored streets.” Having simplified the heart of its apparent complexity brought us closer to the rest of science. To understand and make understanding beautiful, according to Niels Bohr, on how a theory should be.

We did not remain inside the medical art and its own postulates. We used the translational character that science has in its current evolution. No more isolated disciplines, but all together. We understood that an isolated science is not a science. For this reason, despite coming from different techniques, we remained together throughout these years. We advanced along that river flow that sometimes darkened, yet other times was so clear that it reflected our images. At intervals it seemed so reluctant to reveal the mysteries that we plunged into its gloom. We were hurt by the death of our initial companion in this mission, Jesús Herreros, and the inclement events that occurred in others. What strange motivation pursued us not to succumb? We do not know. In everything there is chance and need. They are hidden, unconscious instances, but they

guide us. It is the rite of science to uncover some veil of the mystery.

Time was the mandatory step. Nothing could be done by waiting. We tried not to let the advancing knowledge drift between its efforts. Perseverance is the mother of victories. Ultimately, energy is a scale of packages called quanta. With this strategy, steps followed one after the other more frequently, since the elements collected in the research allowed us to go from the unexplored to simplification.

This research has not been intended as a copy of previous experiences. We have advanced into the dark corners of the cardiac structure-function of the heart. As the new acquired knowledge was incorporated, we were allowed to draw a map in those empty spaces. We gradually understood that each conceptual point that was achieved was not arboreal or linear, but that the same finding interconnected into a whole, in a rhizome-like structure. So is the heart.

During the 18th century, knowledge was grouped together. Later, with intellectual progress, it was divided into fragments restricted to different topics. This process separated sciences from their holistic nature, with inappropriate results as each domain was left at the mercy of its own entropy with a lower energy input from the rest of knowledge. In this research we have undertaken, the different disciplines used to this effect were intertwined, just as it is in the universe, to make knowledge coherent. We went further. As the heart is a thermodynamic organ

that manages a blood flow, the rhizome went beyond medicine. It advanced on physics, hydraulics, and calculus. Thus, an interrelated knowledge, with its interconnected, crisscrossed inputs and outputs was achieved. Although the tracing of previous experiences always illuminated the meaning of ours, the limit of the structure-function reached on the center of the pulse was considerably widened. The glowing question that arises is: What conclusions can we reach with the equations in the framework of cardiac functioning? The aim was the hope of joining all the partial knowledge in a unified structure-function, relating the magnitudes of the model with the observations. We believe that in this river of knowledge the theory of the rhizome led us to a map of the heart, which always constitutes the eternal return to the amazement of its gift.

Dilemmas and errors do not go against this investigation. It is not feasible to advance and explain new ideas without taking risks even in the most exact sciences, more so in a factual one such as medicine that carries human pain and consciousness in its subject of analysis. We have assumed it without forgetting that the river of knowledge continues to flow, always to the next day. We have been in the middle of its course for a long time, far from the stillness offered by its banks. Now, the tears shed and successes achieved have flowed as part of that river. Perhaps we can return to the shore while other explorers of knowledge enter the new waters that we seek to baptize with dedication and honor. Those that today begin to be the past.

The authors

Research Hypothesis

The function of the heart is of an anisotropic mechanical complexity that must be addressed in terms of its structure. In the study of myocardial anatomy, we postulate the principle that its organization is strictly related to its functional capacity. This led our investigations to explain its morphological and mechanical integrity. If we stop in classical descriptions of the heart we realize that ventricular anatomical attention was focused on its external and internal surfaces, granting scant importance to the intimate muscle conformation. It was determined that its arrangement forms two contiguous ventricular chambers, limited by a homogeneous, solid, compact muscle thickness and with a global uniform contraction. It was not considered that cardiac functional capacity required a reinterpretation of the spatial myocardial fiber organization and motion, introducing us in other topics of its functioning that were practically disregarded by cardiology.

An explanation for this apparent ventricular muscular homogeneity with an intricate anatomical arrangement that hides its helical conformation, implies considering that its structural solidity is required in birds and mammals to

eject blood at high velocity in a limited time span by an organ that must serve two circulations (systemic and pulmonary). Currently, the helical myocardium can be confirmed by the anatomical study of the heart via an adequate dissection that manages to uncoil it in its entirety and by other procedures, namely: histological exploration, magnetic resonance diffusion tensor imaging studies, speckle-tracking echocardiography analysis, electrophysiological studies with three-dimensional electroanatomic mapping and “animal villi” investigations. All of these procedures were used for this research.

Dissection leads to differentiate the real internal myocardial anatomy, contrary to the classical concept, finding a helical structure with defined planes that allows the successive physiological motions of narrowing, shortening-torsion, lengthening-detorsion and expansion depending on the propagation of the electrical stimulus along its muscle paths.

This pathway leading from structure to function induced the understanding of topics poorly explained by their mechanical organization, but which should be considered complementary among them and essential for physiology, namely:

1. Anatomical and histological research on the myocardial segmental continuity. Can the myocardium be considered a continuous, single and integral muscle?
2. The unavoidable emerging question is that in order for the muscle segments that make up the ventricular

chambers to twist they should have a supporting point, similarly to what a skeletal muscle does in a rigid insertion: Do they exist in the heart? If this support is real, how does the myocardium insert into this structure? This aspect about a myocardial support is not the only argument to consider since cardiac power generates a force capable of ejecting the ventricular content at a speed of 200 cm/s at low energy expenditure. Undoubtedly, in view of this developed capacity, it is necessary to attach the myocardium to a point of support to achieve its motions.

3. Myocardial torsion constitutes the functional solution to eject the ventricular blood content with the necessary energy to supply the whole organism. In this way, the phylogenesis cardiac morphology is similar to ventricular mechanics, but lacks the comprehension of an electrical stimulus along its muscle pathways to correctly explain its motions. The studies undertaken on this topic aim to demonstrate the integrity of an essential cardiac structure-function. The analysis of left ventricular endo and epicardial electrical activation by means of three-dimensional electroanatomic mapping carried out in a series of patients, allowed us to address a transcendental question to analyze: How does myocardial torsion occur? Before answering this question, it is important to underline that throughout the whole book, when we speak of “myocardial torsion” it should be understood that it refers to an elastic and

non-compressible material such as the myocardium. This means that this torsion, determined by the cardiac base and apex rotation in opposite directions implies a simultaneous longitudinal shortening. Although in the literature the terms twist, torsion and rotation have been used interchangeably, they do not mean the same thing, as will be seen later. “Torsion” is the term most frequently used to refer to cardiac motion, but we must not forget that the rotational motion described for the myocardium is accompanied by a simultaneous longitudinal shortening between base and apex.

4. The sliding motion between the myocardial segments during ventricular torsion-detorsion, implies that there must be an anti-friction mechanism to avoid the dissipation of the energy employed by the heart. Is there a specific histological explanation for this fact? Do Thebesian and Langer venous conduits play a role in this mechanism? Is there an organic lubricating source?
5. The development of the interventricular vortex studied by echocardiography is the consequence of torsion and of the necessary energy impulse the blood fluid requires to be ejected. Its flow dynamics can be understood through the physical theory of dissipative structures, which explains the organization of this intraventricular turbulence.
6. A passive cardiac full phase would be unfeasible due to the small pressure difference with the periphery.

Ventricular filling was investigated as secondary to a generation of negative intraventricular pressure with energy expenditure during early diastole. The sudden lengthening of the left ventricular base-apex distance, after the ejective phase, produces a suction effect by an action similar to that of a “suction cup”: Could this mechanism be explained by the ascending segment persisting contraction during the first 100 ms of diastole? Does this mechanics allow us to consider suction during the early protodiastolic phase as an essential element in the physiology of the circulatory system, by being the continuity link between the pulmonary and systemic circulations?

7. According to the aforementioned bases, should a coupling phase be considered between systole and diastole where cardiac suction takes place?
8. In this three-stage heart (systole, suction, diastole): How does the energetic mechanism in the active suction phase act? Could the cardiac energy of suction and ejection be estimated? Should the left ventricular ejection fraction be considered a poorly reliable index? According to these considerations, would it not be more logical to speak of ejective cardiac energy as a parameter that summarizes the cardiac potential and to which all non-independent variables would concur?
9. Through the cardiac resynchronization procedure, Is it possible, to restore negative pressure to generate left ventricular suction with stimulation in the correct site,

according to the path of the stimulus along the myocardial segments?

10. Could the understanding of this cardiac structure-function of the heart be of importance for surgical procedures of ventricular reduction and containment?

The methods used in this research to explain the hypothesis of the anatomo-functional integrity of the heart consisted of:

1. Cardiac dissection in bovine and human specimens.
2. Histological and histochemical analysis of the anatomical samples.
3. Left ventricular endocardial and epicardial electrical activation in humans by means of three-dimensional electroanatomic mapping.
4. The study of left ventricular suction physiology in dogs after removal of the right ventricle.
5. Measurement of left intraventricular pressure in ventricular resynchronization therapy.
6. Pathophysiological reinterpretation in experimental and clinical studies of heart failure (right ventricular bypass surgery, cardiomyoplasty, ventricular containment techniques, cardiac resynchronization, univentricular mechanical assistance, left ventricular repair).
7. Echocardiographic analysis to corroborate the research and usefulness of this knowledge in clinical practice since this technique has the ability to provide non-

invasive knowledge in the complex mechanism of myocardial contraction.

8. Diffusion tensor sequences using cardiac magnetic resonance imaging to identify the orientation and deformation of myocardial fibers.

The findings and clinical data here presented are the result of experimental tests performed under the approval of all required regulatory authorities and under the informed consent of patients following the principles described in the current World Medical Association Declaration of Helsinki (2013). The experiments were conducted in accordance with the UK Animal Scientific Procedures Act 1996, the EU Directive 2010/63/EU for experimental animals and the “National Institutes of Health” guide for the care and use of laboratory animals (NIH Publication No. 8023, updated in 1978).

Proposition I
Support and Functional Anatomy of the Heart. The helical myocardium

1. Phylogenetic aspects of the circulatory system

The circulatory system of worms (Annelida, Nemerthea) is made up of a closed system with two capillary beds (pulmonary and systemic) and two semicircles, called arterial and venous. In this unique circulatory system blood is propelled peristaltically (ejection and suction) since it lacks the impulse of a heart. (Figure 1A).

In the evolution to fishes, three linear dilations called venous sinus, atrium and ventricle appear consecutively in the venous semicircle of a primitive heart. Although it is still a single circuit, a pumping chamber (ventricle) appears, increasing the possibility of intravascular pressure. (Figure 1 B)

In the subsequent biological development, consisting of amphibians and reptiles, more prominent modifications occur. At this stage of evolutionary development two circuits are identified: the systemic and respiratory