The Journal of
Thoracic and Cardiovascular Surgery

Vol 124, No. 5, November 2002

Basic science review: The helix and the heart

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Read at the Eighty-first Annual Meeting of The American Association for Thoracic Surgery, San Diego, Calif, May 6-9, 2001.

Received for publication Oct 12, 2001; accepted for publication Dec 26, 2001.

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J Thorac Cardiovasc Surg 2002;124:863-83

0022-5223/2002 $35.00+0 **12/6/122439**

doi:10.1067/mtc.2002.122439

It is an enormous privilege and honor to be asked to give the basic science lecture. Please join me on an adventure that I have taken over the past three years. I described this type of voyage to my daughters many years ago as "discovery," in which you walk down certain common pathways but always see something different on that journey. I will tell you about my concept of how the helix and the heart affect nature, the heart, and the human.

To pursue this new route, I select a comment from my hero, Albert Einstein, who said, "All our science, measured against reality, is primitive and childlike, and yet is the most precious thing we have." We all have to be students, who are often wrong and always in doubt, while a professor is sometimes wrong and never in doubt. Please join me on my student pathway to see something I discovered recently and will now share with you.

The object of our affection is the heart, which is, in reality, a helix that contains an apex. The cardiac helix form, in Figure 1, was described in the 1660s by Lower as having an apical vortex, in which the muscle fibers go from outside in, in a clockwise way, and from inside out, in a counterclockwise direction.

This combination of clockwise and counterclockwise vortexes is common in nature. For example, within the flower bud of a daisy (Figure 2), there are clockwise and counterclockwise spirals. These flower buds increase in size as they proceed from the center outward. Insertion of a radial line across the spiral curve produces the natural pattern of enlargement, called growth (Figure 3). Nature contains many pathways of clockwise and counterclockwise spirals that are called reciprocal spirals.

One example of natural reciprocal spirals is the sea shell. If one takes the tip of that shell and draws it outward, the formation becomes a helix (Figure 4), and that helix is very similar to the shape of the heart.

These helical patterns are common in many animals with horns, such as the ram or eland, in which clockwise and counterclockwise spirals define their shape. If these horns counteract each other, from one animal in combat with another, they do not break, because nature introduces another trick—the formation of spirals within spirals; that is nature's way of supporting one structure within itself (Figure 5). In a larger sense, nature introduces a harmony of structures from both outside and inside the visible shape.

Looking into that harmony draws us back many years to the observations of Pythagoras in 600 BC, who described the golden section: the small is to the large as the large is to the whole (Figure 6). Throughout nature, there is a symphony of harmonies between different parts. The numerical character of this interaction was described by Fibonacci, living in Pisa in AD 1250. Mathematically, he defined this concept of harmony between parts as a logarithmic spiral, with a consistent relationship between proportions.

Throughout nature, these logarithmic spirals are commonplace. A sequence we know best is the logarithmic spiral of DNA, a double helix holding the sugar and

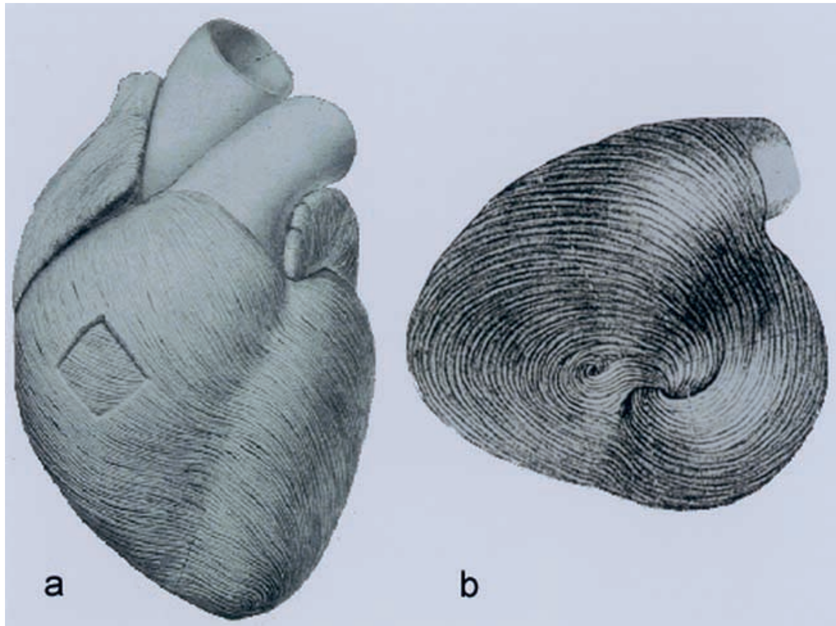

Figure 1. The helical heart is seen in a, and the apical view in b defines the clockwise and counterclockwise spirals.

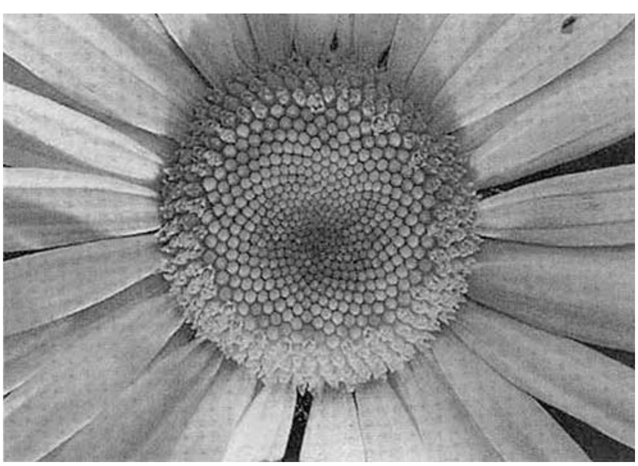

Figure 2. A daisy shows the buds spiraling in clockwise and counterclockwise directions from the center. (Copyright Scott Camazine 2002).

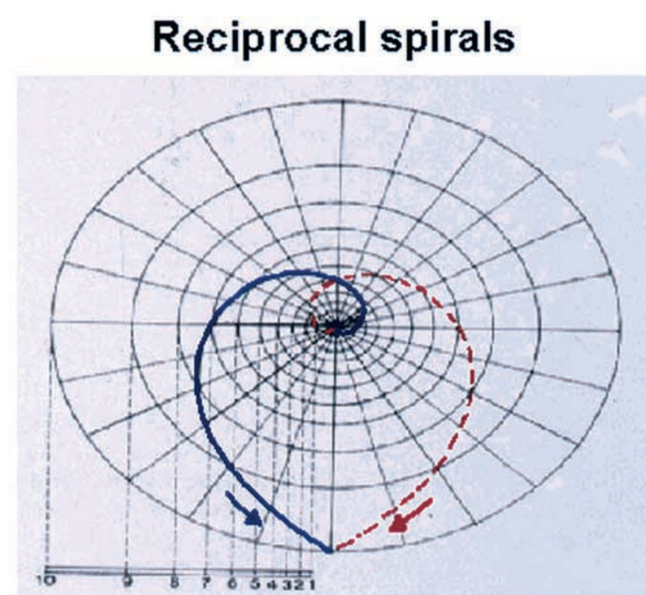

Figure 3. The reciprocal spirals within the daisy grow progressively, and growth rate is defined by the radial lines transecting the spiral coils. (From THE POWER OF LIMITS by György Doczi. Reprinted by arrangement with Shambhala Publications, Inc., Boston, www.shambhala.com.)

phosphate ions that compose the recipe for the blueprint of the master plan of life (Figure 7, *left*). From this genetic pattern, we can proceed upward from DNA to observe the spiral galaxy in heaven that exists 37 million light miles away (Figure 7, *right*). How remarkable that the same spiral formation recurs in this enormous macroscopic form.

We will now return to the human being, in whom counterclockwise and clockwise spirals exist within our fingertips. They have harmony for each of us, yet differences exist, for there is no similarity between individuals (Figure 8, *left*). At the same time, this harmonic pattern within our fingertips also occurs in our heart, where clockwise and counterclockwise spirals are evident at the apex (Figure 8,

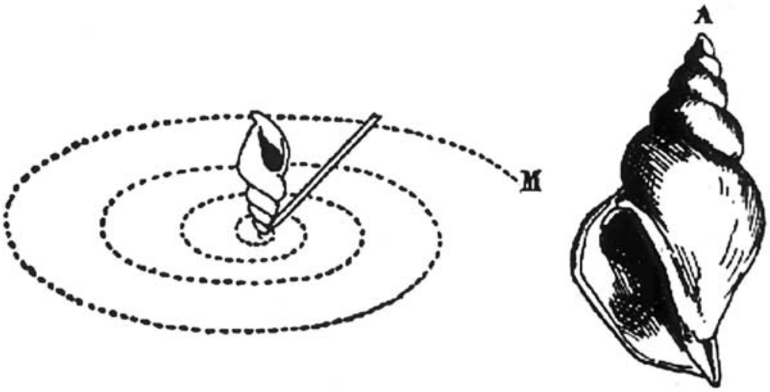

Figure 4. Elevation of the spiral center yields a helix. (From Cook TA. The Curves of Life, 1979. Reprinted with permission of Dover Publications, Inc.)

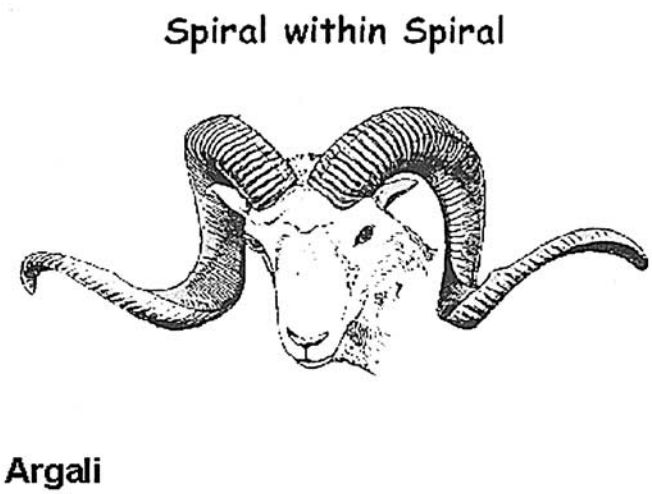

Figure 5. The reciprocal helixes correspond to the horns of the ramlike argali, in which internal support is provided with coils within coils to prevent collapse on contact. (From Cook TA. The Curves of Life, 1979. Reprinted with permission of Dover Publications, Inc.)

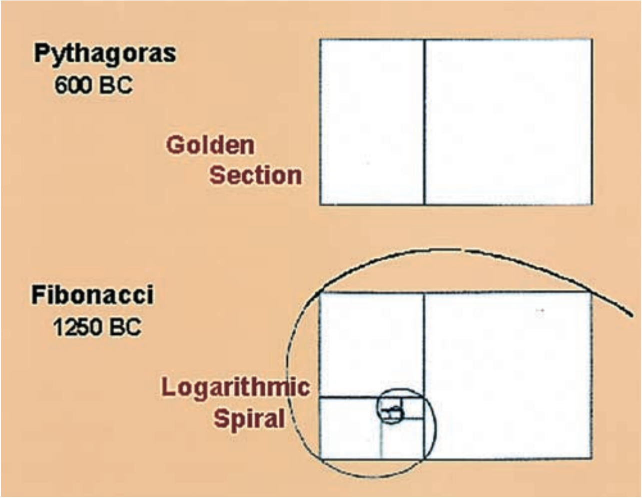

Figure 6. The proportionality between structures was described by Pythagoras, with the golden section, and the harmony of summed proportionate elements was described mathematically by Fibonacci as a logarithmic spiral.

right). This ventricular image was shown in 1864 by Pettigrew in England. As surgeons we look at the heart anatomically and observe the internal and external spiral loops, which were previously called the bulbospiral and sinospiral loops. Their infolding into the heart develops a pathway that I will subsequently describe.

External inspection of the apex, proceeding toward the base, shows a clockwise and counterclockwise spiral formation (Figure E1, online only), with loops going from without to within and from within to without. The same spiral formation persists if the apex is viewed from the base (Figure 9). These cardiac sections are similar to those that appear in the *Handbook of Physiology* and were made by Dr Francisco Torrent-Guasp. Their format characterizes a structural problem that has existed for many years and is called the Gordian knot of anatomy.

Anatomists have traditionally dissected the heart, but they did not understand the perennial problem of where the heart started and where the heart stopped. Dr Torrent-Guasp has solved this mystery by showing the site of origin and end of the myocardial fiber band. He formalized this description by indicating that the heart looked like a “rope” (Figure E2, online only). This seemed peculiar when I heard it, yet visualization of the rope image shows three parts: a beginning and an end at the aorta and pulmonary artery; a wraparound loop called a basal loop; and then a helix that he called the apical loop (Figure 10).

My initial response was, “Where did you get the idea that the heart really looked like a rope?” Dr Torrent-Guasp said,

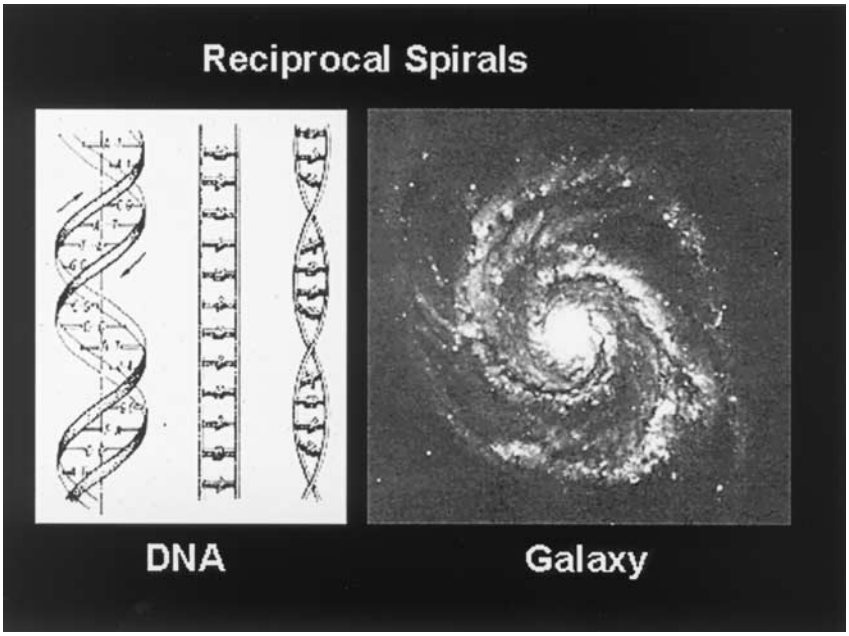

Figure 7. The natural spirals range between the double helix of DNA *(left)* to the spiral nebula *(right).*

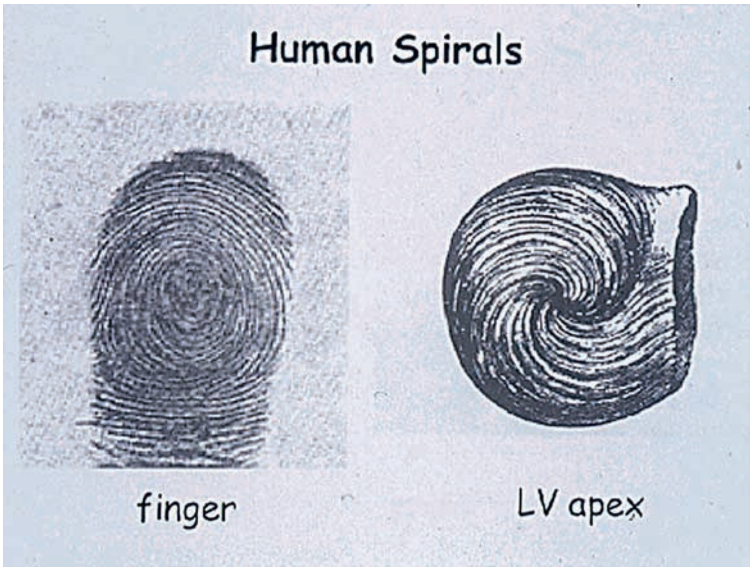

Figure 8. The spirals in the human exist in the fingerprint *(left)* to the cardiac (left ventricular) apex *(right).* (From Cook TA. The Curves of Life, 1979. Reprinted with permission of Dover Publications, Inc.)

"Well, I went back to phylogeny." He described a worm (Figure 11) that is a billion years old, with a vascular tube that appears like a rope, with a venous and an arterial system. Approximately 400 million years ago, a fish evolved to show the first generation of a heart, containing a single pumping chamber, and included gills within the system. Two hundred million years ago, the amphibian and the reptile appeared, in which we observe an atrium and a ventricle. Each chamber was separated by an atrial and ventricular septal defect. Human beings developed about a hundred thousand years ago, and both the atrial defect and the ventricular defect are closed.

Exposure to this information stimulated me to review again the illustrations in Netter's description of anatomy underlying heart development. At 20 days of life, the heart of an evolving human being looks like a worm, much as it

Figure 9. ***Left,*** **The spiral formation of the ventricle is shown from apex to base and defines the double helix.** ***Right,*** **The** ***right panel*** **shows the band with no start or end, or the Gordian knot of anatomy.**

Figure 10. The rope model of the heart shows the beginning and end of the myocardial band at the aorta and pulmonary artery ***(right),*** **the circumferential wrap of basal loop** ***(center),*** **and the helix** ***(left).*** **(From Torrent-Guasp F, Buckberg GD, Clemente C, Cox JL, Coghlan HC, Gharib M. The Structure and Function of the Helical Heart and its Buttress Wrapping. I. The Normal Macroscopic Structure of the Heart.** ***Semin Thorac Cardiovasc Surg.*** **2001;13:301-19. Reprinted with permission of WB Saunders.)**

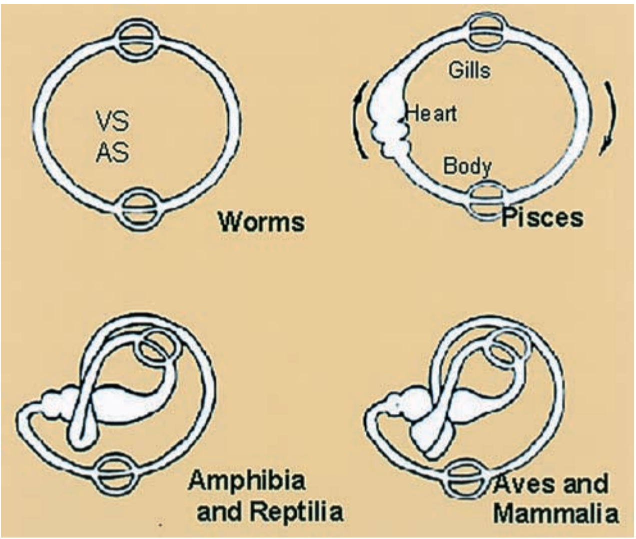

Figure 11. The evolution of the ropelike model from the worm, to the single pulsatile heart in the fish (pisces), to the atrium and ventricle with septal defects as seen in amphibia and reptiles, to the dual-chambered heart with defects closed, as in birds (aves) and man (mammalia). ***VS,*** **Ventricular septum;** ***AS,*** **atrial septum.**

did 1 billion years ago. At 25 days of life, a clear-cut venous system and an arterial system and single pump developed. In a sense, we mirror, at 25 days, the appearance of a fish more than 400 million years ago. At 30 days, the embryologic heart contains a patent ventricular septal defect and an atrial septal defect, so that we resemble the amphibian and the reptile of 200 million years ago. Finally, at 50 days of life, there is an intact atrial and ventricular septum. Remarkably, at 50 days of life, our cardiac evolution encompasses 1 billion years of the phylogenetic development.

We must now answer the next question: "How can this ventricular appearance reflect the heart and its relationship to the rope?" To do this we must compare the heart to the coiled rope, while uncovering the three components: a beginning and an end; a surrounding basal loop; and a helix.

To unfold the heart, we must separate the aorta from the

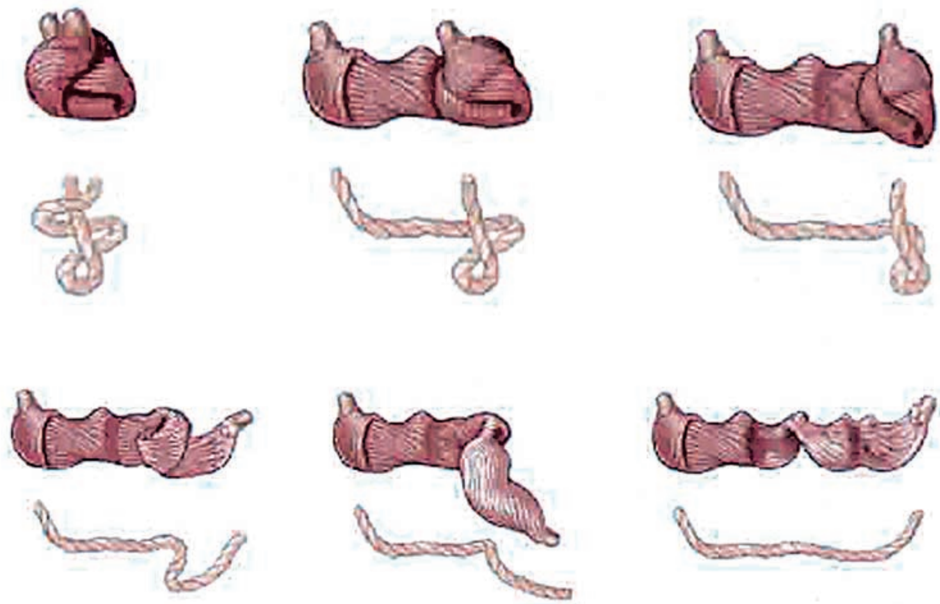

Figure 12. The comparison of the unfolding of the rope and heart, as described in the text. (From Torrent-Guasp F, Buckberg GD, Clemente C, Cox JL, Coghlan HC, Gharib M. the Structure and Function of the Helical Heart and its Buttress Wrapping. I. The Normal Macroscopic Structure of the Heart. *Semin Thorac Cardiovasc Surg.* 2001;13: 301-19. Reprinted with permission of WB Saunders.)

pulmonary artery, as shown in Figure 12. The consequence is to expose the free wall of the right ventricle. These basal loop fibers are transverse and cover the underlying helical apex. The next step is to further define how this basal loop wrap surrounds both ventricles. Once done, we must then unfold the helix of the heart. This requires the unroofing of the aorta from its ventricular attachment to separate the ascending and descending limbs of this helix. This is accomplished by unwrapping the coil. When the coil is unwrapped, a longitudinal myocardial band is demonstrated that corresponds directly to an open stretched rope.

Clearly, skeptics will suspect this reflects only a cartoon. However, Dr Torrent-Guasp has performed this unfolding or unscrolling while dissecting an intact heart (Figure E3 [video], online only). The entire dissection to unfold the band is done with the hands; there are no instruments.

The first step is to remove the pulmonary artery from the aorta. Once done, the dissection proceeds along the ventricular septum to then open the free wall of the right ventricle; this basal loop band of the ventricle surrounds the apical loop like a buttress. The dissection follows natural cleavage planes, and the circumferential buttress is removed from the back wall of the septum to become the outer shell of the left ventricle. The fiber directions in these normal cleavage planes become clear as the dissection proceeds. There is transverse direction of fiber orientation throughout the basal loop separation. The next step is unroofing of the aorta, severing the left and right trigones to then enable the unfolding of the ventricle. This unscrolling separates the ascending and descending parts to thereby uncoil the helix. The natural cleavage planes persist and their oblique direction is evident when the helix is uncoiled. This allows the heart to become completely dissected, extending from the aorta to the pulmonary artery, connected by intervening muscle. This is shown by simply continuing the unwrapping of the dissected apical loop, to define the intact myocardium as a single muscle band that extends between the aorta at its termination to the pulmonary artery at its beginning.

Reformation of the intact heart requires refolding the ventricle. This is accomplished by taking advantage of the transition caused by the internal myocardial fold or twist in the middle of the band that allows transverse fibers to become oblique, to then form the apical loop. The oblique ascending segment is returned by recoiling the helix to restore the coil in the ventricle. This begins to restore the intact heart positions of the pulmonary artery, aorta, and descending loop. The heart is reformed by reattaching the aorta to the descending segment, at the trigones. Dr Torrent-Guasp calls these attachments "the feet of the aorta." The left ventricle and septum become clear, and the only remaining opened segment is the free wall of the right ventricle. Both ventricles are refolded completely by reattaching the pulmonary artery to the aorta. The consequence is that the muscular band becomes an intact heart!

A fascinating study was done by Dr P. P. Lunkenheimer, in Germany, which can counteract concerns that this dissection is done by one individual, and may not be reproducible, and enhances the credibility of the helical spiral concept. His study uses an insufflation technique that causes cardiac emphysema to avoid the internal dissection of the heart and manually separates muscle bands. This was achieved by injecting air into the aorta to produce dissection of the coronary arteries. The intramyocardial results were followed by a computed tomographic scan to allow exploration of multiple sequential parts of the ventricle (Figure E4, online only).

This method (Figure E5 [video], online only) is termed "transcoronary pneumonic spreading of the myocardial network." A catheter is placed within the aorta to inject air, under pressure of 600 mm Hg. This dissects the wall of the coronary arteries to produce sudden intramural expansion along the fibers to display the internal architecture and demonstrate an internal spiral formation within the ventricle that occurs without external manual dissection. A clear-cut clockwise spiral is seen on the inside, with a counterclockwise spiral on the outside. The computed tomographic scan sections move downward from the base of the heart to the apex. This evolving spiral formation within the heart exists, despite no mechanical function, and each clockwise and counterclockwise spiral is different at each transverse section. This formation shows that each spiral maintains its own integrity and simultaneously contributes to the whole heart configuration. This remarkable pattern of spirals, moving in different directions, creates the fundamental architectural form of a dead heart. The dual helix sets the anatomic structure of an uneven or anisotropic spiral network that interfaces from one spiral to another. Consequently, the spiral geometry of the ventricle becomes now defined both by dissection and with noninvasive computed tomographic scan technology.

The next step is to determine whether this form of ventricular architecture can develop a corresponding functional reality. To accomplish this, we must show sequential contraction that proceeds along the myocardial band. This was accomplished by a multiple gated acquisition scan by a team in Barcelona using multigated imagery. They clarified the progressive contraction of the ventricle, starting in the right ventricle, which demonstrates that the heart undergoes a sequential contraction, proceeding along the underlying muscular folds in the ropelike model.

The evolving sequences of the multiple gated acquisition scan, studied with Fourier analyses, first demonstrates contraction of the right segment of the basal loop. That contraction proceeds around the basal loop toward the left segment of the basal loop to now surround the left ventricle. The next step is contractile motion and only after moving around the apex, along the ascending segment, to sequentially activate contraction of both descending and ascending segments of the apical loop. Finally, the heart relaxes in diastole. This sequence of motion, which defines the sequence of contraction along the band, must now be coordinated with cardiac function.

The classic view of cardiac anatomy relates to contracting and relaxing, or more specifically, constricting to narrow and eject, and dilating to widen and fill. This sequence was defined by William Harvey. However, the predominant motion of the heart is not constricting and dilating, but rather shortening and narrowing. There are four fundamental motions that include narrowing, shortening, lengthening, and widening and are shown in Figure 13. Each motion occurs by the effective movement of the segments of the myocardial band. As a result of contraction of the basal loop, there are constrictions or a squeeze on the ventricle, as the outer ring develops a stiff outer shell that constricts or compresses the apical loop. The next motion is a downward twisting of the muscle fibers to shorten and thicken and thereby make the heart eject. This twisting or torsion was described by Borelli, in the 1600s, to simulate the wringing of a rag. The next step is progression of contraction into the ascending segment; this results in twisting and thickening in an opposite direction. This sequence is followed by relaxation to allow the ventricle to fill during the remainder of the diastolic phase.

These concepts work similarly in life, as we will show on the cardiac surface in the operating room (Figure E6 [video], online only) where the heart twists to eject and reciprocally twists to fill in a clockwise and counterclockwise manner, and also from visible images of transmural muscle observed on a magnetic resonance imaging scan. The exposed heart shows the apex at the cardiac tip, together with natural twisting and untwisting of the conical heart muscle in reciprocal directions. Further evaluation by magnetic resonance imaging shows that the apex moves negligibly and defines that the predominant action is shortening and lengthening, rather than narrowing and widening. These dynamic movements are responsible for ejection during shortening and suction to fill during lengthening and characterize the normal activity of the heart.

These structural and functional magnetic resonance imaging actions are brought together by correlating their activity with pressure tracings in the catheterization laboratory or the operating room. The contractual events begin immediately after the heart completes its filling in diastole (Figure E7, online only). The initial contraction involves the basal loop that causes constriction whereby a stiff outer shell muscle is formed that surrounds both ventricles. This contraction of the basal loop is initially responsible for the isovolumetric phase of systole, which narrows the ventricle and thereby produces the mitral valve narrowing seen by echocardiographic recordings (Figure E8, online only).

The next sequence is descending loop contraction that twists downward to thicken and cause ejection (Figure E9,

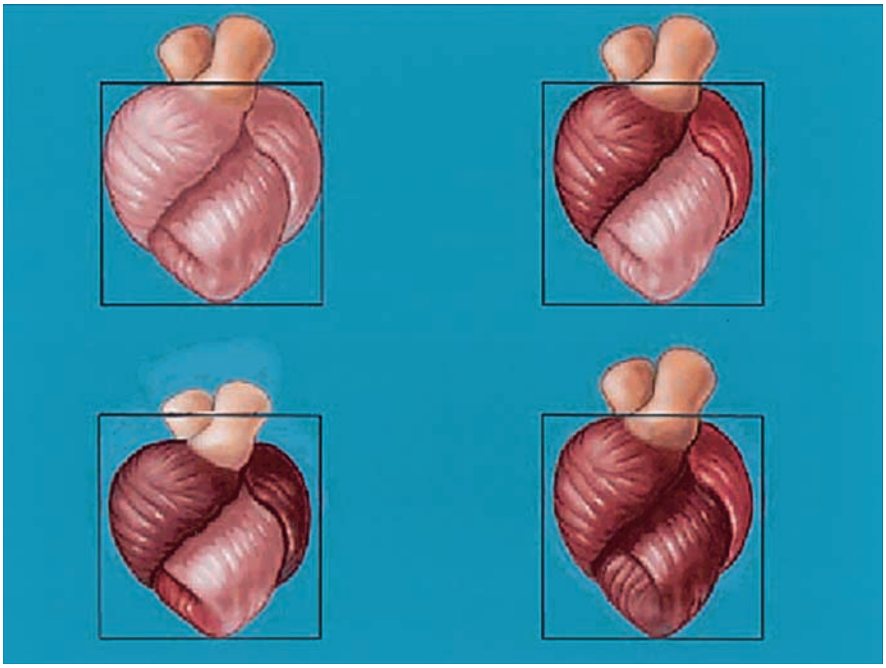

Figure 13. The four motions of the heart, which include narrowing, shortening, lengthening, and widening, as described in the text. (From Buckberg GD, Clemente C, Cox JL, Coghlan HC, Castella M, Torrent-Guasp F, Gharib M. the Structure and Function of the Helical Heart and its Buttress Wrapping. IV. Concepts of Dynamic Function from the Normal Macroscopic Helical Structure. *Semin Thorac Cardiovasc Surg.* 2001;13:342-57. Published with permission of WB Saunders.)

online only). The intraventricular consequences during this downward twisting or torsion of this segment are to produce thickening, rather than the narrowing we previously considered to be the cause of the ejection phase to fill the aorta. The interval of systole extends beyond ejection, as the sequential contraction of the descending segment proceeds around the helix to then ascend into the ascending segment. Contraction of the ascending segment starts shortly after the descending segment and persists after the descending segment contraction stops. The result is production of torsion that creates an avenue for suction. The next action is the isovolumetric lengthening of the heart during contraction of the ascending segment. Although the mitral valve opens, there is negligible flow through the mitral and aortic valves when elongation starts. The mitral valve is open during lengthening, and at the peak of elongation at the end of the isovolumetric phase, ventricular pressure falls below the atrial pressure and venous return is achieved by sucking blood *actively* into the ventricle (Figure E10, online only). Each of these actions occurs in systole, to provide a contractile sequence to first narrow, second shorten, third lengthen, to precede the fourth phase of repose during diastole, for cardiac relaxation and *passive* filling of the ventricular chambers (Figure E11, online only).

These sequential systolic actions cause a conceptual dilemma. It is readily apparent how a heart can contract and shorten, but the unanswered question is how can a heart contract and lengthen?

The response requires borrowing some more tricks from nature (Figure 14). The underlying anatomy defines the transverse basal loop for contraction that overlies the oblique helix responsible for ejection and suction. Some insight is provided by a snake, which contracts its paraspinal muscles to thicken to raise off the ground. As its contraction progresses, it gets higher, and during this sequence it lengthens. We can now refer these actions to the apical loop that is a helix or reciprocal spiral. At the beginning of systole, there is a clockwise and counterclockwise twist to the descending segment, to wring and produce ejection. This resembles the torsion, as described by Borelli in 1680, for heart contraction to eject. At the time of initiating descending segment shortening, there is simultaneous lengthening of the ascending segment to bring it into a more transverse position. That muscle is still flaccid; it has not yet started to contract.

Dr Torrent-Guasp's dissection has shown that the heart contains a second part of this helical coil, which he terms the ascending segment. During contraction of the ascending segment, a reciprocal twist in a separate direction develops, with a clockwise and then counterclockwise turning of the underlying muscle. The fibers that were not contracting as the descending segment began to contract now become

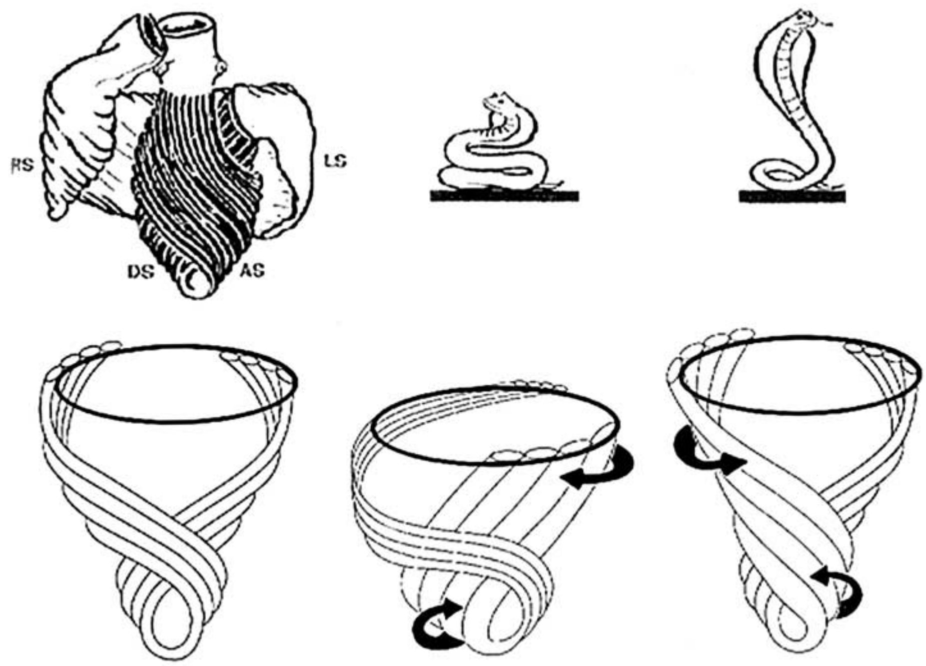

Figure 14. Comparison of the basal loop, in *upper left* in white (*RS* and *LS* are the right and left segments) and the apical loop *(dark color)* and the elevation of the snake during contraction *(right two panels)*. The bottom diagram shows the clockwise and counterclockwise twisting of the descending and ascending segments *(DS* and *AS*), as described in text. (From Torrent-Guasp F, Buckberg GD, Clemente C, Cox JL, Coghlan HC, Gharib M. the Structure and Function of the Helical Heart and its Buttress Wrapping. I. The Normal Macroscopic Structure of the Heart. *Semin Thorac Cardiovasc Surg.* 2001;13:301-19. Reprinted with permission of WB Saunders.)

thicker and shorter. There is initially co-compression during ejection, and when descending contraction stops, the thickened contracting ascending segment becomes more longitudinal and the heart lengthens.

The snake is not a very good model for comparison because the snake is longitudinal. We can, however, borrow another trick from nature that relates to the ram model, where the horns contain the spiral within the spiral organization, as shown in Figure 5. This internal coiling reflects why the ram's horns do not break when they make contact in combat. This concept can be transposed to the twisting motion within the heart, by inserting inner spirals into the twisting motion within the heart by placing them within the descending and ascending apical loop muscle segments (Figure 15). The spiral compresses as the segment descends, to reflect a twisting coil that develops torsion in a clockwise and counterclockwise direction to eject. The next step in motion occurs by twisting the coil in an opposite direction to produce lengthening and filling.

The intriguing factor about this interaction is that it includes a dual spiral formation, whereby the coils of each segment of the apical loop are of different lengths. The spiral formation within the helical heart conforms nicely to the mathematical description of spiral described by Fibonacci (Figure 16). The different lengths become evident after manual dissection of the ascending segment from the descending segment. These lengths have a harmonic proportion, and the complementary lengths of the descending and ascending segments conform, precisely, to the ratio Pythagoras described within the golden section: the small is to the large as the large is to the whole.

To me, this reflects a fascinating miracle that creates an awe about how the heart works. Clearly, the heart contains a remarkable hidden harmony of spirals. That hidden harmony starts with the master plan of DNA, a double helix that provides direction. The configuration then moves from DNA to the spirals evident on the outside of the heart, which we have dissected to show cardiac internal form. The spiral within a dead heart (Figure 17, *top panel*) must then come to life and subsequently develop a spiral during beating, which proceeds in different directions to produce the clockwise and counterclockwise twists responsible for ejection and suction (Figure 17, *bottom panels*).

Our study of mechanisms of ejection and suction allows us to borrow another trick from nature—the coil within a coil, which is responsible for clockwise and counterclockwise rotation and functional activity. To understand internal activity of the heart, we must then consider actin, myosin, BSR

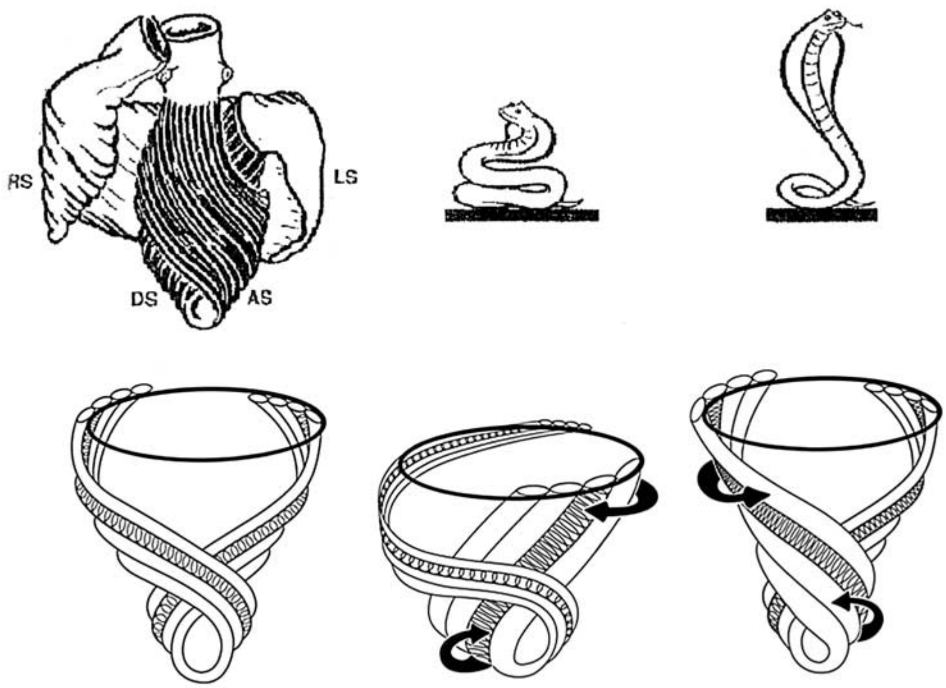

Figure 15. The scheme in Figure 14 is repeated, but now with internal coils within the descending and ascending segments to reflect the coil within coil formation, which parallels the configuration within a ram horn in Figure 5, to explain twisting to shorten to eject blood and reciprocal twisting to lengthen to suction venous return. (From Buckberg GD, Clemente C, Cox JL, Coghlan HC, Castella M, Torrent-Guasp F, Gharib M. The Structure and Function of the Helical Heart and its Buttress Wrapping. IV. Concepts of Dynamic Function from the Normal Macroscopic Helical Structure. *Semin Thorac Cardiovasc Surg.* 2001;13:342-57. Reprinted with permission of WB Saunders.)

and calcium (Figure 18). The configuration of myosin reflects a double helix. The pathway proceeds through adenosine triphosphate into the thin filament of actin, which is, again, a double helix; then to tropomyosin, which is a double helix; and then toward the role of calcium. The appearance of calcium is explored by confocal microscopy—to study an individual myocardial cell—to reflect yet another calcium spiral coil within this one individual cell (Figure 19). Further study shows calcium moving down the spiral coils to show individual calcium ions, which reveal a related red spiral coil.

There is a symphony of interrelated form within the heart, and the spirals, perhaps, become the "keys to the kingdom." This kingdom reflects gargantuan relatives that course from ionic to cosmic in size (Figure 20).

The next logical question is why surgeons become so involved in basic anatomy and physiology when our job to is to rebuild structure and function. Of course, the nature of structure and function relates specifically to our daily activity and thereby prompts our search for the correctable mechanism of congestive heart failure, the leading cause of death in America. The helix becomes architecturally altered in shape, and that provides the underpinnings of uncovering a surgical method to treat this disease. The normal helical or elliptical formation of the heart is replaced by a spherical chamber. Our recognition of the functional counterpart of this spherical structure allows the surgeon to understand this anatomy and then make changes in the operating room.

The contrast between shape and resultant function is most evident by magnetic resonance imaging (Figure E12 [video], online only). The normal heart develops ejection and suction as a functional consequence of the contraction integrity of the apical ellipse, which maximizes shortening and lengthening. In contrast, the spherical shape of heart failure, as characterized by an enlarged dilated ventricle, has diminished capacity to shorten and lengthen. A secondary effect of cardiac stretching is to widen the mitral anulus and alter papillary muscle function to render the mitral valve incompetent. The end point is altered heart form and resultant abnormal functional component.

This relationship is characterized in the normal heart by comparing function against the underlying helix formation. It is widely recognized that, within the normal heart, there is 15% fiber shortening of each myocyte. There is, however, a discrete relationship between fiber shortening and fiber angulation (Figure 21). When heart muscle fibers adopt a

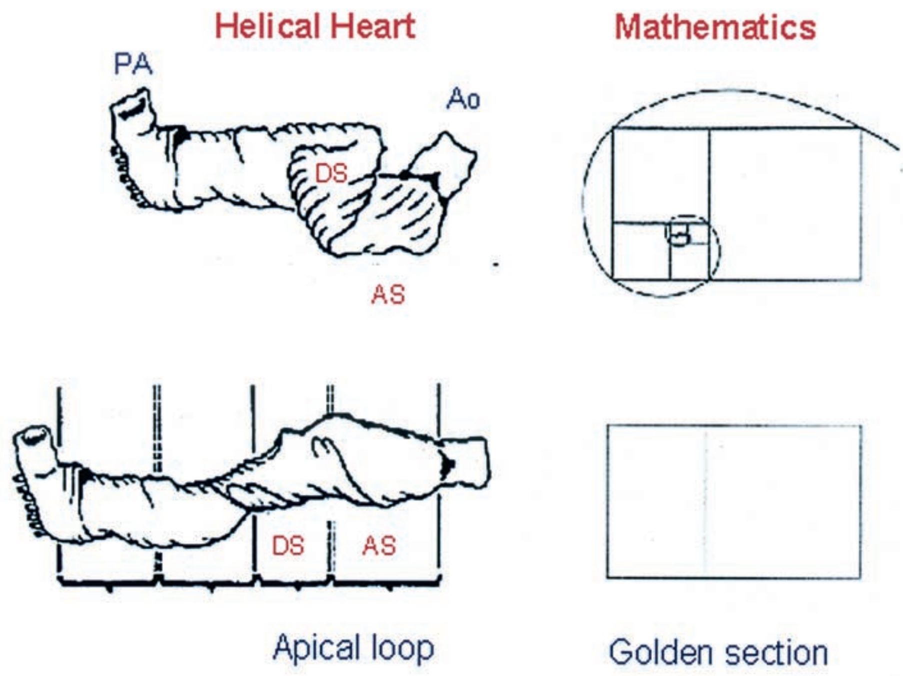

Figure 16. The comparison of the spiral formation of the apical loop and the mathematical spiral *(upper figures)* and the proportional harmony of the descending and ascending segments (*DS* and *AS*) in the *lower figures.* These respective lengths conform to the golden section; the small is to the large, as the large is to the whole. *Ao,* Aorta. From Torrent-Guasp F, Buckberg GD, Clemente C, Cox JL, Coghlan HC, Gharib M. the Structure and Function of the Helical Heart and its Buttress Wrapping. I. The Normal Macroscopic Structure of the Heart. *Semin Thorac Cardiovasc Surg.* 2001;13:301-19. Reprinted with permission of WB Saunders.)

spiral formation, proceeding toward the apex, the 15% fiber shortening causes a 60% ejection fraction. Conversely, if fiber orientation is horizontal or transverse, as occurs within the basal loop, the same 15% fiber shortening produces only 30% ejection fraction.

These fiber formation concepts are directly related to the altered cardiac anatomy in patients with congestive heart failure (Figure 22). The ischemic heart dilates because the apex is lost from anterior infarction; apical dilatation also occurs from valvular insufficiency with ventricular stretching caused by volume overload. In the nonischemic failing heart, the muscle itself becomes damaged and the spherical shape replaces the apical contour. Our surgical intent is to begin to understand how this spherical anatomy can lead us to more fully understand the functional counterpart that causes heart failure.

These changes in fiber orientation are evident from the normal ventricle, which is formed by the basal loop and a helical apical loop. These structural components are separated in Figure 23, made to define fiber orientation. With heart failure, the helical apex is lost and becomes replaced by a sphere. The structural consequence is that the oblique apical loop fibers become more transverse, so that the fiber orientation of the apical loop begins to resemble the basal loop. The oblique orientation causing 60% ejection fraction develops a more transverse fiber orientation whereas only 30% ejection fraction occurs when fibers are normal. Of course, this extent of shortening becomes diminished if disease alters function in the underlying fibers. The underlying anatomy of heart failure may reflect changing the oblique apical loop into a more transverse basal loop architecture, with resultant diminished function.

In one sense, the heart that is damaged looks like a basketball; the heart that is normal resembles a football whose function, when thrown, becomes a spiral pass (Figure 24). Our objective in dealing with surgical treatment of heart failure is to change the basketball back into a football, and restoration of the helix is our goal.

During this meeting of The American Association for Thoracic Surgery, we have shown that the spherical ventricle that characterizes ischemic cardiomyopathy can be geometrically changed. Yesterday, Dr Athanasuleas described the work of our international team, the RESTORE group, to confirm the prior ventricular rebuilding studies described by Dr Vincent Dor (Figures E13, E14, E15, E16, E17, and E18, online only). The method is straightforward, whereby the nonfunctional abnormal ventricular segment is opened to expose the spherical cavity. A circumferential suture is

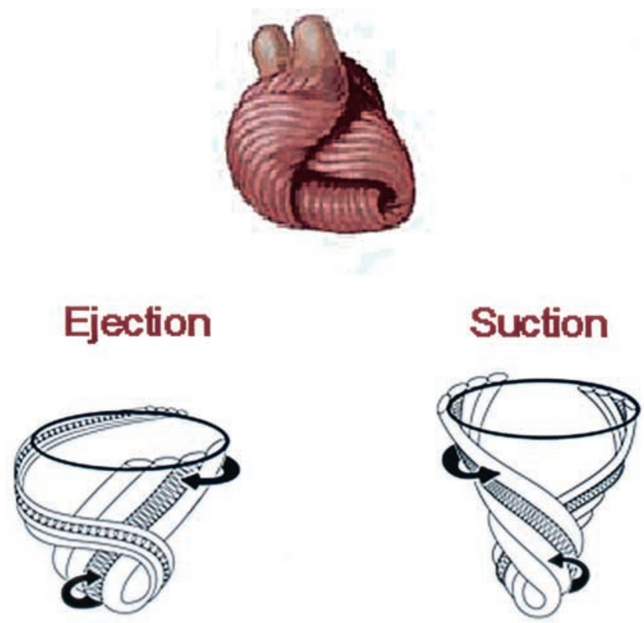

Figure 17. The helical external ventricular shape is shown in the *top panel*, and the internal, coil formation of the descending and ascending segments responsible for ejection and suction are shown in the *bottom panels*. (From Buckberg GD, Coghlan HC, Hoffman JI, Torrent-Guasp F. the Structure and Function of the Helical Heart and its Buttress Wrapping. VII. Critical Importance of Septum for Right Ventricular Function. *Semin Thorac Cardiovasc Surg.* 2001;13:402-16. Reprinted with permission of WB Saunders.)

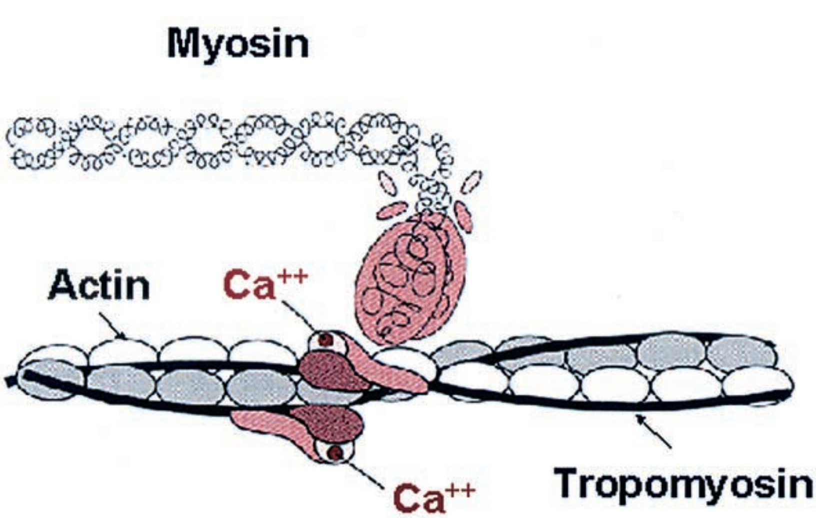

Figure 18. The helical formation of myosin, actin, and tropomyosin, together with the interface of calcium, are defined (From Braunwald E. Essential Atlas of Heart Diseases. Philadelphia: Current Medicine Inc; 1997. Figure 4.1, B [Structure of the heart]).

inserted at the junction, between the contracting and noncontracting regions, to use the concept of Dr Francis Fontan, whose objective is to try to rebuild the apical anchor. An oval surgical neck, or new apex, is formed when the suture is secured. A patch is then placed over that newly constructed oval segment of the apex, or the defect is closed directly. The final step is closing residual muscle over the patch, thereby replacing the sphere with a more elliptical shape.

Dr Hisayoshi Suma also demonstrated an alternate approach to apical rebuilding (Figures E19, E20, E21, E22, E23, and E24, online only). We called this procedure

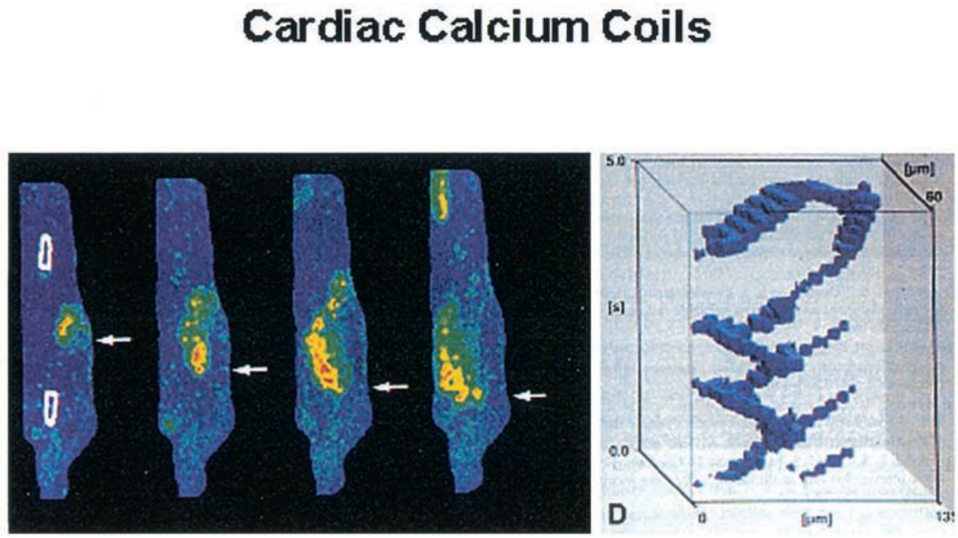

Figure 19. The coils of calcium within one cell that produce a coil-like arrangement are shown. (From Lipp P, Niggli E. Microscopic Spiral Waves Reveal Positive Feedback in Subcellular Calcium Signaling. *Biophys J.* 1993;65: 2272-6. Reprinted with permission of the Biophysical Society.)

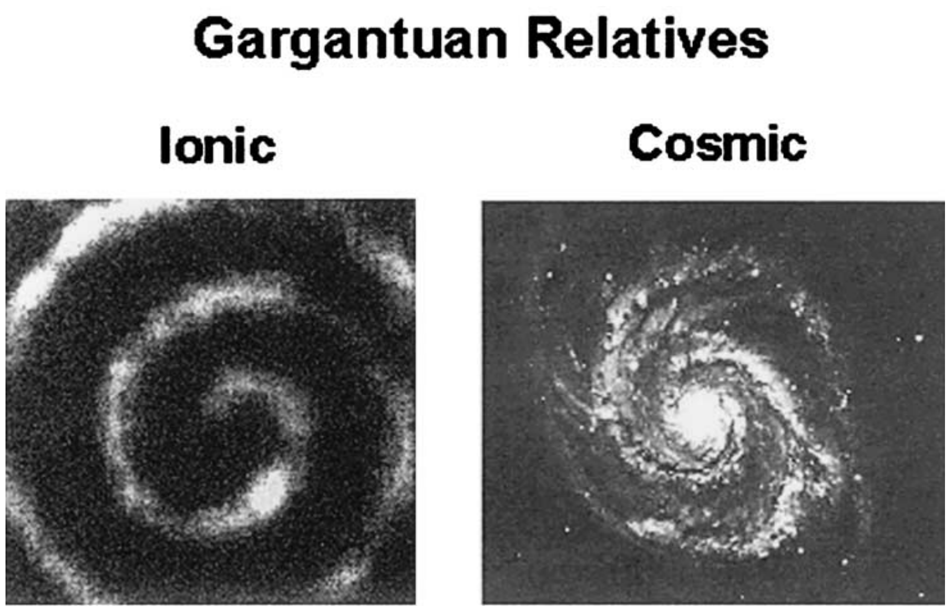

Figure 20. The gargantuan relationship of the ionic coils of calcium *(left)* is compared to the cosmic spiral in a galaxy *(right)*. (From Ball P. the Self-made Tapestry: Pattern Formation in Nature. Oxford: Oxford University Press; 1998. Reprinted with permission of David Clapham.)

pacopexy, to recognize Dr Torrent-Guasp's contribution to our thinking. The spherical ventricle is opened, and a neck is formed with either a running single suture or multiple individual sutures along the septum. A cone is formed when the sutures are brought together to make a neck. The oval neck is then closed by a patch that is placed in a position that starts at the papillary muscle below, and extends upward to a site just below the aortic valve. The sphere is converted to an elliptical form after the sutures have been secured during patch placement. The residual muscle is closed, usually in an imbricating way, to complete the return of the global spherical ventricle toward a conical or more apical configuration.

These observations lead me to believe that we may have

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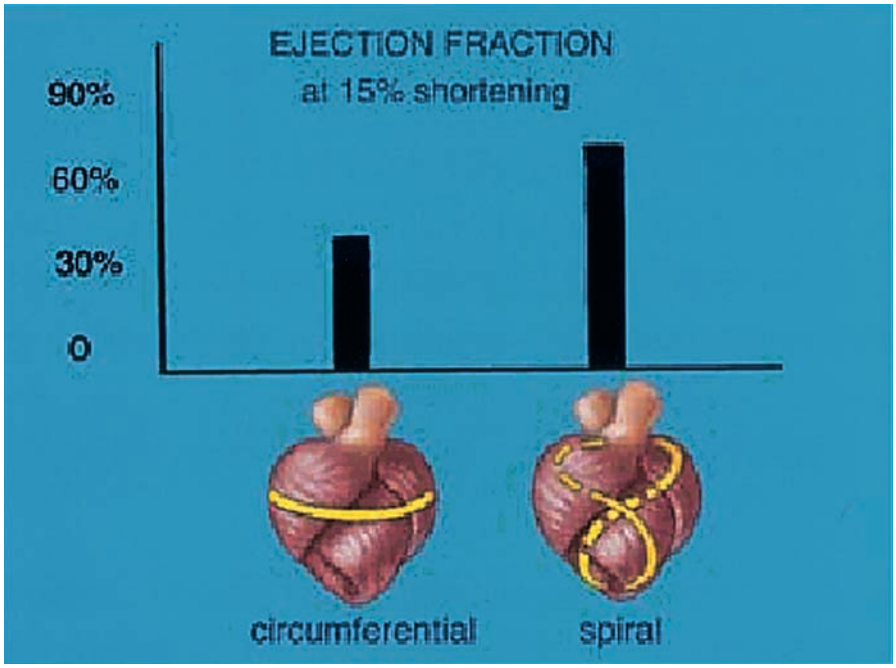


Figure 21. The relationship between fiber angle and ejection fraction is compared for contractile shortening of 15%. Note that the transverse, or circular, arrangement allows a 30% ejection fraction, which becomes 60% with a spiral orientation. (From Buckberg GD, Coghlan HC, Hoffman JI, Torrent-Guasp F. the Structure and Function of the Helical Heart and its Buttress Wrapping. VII. Critical Importance of Septum for Right Ventricular Function. *Semin Thorac Cardiovasc Surg.* 2001;13:402-16. Reprinted with permission of WB Saunders.)

found a "solution" surgically, by more carefully understanding nature and how it affects the heart. In ischemic disease, we try to make an ellipse by excluding the noncontracting scarred segment to alter shape and size of the dilated heart (Figure 25).

With nonischemic dilated cardiomyopathy, Dr Suma showed a longer site of patch placement to exclude damaged noncontracting muscle to produce more elliptical formation. It is possible that, in the future, we can deal also with valvular cardiomyopathy with the same geometric approach. We learned yesterday at this meeting from Dr Bruce Lytle that valve replacement to restore only valve competence is associated with a 70% mortality over 10 years. Clearly, the focal approach to only the valve does not directly deal with the resultant dilated heart in patients with valve disease. Our future objective is to change not only the valve, but also the ventricular geometry, and thereby restore the helix in nonischemic patients with ventricular dilatation from valvular incompetence.

My next question addresses whether this formation of an apex in a heart relates only to biology. I believe it also relates to structure in terms of architectural configuration.

Historically, we observe a Greek temple (Figure 26, *left*) (Figure E25, online only) where the underlying pillars support the beam. These pillars are close together, like a box, to provide the tensile strength of the solid upper transverse structure. Only one person can walk between this pillar/beam structure within the box. The Romans made the next contribution by introducing the semicircle configuration, whereby a central keystone exists to deal with stresses that move toward the upper focal point (Figure 26, *right*) (Figure E26, online only). The result is that more people can walk through these semicircular forms, but to make this archway higher, it must be wider. This spherical design resembles the architecture of the heart in congestive heart failure.

The next objective is to produce an apex, and this new shape configuration is created by Native Americans or Celtics in their construction of huts. The new form contains an apex, the stress forces now proceed downward, and the structure is supported by a buttress formation on the ground. For enlargement, to bring more people into this area and thereby make a tent, the construction introduces an internal buttress, the Gothic arch that contains an apex. To further expand the open space, as will occur in a church (Figure E27, online only), we now find the classic Gothic dome and the introduction of flying external buttresses (Figure 26, *bottom*). This concept is broadened for further enlargement, as occurs in a cathedral. Each structure contains higher and wider Gothic domes that again receive internal support from the flying buttresses.

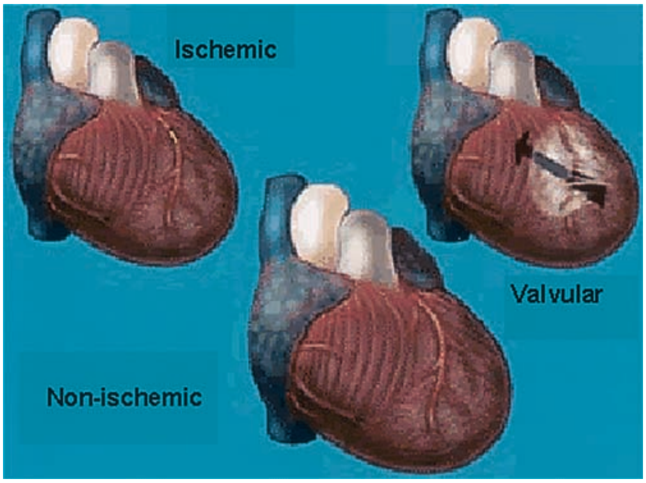


Figure 22. The spherical shape of the dilated heart in cardiac failure is shown for ischemic, valvular, and nonischemic cardiomyopathy. (From Buckberg GD, Coghlan HC, Torrent-Guasp F. The Structure and Function of the Helical Heart and its Buttress Wrapping. V. Anatomic and Physiologic Considerations in the Healthy and Failing Heart. *Semin Thorac Cardiovasc Surg.* 2001; 13:358-85. Reprinted with permission of WB Saunders.)

These changes in architecture follow precisely the changes that are evident in the anatomic structure. The question is, "Did God first make a church, or did he make a heart?" In an upside-down heart we see the apex surrounded by the buttress of the basal loop (Figure 27). Was this cardiac anatomy a unique form related only to the heart? Perhaps it stemmed from the glacial age, where the overall form of the iceberg looks much like a ventricle (Figure 28). This drawing of what we see, and what is below water, was found in the magazine of Delta Airlines and called "Imagination." Many years ago I read a statement by Egon Schiele, an artist, who said, "A painter can make you look, but to see is something special." Clearly, the church, heart, and iceberg share common architectural relationships.

The architectural structures I just discussed are not alive. Our next step is to bring life into them. The heart contains an apex, or a cone formation that has a vortex, and this vortex design is what makes cardiac muscle work. One may think that the tip of that vortex does not move but, in reality, it becomes the motor of the ventricle. In one sense, the tip of that motor of the ventricle is the focal point of a hurricane. This relationship can be seen in a large hurricane (Figure E28, online only). Of course, the critical central point can also go in an opposite direction and, astrologically, becomes the nebula of heaven (Figure 29). How remarkable that throughout nature we see the same structure and the same change in form in so many different arenas.

These observations led me to ask a question about "nature and creation." A stimulus came from reading about

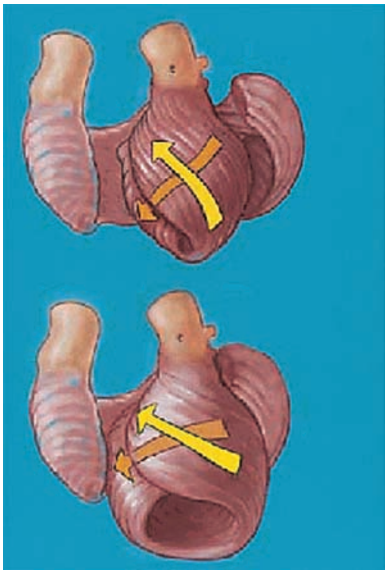


Figure 23. The fiber orientation of the basal and apical loops are shown for the normal heart *(top)* and the failing heart *(bottom).* Note that the circumferential basal loop is not changed, but that the 60° oblique fiber angle in the normal heart is made more transverse in heart failure. The apical loop in the failing heart develops a more basal loop configuration. (From Buckberg GD, Coghlan HC, Torrent-Guasp F. the Structure and Function of the Helical Heart and its Buttress Wrapping. V. Anatomic and Physiologic Considerations in the Healthy and Failing Heart. *Semin Thorac Cardiovasc Surg.* 2001;13:358-85. Reprinted with permission of WB Saunders.)

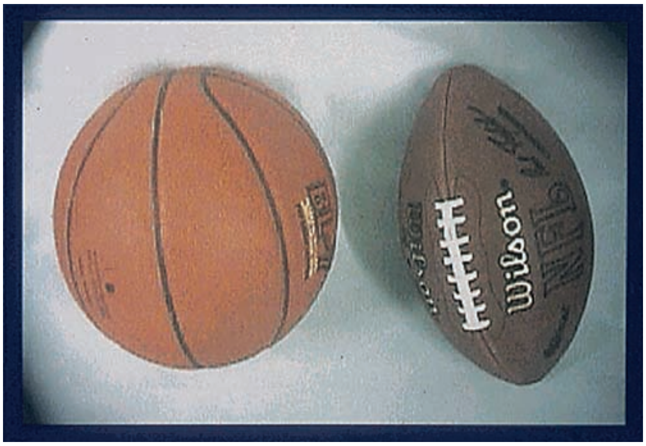


Figure 24. The athletic corollary to shape changes between the normal, elliptical football and the globular, spherical basketball shape in heart failure. The surgical objective is to remake the elliptical football. (Reproduced with permission of Hisayoshi Suma, MD.)

Leonardo da Vinci, who stated: "Nature can be finite, but man can be infinite, because the hand, the mind and the eye can coordinate to produce creation." I will now turn to the

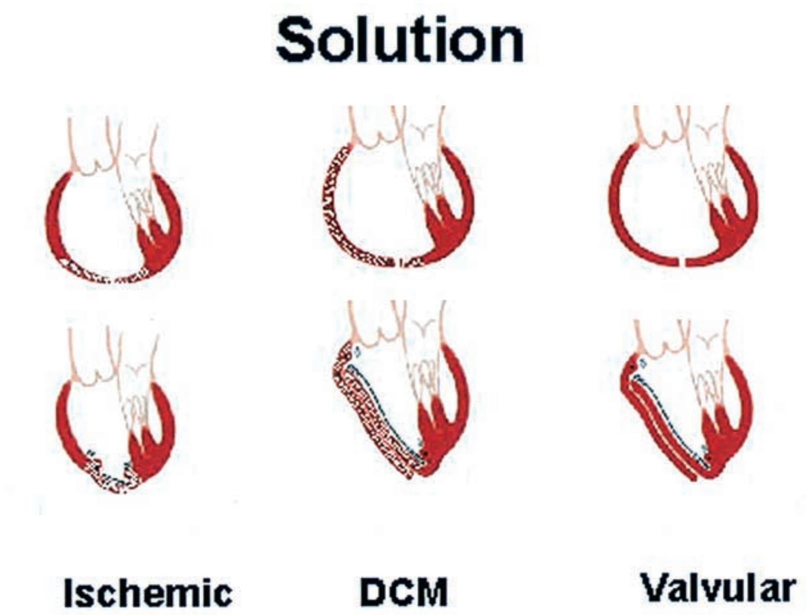


Figure 25. The possible surgical solution to shape change in heart affected by ischemic, dilated cardiomyopathy *(DCM),* and valvular disease, which restores a more elliptical configuration to the left ventricular chamber.

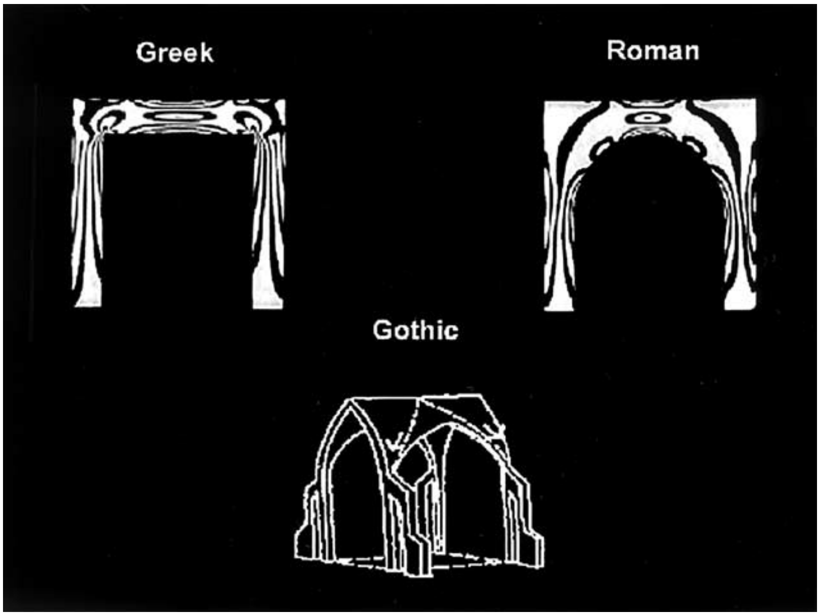


Figure 26. Architectural changes in form that compare the Greek pillared chamber with a transverse beam *(left),* the Roman sphere with a centerpiece keystone at the top *(right),* to a Gothic dome with an apex and circumferential support by external buttresses *(bottom)* to allow forces to be directed downward from the apical tip.

human being to look for an extension of these relationships between parts (Figure 29).

A major stimulus for this lectureship was formulated when I met Dr Francisco Torrent-Guasp 3 years ago (Figure E29, online only). Paco (a shortened name for Francisco) opened my eyes to a new way of looking at the ventricle. He uncovered a novel approach to cardiac anatomy as a student about 50 years ago, when he was in Salamanca. His obser-

Figure 27. The cardiac gothic dome with the heart inverted to place the apex from the apical loop at the top and the circumferential support by the basal loop buttress.

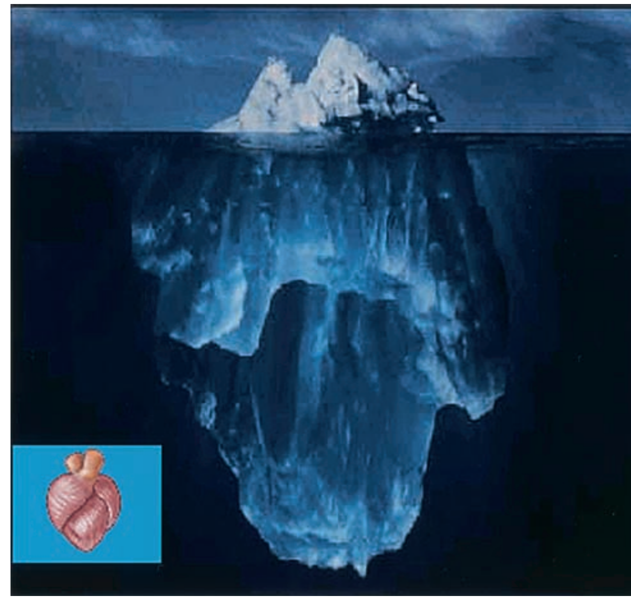


Figure 28. The iceberg is compared to the *inset* of the heart to show the comparable natural form between the glacial age and the heart. (Published with permission of Corbis Images.)

vations are described in a book that he gave to me, written in Spanish, but unfortunately copies are not available in the United States.

He observed the same vortical formation of the apex that we showed earlier and related to the conformation of a hurricane storm. His studies showed the vortex going to the apex and also defined the muscle trajectory motion that proceeded to cause the same clockwise and counterclockwise rotation responsible for ventricular function (Figure E30, online only). Did Dr Torrent-Guasp see this reciprocal spiral relationship in the heart, or did he also look at a pine cone to see its configuration? Analysis of the pine cone (Figure E31, online only) shows that orientation of fiber petals follows exactly the same clockwise and counterclockwise rotation seen previously in the daisy that I used to introduce the reciprocal spiral relationship in nature.

Dr Torrent-Guasp made an interesting comment: "Gerald, nature is simple, but scientists are complicated." On hearing this, I said, "Well, how did you begin to understand the fact that the heart sucked during diastole?" He said, "I went back and read about Erasistratus, who lived 2300 years ago and stated there was suction to achieve venous return." Erasistratus also thought that blood had both blood and air in it. He could not understand how the blue blood got red, but he understood that the heart sucked in diastole. Erasistratus may also have been the first arrhythmologist. There is a painting by Guillemot showing how Erasistratus treated Antiochus, who was the son of the king. (Figure E32, online only). His patient had palpitations only when he saw the king's wife; Erasistratus diagnosed this occurrence and told the king. The king divorced his wife, who married his son, and his son's arrhythmias then went away. So, Jim Cox, does your concept of arrhythmia management stem from a legal bent from the past?

Paco also described Galen, who was the "doctor of the gladiators." Galen looked inside the chest of warriors who were injured, and he observed the heart sucking in diastole (Figure E33, online only). Galen also changed what Erasistratus thought about blood, by observing that blood was blood, and discounted the concept of blood and air. Their cardiac physiologic thoughts were similar, and from that time onward, everybody believed Galen's observations of the to-and-fro motion of the heart to produce flow. This changed when Harvey, in 1638, contributed his remarkable observation of the circulation (Figure E34 and Figure E35, online only). Harvey wrote the book *The Anatomic Exercises* or *Du Mortu Cordis*, which was an enormous scientific contribution. Harvey's breakthrough stunned his colleagues, who still clung to the theories of Aristotle and Galen and others, theories Harvey was thought to have proven to be both inadequate and inaccurate.

Critical reviewers observed that Harvey contradicted Vesalius, who fitted anatomy to the Galenical system that supported the tidal ebb-and-flow concept. Galen suggested

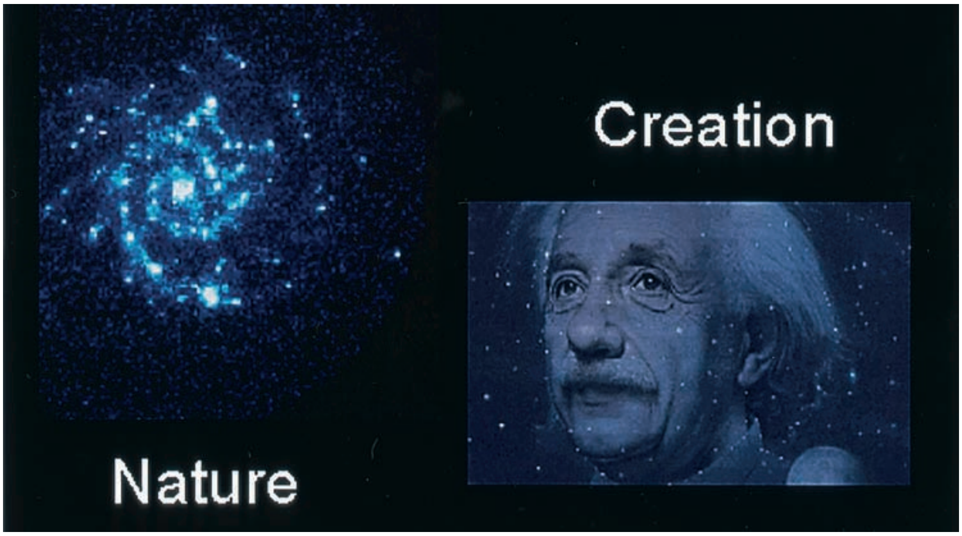


Figure 29. The transition between nature and creation, as explained in the text. (© 1999 Time Inc. Reprinted by permission.)

that one could understand, exactly, how the heart works by looking at the waves in the ocean. Conversely, Harvey indicated the heart did not dilate by taking the shape of a cupping glass and suck blood into it. These observations defined something very important about our leaders. They can be wonderful, but they are not perfect, because the heart does, indeed, suck blood during diastole.

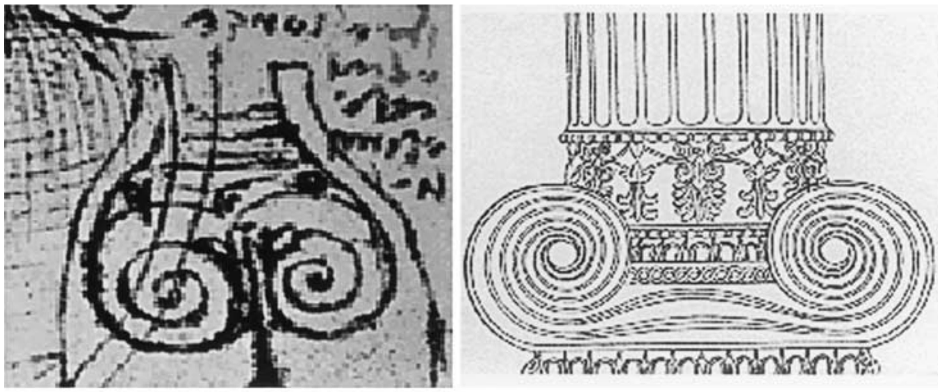
I then reviewed some work of Andreas Vesalius, who is considered the father of anatomy. In the 1500s his drawings, made from dissected hearts, showed relative thickness by making transverse sections of the myocardium. He described this dissection as "The earliest example, since Leonardo da Vinci, that shows the thickness of the walls and shape of the ventricular cavity."

I then looked at a volume of Leonardo da Vinci's anatomic sections. In them, Leonardo showed in the 1400s the same transverse section of the heart that preceded those of Vesalius and stated that the apex, or tip, of the heart comprises the left ventricle. This confirmed how Leonardo knew the apex was very important. Leonardo da Vinci was also fascinated with vortexes. We have learned much about his concepts of vortexes from Dr Francis Robicsek, who informed us about Leonardo's observations of the clockwise and counterclockwise spirals within the aorta as the outlet of the left ventricle.

We must also wonder about how Leonardo discovered the way that the blood flowed through the aorta. Did he look back at a Greek temple 500 years BC (Figure 30) to see the same clockwise and counterclockwise spirals at the top of columns? Did he look further back to neolithic times, approximately 5000 years BC (Figure E36, online only), when prehistoric people made images on graves showing clockwise and counterclockwise spirals? Did he look back 400 million years ago to a tiny fish that has the same clockwise and counterclockwise spirals in its truncus arteriosus?

The image of the zebrafish shown in Figure 31 was taken from Mory Gharib, the honored guest at this year's (2001) meeting (Figure E37 [video], online only). I also show the correspondent size of the human hair, which is 100 microns wide. The aorta of the zebrafish is only 30 microns thick. This heart wall is only 5 cells thick, yet within the aorta we see the same clockwise and counterclockwise spirals with each heartbeat that occurs in the human aorta. The ejection fraction of this microscopic heart is normal, at 60%, and the aorta enlarges during systole to preserve the same spiral aortic formation that occurs in human beings. Note also that the red cells move, one at a time, through the gills, to provide an astounding pathway to understand the helix and the circulation. Should we look at something microscopic existing 400 million years ago, that is smaller than the size of a single hair, or should we proceed in a different direction and look upward at the cosmic waltz (Figure 32), where a galaxy shows two clockwise and counterclockwise spirals where each spiral is 5.9 thousand trillion miles wide? Nature provides the same pattern in each element.

I will now conclude by looking back, again, at "being and becoming" and return to my hero, Albert Einstein, who described general relativity. Einstein understood the concept of equivalence and proportionality, and said, "Matter tells space how to bend, and space tells matter how to move." Analysis of his concept shows that matter, which may be the sun, pushes on time-space, a phenomenon described as if bending on a rubber band. This push is not a straight line, but rather occurs in an elliptical fashion. When



a b

Figure 30. The reciprocal coil architecture described in 1492 by Leonardo Di Vinci for flow in the aortic valve (a) is compared with the temple in Erectheum approximately 500 BC (b). (From Cook TA. The Curves of Life, 1979. Reprinted with permission of Dover Publications, Inc.)

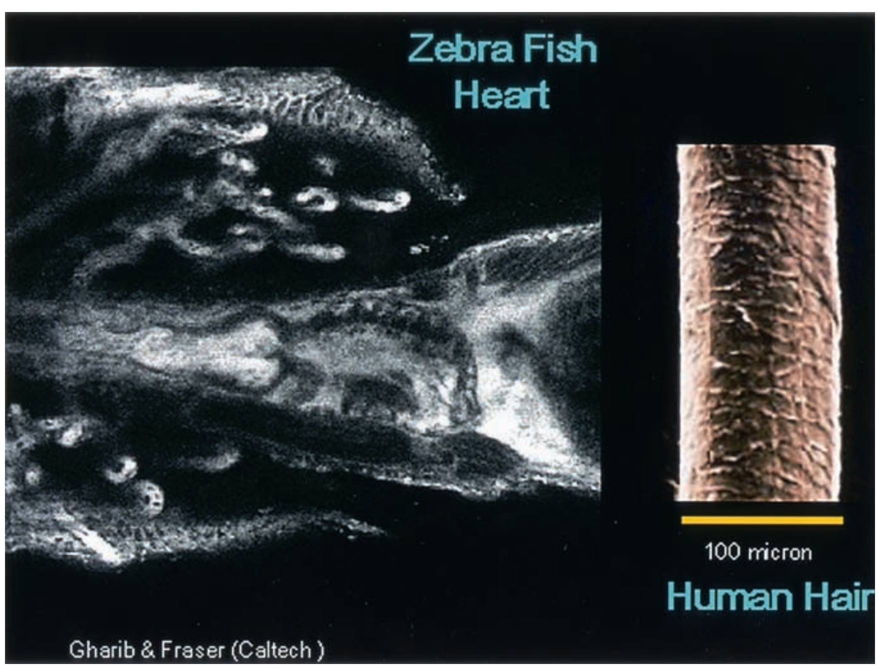


Figure 31. The comparison of the truncus arteriosus in the zebrafish *(left),* existing for 400,000 years, with an aorta one third the size of a 100-μm human hair *(right).* Flow dynamics show the reciprocal spiral aortic flow to be generated by a 5-cell thick heart with a 60% ejection fraction. (Published with permission from Mory Gharib.)

matter pushes really hard on time-space, a bottomless hole develops that reflects a spiral. The resulting spiral, of course, moves both downward and upward. Einstein said that God did not play dice; he did not take chances. Is it possible the concept of going downward and upward in space (Figure 33) is similar to ejection and suction in the heart? Are they really the same thing? As we review how cardiac suction started, this basic biologic concept was observed many years ago by the Greeks and was changed by Harvey, but now is changed back again to what occurs in nature.

I return to Galen, who made the fundamental observation in his description of the heart in AD 180. He said, "The overlying heart, at each diastole, robs the vena cava by violence of a considerable quantity of blood." His words include the violent suction of blood from the vena cava,

Figure 32. The cosmic waltz in which reciprocal spiral formation exists in two galaxies that are 5.9 thousand trillion miles wide.

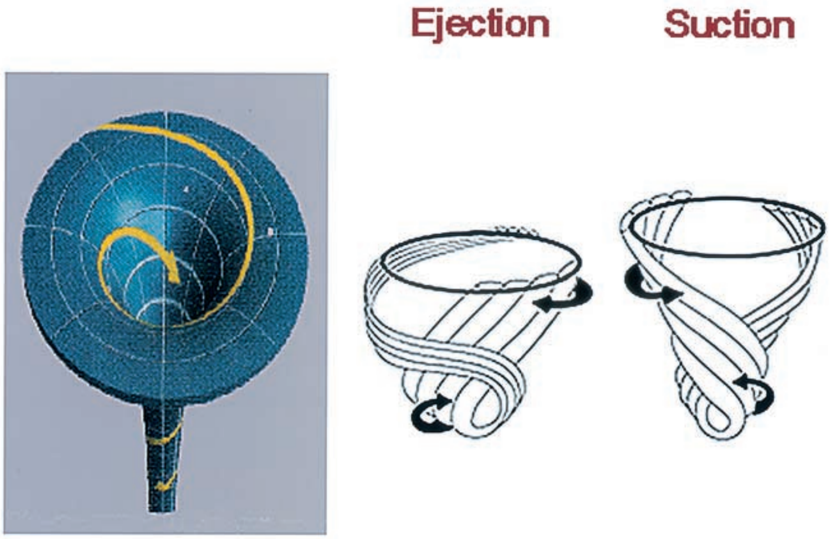


Figure 33. *Left panel,* Spatial configuration shows the effects of general relativity, where mass pushes on time-space in a pattern that bends toward the bottomless hole in a spiral trajectory, with subsequent ascent in a reciprocal direction. Could these changes in gravity and acceleration correlate with cardiac ejection and suction *(right panel)*? (*Left panel,* © 1999 Time Inc. Reprinted by permission.)

observed by his looking within the chest of a gladiator who received a chest wound and whose injury simultaneously exposed underlying biology.

Galen was also taught by someone, through his understanding of the writings of Erasistratus. When asked of his thoughts of Erasistratus, he said, "He had plenty to say in his early career, but now, like a slave with excessive rascality when caught in the act of thieving, he hides the missing article and denies seeing it." Clearly, he did not like Erasistratus, but he disliked someone more, and that was

Lycus of Macedonia. He said that Lycus had the worst doctrine of all and spoke as though uttering an oracle from the inner sanctuary. When asked to describe Lycus of Macedonia, he said that Lycus was not as good as many other wonderful Greeks he previously studied: "Lycus is speaking neither good Erasistratism, nor good Asclepiadism, far less good Hippocratism." He described Lycus as "like a white crow, which cannot mix with the genuine crows owing to its colour, nor with the pigeons owing to its size." But then he made, perhaps, the most wonderful comment on the concept of learning. He said that Lycus of Macedonia "is not to be disregarded, because he may, perhaps, be stating some wonderful truth, unknown to any of his predecessors." This means that no matter how much we like or dislike someone, we always must listen to him or her to learn. If we do that, we become introduced to a thought of mine: Ignorance is being unknowledgeable, but able to learn; arrogance is being knowledgeable but unable to be taught.

We must maintain our student ways, because as we do this, we enter the spiral pathway of learning (Figure E38, online only). We learn more as we go down this spiral loop and thereby increase our concept of knowledge. Simultaneously, as we obtain knowledge, we can begin to move upward, in a different direction, by grasping and using these concepts to develop wisdom. We must then use these methods to understand *growth.* Knowledge develops through analysis, differentiation, or taking things apart. Wisdom evolves by synthesis, integration, or by putting things together, to see with the eyes of the mind.

These steps are not very helpful unless we undertake one other action, which is wholeness: to bring together diversities, to have complementary activity. I believe that we, as cardiac surgeons, are particularly fortunate because we can learn, we can understand, and we can act on the part of our patients.

I will conclude with one final statement from Albert Einstein, who said: "There exists a passion for comprehension, just as there exists a passion for music. That passion is rather common in children, but gets lost in most people later on." I hope not!