INNOVATION IN SURGERY

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Creativity in surgery is not different from creativity in any other area of our culture. The areas where human creativity can be demonstrated are called *domains*. For most people in our society, domains are basically ways to make money. They choose to take 1 job over another on the basis of their abilities and chances to make a good living. There are, however, certain individuals (and the creative ones are often among them) who choose certain careers because of a powerful calling to do so. They would do what they like to do even if they were not paid for it, just for the sake of doing the job. These unique individuals simply love to work. They find their jobs interesting, challenging, and fulfilling. Most surgeons are like that.

Creative surgeons are those who are able to come up with new operations, new ideas, or new things. They are innately curious and thrive on their ability to see things others cannot see. Many surgeons are creative but only at a personal level. They are incapable of proving to their colleagues that they are indeed creative. Their colleagues are the gatekeepers of the surgical specialty (a domain) and dictate how it should be practiced. They are the judges of surgical creativity. Although we may not agree with them, they are necessary because, without their assessment, there is no reliable way to determine whether the claims of a self-styled creative surgeon are valid. Who is correct? The surgeon who believes in his/her own creativity or all the surgeons who negate it?

To be creative in 1 domain, the social milieu has to recognize it. Unfortunately, some creative people are not recognized immediately after their creative disclosure because society is not ready to accept it. The more absurd the idea, the more resistance it will find among the gatekeepers of our culture. That is why Galileo Galilei (1564-1642) was tried by the Inquisition in Rome when he amassed evidence that proved that the

earth revolves around the sun and is not the center of the universe as had been believed.

Leonardo da Vinci (1452-1519), the paragon of creativity, was a Florentine artist and scientist. His paintings, drawings, and notebooks reveal a level of inquisitiveness that could not be appreciated until modern times. Perhaps the reason for Leonardo's habit of leaving unfinished work was that no one could understand or appreciate him. The ascertainable total of human knowledge and human experience exceeded the compass of 1 human intellect. There will never be another Leonardo. With the explosion of knowledge that occurred during the past century, it is impossible for anyone to be creative in so many domains as was Leonardo. It is now extremely difficult to master more than 1 domain of knowledge. That is why surgeons are becoming increasingly more specialized. To be creative, one has to have an in-depth knowledge of the domain. Just as a musician must know music in depth to write new songs, a surgeon must know his or her specialty in depth to develop a new operation or a new device.

Creative people agree with the quotation attributed to Thomas Edison: "Creativity is 1% inspiration and 99% perspiration." A truly innovative operation is seldom the result of sudden insight. More often, it originates after years of hard work. Its actual conception, however, may emerge during a moment of crisis in the operating theater, as in the following example:

In June 1985, Michael Pasque, a surgical resident at the University of Toronto who had not rotated through my service, came in to watch me replace the mitral valve on Mrs D, an elderly woman with calcified rheumatic mitral stenosis. Michael was impressed with my dexterity and rationale for doing things I had done during the operation. As I was closing her chest, a large volume of bright red blood began to pour out the chest tubes. I rapidly reopened Mrs D's chest and diagnosed rupture of the posterior wall of the left ventricle. As I was placing her back on cardiopulmonary bypass, I mentally reviewed what I knew about rupture of the posterior wall of the left ventricle after mitral valve replacement. I knew the literature well, and I had discussed this problem with my good friend, Anwar Zacharias, who had written a paper on this subject after reviewing the experience at the Cleveland Clinic. By the time Mrs D was back on car-

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J Thorac Cardiovasc Surg 2000;119:S38-41.

0022-5223/2000 \$12.00 + 0 12/0/104725

doi:10.1067/mtc.2000.104725

diopulmonary bypass, I had already decided that I was not going to repair the ventricular tear by placing multiple large pledgeted sutures through the posterior wall of the left ventricle because of its associated high operative mortality rate. Because the tear started in the endocardium, that was where I should go. Without hesitation, I rearrested the heart, reopened the left atrium, and explanted the bioprosthesis. Michael Pasque and everybody else in the operating room were silent. I saw a small tear between the mitral annulus and the posterior wall of the left ventricle. After a few seconds of observation and thinking, I took a piece of autologous pericardium, trimmed it in a semicircular fashion, and sutured its circular side to the endocardium of the left ventricle all around the tear and its straight side to the mitral annulus. I reimplanted the same bioprosthesis (I imagine I was already very aware of cost containment!). Mrs D was separated from cardiopulmonary bypass without difficulty and did not bleed. Michael asked, "How many times have you done this operation?" I replied that that was my first. He said, "Where did you learn it?" I told him I had just figured it out. He exclaimed, "I don't believe it!" I said, "Believe me, it is true. If she does well, I will report this case." My first paper on reconstruction of the mitral annulus was published in 1987.¹

The result of Mrs D's operation was so gratifying that I began to perform the same operation in patients with mitral annulus abscess and extensive calcification of the annulus and in those patients with multiple previous mitral valve replacement and destroyed annulus. I taught the operation to my colleagues and to numerous other surgeons who visited me. By the end of the 1980s, I had presented and written several papers on that subject. Around that time, Lawrence Bonchek, MD, called me to say that he had operated on a patient with a large mitral annulus abscess that was debrided and patched with autologous pericardium the way I had described and that the patient had done very well. It was a great feeling to know that other surgeons could apply what I had developed. John Kirklin, MD,² stated in an introduction of 1 of his books that a good operation should be safe, teachable, and reproducible.

That was how reconstruction of the mitral annulus was developed. Although I conceived it during an intraoperative crisis, I had spent the previous decade studying the mitral valve and conducting animal experiments on the role of the mitral valve in left ventricular function. I also had a sound knowledge of the biologic fate of autologous and glutaraldehyde fixed bovine pericardium because I had used them extensively in patch

enlargement of the aortic annulus and because I had done a couple of hundred mitral valve operations for a variety of problems.

Attention is a limited mental resource, and it is indispensable in acquiring new knowledge. A great deal of our limited supply of attention is committed to the task of surviving from 1 day to the next. It takes a lot of effort to do our jobs as surgeons and to keep assimilating new information as an operation is performed. Take, for example, the performance of a mitral valve operation. So much attention is required to observe the patient's hemodynamic stability, to open the chest, to place the patient on cardiopulmonary bypass, to protect the heart, to expose and evaluate the valve, and to correct its problem that there is not enough attention left for lateral thinking during the performance of those tasks. It takes an enormous amount of attention to do a perfect job in a timely fashion. It takes an incredible amount of self-discipline to expand our attention to develop new ideas and to begin to see things from a different angle. The moment we succeed, we begin to be creative.

During my cardiac surgical training in the late 1970s, I observed that patients who had undergone mitral valve repair had a less complicated postoperative course than those patients who had undergone mitral valve replacement. I actually conducted a retrospective study during my residency to prove my contention. I presented my work at the "residents research day" that Wilfred Bigelow, MD, used to hold every semester at the University of Toronto. Several attending surgeons commented that the results of my study were potentially biased because the patients who had undergone mitral valve repair were probably not as sick as those patients who had undergone replacement. Dr Bigelow, however, was so impressed with my observations that he sent me to Paris to learn more about mitral valve repair. He told me that Professor Charles Dubost had a young surgeon who was doing wonderful things with the mitral valve. That was when I first met Alain Carpentier, MD. In those days, Dr Carpentier frequently spent more than 2 hours repairing a mitral valve, and his patients did very well. Most of his patients would have undergone a mitral valve replacement in Toronto and would have struggled during the early postoperative course. Indeed, even in Dr Carpentier's hands, patients who underwent mitral valve replacement did not do as well as those patients who underwent mitral valve repair.

I hypothesized that the presence of the mitral valve was important for left ventricular function. In reviewing the literature, I found that several physiologists had made inferences regarding the same thing, but before

the days of cardiac surgery. Soon after my return to Toronto, I conducted a pilot project in animals and wrote my first grant-in-aid to test my hypothesis. I found that mitral valve replacement was detrimental to ventricular function in dogs. A couple of years later, I showed that left ventricular function was better after mitral valve repair than mitral valve replacement in humans with chronic mitral regurgitation. This topic remained 1 of my academic focuses, and later I concluded (as the late Walton Lillehei, MD, did some 20 years earlier) that the preservation of the attachments between the papillary muscles and the mitral annulus is important for left ventricular function after mitral valve replacement. Many other investigators confirmed our findings, and it is now widely accepted that mitral valve repair is better than mitral valve replacement and that, if replacement is necessary, maintenance of continuity between the papillary muscles and mitral annulus is important for postoperative left ventricular function.

Creativity is a complex process that requires more than a creative person. The environment where the creative person lives or works is extremely important. The Florentine Renaissance is a good example of that. Florence had become 1 of the richest cities in Europe, and its urban leaders decided to invest in making it the most beautiful city in Christendom early in the fifteenth century. They sponsored the construction of spectacular churches, palaces and bridges and commissioned artists to create magnificent frescoes and statues. Filippo Brunelleschi (1377-1446) was 1 of the greatest personalities of this early Renaissance. He was born in Florence and was trained as a goldsmith. Many-faceted, he did very well as an architect, designer, artist, and scientist. He is remembered mostly, however, for the final design and completion (with assistance from Ghiberti) of the great cupola of Santa Maria del Fiore, the Florentine cathedral, probably the largest groin vault ever built. He died in 1446 and was buried in the cathedral. It is unlikely that Brunelleschi and friends would have been so creative if they had lived in a less affluent place. My surgical innovations have also been the result of working in an academic environment that nurtures creativity.

After I completed my residency, I had to learn in great detail the anatomy and function of the aortic root to start a program on aortic valve replacement with aortic valve homograft in 1980. In those days, I implanted aortic valve homografts almost exclusively in the subcoronary position. It was difficult to obtain enough aortic valves homografts, and I decided to re-examine the abandoned issue of stentless porcine aortic valves. I

began to implant them in sheep, and a few years later, by 1987, I was using them in humans.

I was proficient in implanting stentless biologic valves when Jack Butany, MD, our cardiac pathologist, called and asked me why I had replaced the aortic valve of a particular patient. I told him the patient had symptomatic aortic insufficiency and needed aortic valve replacement. He suggested that the valve dysfunction might not be due to aortic cusp disease because he could find no macroscopic or histologic abnormality on any of the 3 cusps that I had sent him. He implied that I had replaced a "normal" aortic valve. That was all I needed to trigger my curiosity about aortic valve dysfunction in patients with normal aortic cusps. I contacted Harry Rakowski, a very experienced and smart echocardiographer, and he and I reviewed several preoperative echocardiograms of patients who had undergone aortic valve replacement for aortic insufficiency and normal aortic cusps. From there, I developed a new understanding of the functional anatomy of the aortic valve. I concluded that, if I were able to implant a donor aortic valve in the subcoronary position of a recipient's aortic root, I should also be able to create a new aortic root using the recipient's normal aortic cusps.

It was in this frame of mind that I performed my first aortic valve-sparing operation on Ms L, a 19-year-old girl who had Marfan syndrome, a 58-mm aortic root, and moderate aortic insufficiency and who did not wish to be on anticoagulant therapy. I had scheduled her to have an aortic root replacement with an aortic valve homograft, but when I opened her aortic root, I changed my mind. Her aortic cusps appeared entirely normal, and all she needed was a new aortic root that was able to support her own aortic cusps. After measuring the aortic cusps and making a few theoretic geometric extrapolations, I chose a tubular Dacron graft of certain diameter to replace her aortic root. The graft was sutured on the outside of the left ventricular outflow tract, and the 3 aortic cusps were resuspended into the new aortic root made of Dacron fabric, just like an aortic valve homograft in the subcoronary position. The coronary arteries were reimplanted in their respective sinuses. When we discontinued cardiopulmonary bypass, Dr Rakowski looked at her transesophageal echocardiogram and told me that she had a normally functioning aortic valve without any insufficiency or stenosis. He asked how I came up with this new operation. I told him that it was a long story and that I would tell him over a glass of wine someday. Ms L. did very well after the operation, and now, a decade later, her aortic valve continues to function normally.

By the end of that year, I had done 10 reimplantations of the aortic valve in patients with aortic root aneurysms, presented the data at an annual meeting of the American Association for Thoracic Surgery, and published the paper in *The Journal of Thoracic and Cardiovascular Surgery*.³ I asked Karyn Kunzelman, PhD, a young scientist from the University of Washington in Seattle, to help me to better define the geometric relationships of the aortic root and its components during this type of operation. Her contributions were invaluable. They have allowed a more scientific base for these operations, and we now can match the procedure to the pathologic process with excellent functional results. By the end of 1999, I had preserved the aortic valve in more than 200 patients with aortic root aneurysm and aortic insufficiency. We have learned a lot about the reconstruction of the aortic root, and we have also taught what we know. Dennis Tyras, MD, attended 1 of our teleconferences at which time we demonstrated the different types of aortic valve-sparing operations for the various aortic root problems. Two weeks later, he called me to say that he had performed an aortic valve-sparing operation on a patient in chronic hemodialysis with an ascending aortic aneurysm and heart failure because of aortic insufficiency. He corrected the patient's aortic insufficiency and ascending aortic aneurysm without using a prosthetic heart valve. Dennis made me very happy that day.

The Toronto Hospital has been my Florence, an academically stimulating place one needs to be creative.

My referring cardiologists have provided me with an abundance of patients with all sorts of interesting cardiac problems, and I have been fortunate to work with a cadre of outstanding physicians who have been always ready and willing to assist me in new ventures.

I could not conclude without mentioning luck. Creative individuals usually see themselves as very lucky people. To be in the right place at the right time is also important for creative people. Those who can seize an opportunity to be creative are the lucky ones.

Creativity is a quality of those who know themselves, their strengths, and their values and who know how they best perform. The key to being creative is to find an enticing domain. One has to master all that is known about a domain to be able to change it. Intellectual arrogance is very detrimental to creativity. When I attended school, my father repeatedly told me that I should never believe that my education was completed or believe that I knew everything.

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