A Tale of Serendipity, Ingenuity, and Chance

50th Anniversary of Creation of the Swan-Ganz Catheter

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On the 50th anniversary of the invention of the Swan-Ganz catheter, the untold, intimate details of its development deserve recounting, in part because it illustrates how often advances in science require equal measures of brilliant intuition, persistence in adversity, stunning serendipity, plain good luck, and the play of chance.

It is 1968. In-hospital mortality from acute myocardial infarction (MI) is a staggering 30%, predominantly due to left ventricular (LV) failure. In Los Angeles, II.J.C. “Jeremy” Swan, MD, known for his work in pediatric catheterization at the Mayo Clinic, is the newly installed chief of cardiology at Cedars of Lebanon Hospital. Swan believes bedside measurement of LV function in MI patients might improve outcomes. Swan asks staff cardiologist Ronald Danzig, MD, to try floating fine tubing through the right heart until it wedges in the distal pulmonary artery (PA). Danzig’s success rate in entering the PA is dismal. The tubing consistently coils up comfortably in the right atrium (RA).

Outside-the-Box Intuition

Some weekends later, pondering Danzig’s frustration as he sits on Santa Monica beach watching sailboats, Jeremy has a Newton-apple flash of inspiration: a catheter equipped with sheets and sails could pass through the RA, the right ventricle (RV), and then to the PA, carried by the force of blood behind it. Jeremy proposes his idea to Danzig, cath lab director Harold Marcus, MD, and newly arrived cardiovascular animal laboratory researcher Willie Ganz. Danzig is not enthusiastic, imagining himself at the bedside trying to disentangle Swan’s sail from tricuspid valve chordae. Marcus, similarly unmoved, sarcastically envisions Swan’s imagined device “wafting through the circulatory system like a Mary Poppins umbrella.”

Persistence

But Swan, like his contemporary Minnesota cardiac surgery legends of prior decades, is undeterred by his colleagues’ profound skepticism and behind-the-back ridicule. He persists. He is a consultant at Edwards Laboratories, a respected leader in prosthetic cardiac valve technology located an hour’s drive south of Los Angeles. At his next consultant’s meeting, Jeremy promotes his idea to Edwards’ Director of New Product Development David Chonette and his assembled engineers. They too are profoundly unimpressed, if for a different reason: no one can envision construction of a practical small diameter catheter festooned with remotely controlled sheets and sails.

Serendipity

As Swan’s inspiration is once again crushed, astonishing serendipity lifts his consultation from abject failure. Someone suggests that maybe the same effect could be accomplished by replacing his sails with a balloon. Where in the world did that idea come from? One of Edwards’ minor business ventures is putting a balloon on an embolectomy catheter. That they know how to do. The incandescent moment of invention occurs when an ingenious idea is juxtaposed with an unrelated device, in the only place in the world where those 2 ideas might come together.

Yet, it was hardly a eureka moment. Chonette recalls that not one of the participants were particularly
enthrallled with their hybrid, and so “mostly as a favor to Jeremy,” he procures an infant feeding tube and secures a balloon to one end. In late 1968, Chonette delivers a few of these prototypes to Willie Ganz in his animal research laboratory. On the first try, the single-lumen catheter shoots instantly into the PA. Based on just 1 proof of principle, Willie and David take responsibility for creating a more practical catheter with an additional lumen for measuring pressure.

A new year arrives, and in mid-1969, I join Jeremy's full-time staff as an unknown (1 publication) graduate of Harvard's cardiology fellowship. As Danzig leaves to enter private practice, cardiology fellow George Diamond, MD, and I are trying to satisfy Jeremy by bedside retrograde LV catheterization in Cedar's Myocardial Infarction Research Unit (MIRU), a dedicated i-bed room adjacent to our cardiac care unit. Willie gives us one of his new double-lumen catheters to test. At the end of an unrelated animal laboratory experiment, George and I decide to give it a try. We insert the catheter blindly into the dog's internal jugular vein. Within seconds, the catheter is stuck. It will not move forward even though it records only an atrial pressure tracing. We imagine that somehow we have accidentally entered the coronary sinus, so we tug back on the catheter. A PA waveform appears. Baffled, get the fluoroscope; the catheter tip lies in a distal pulmonary vessel. Dumbfounded, we realize that our “RA pressure” is actually pulmonary capillary wedge pressure (PCW). The catheter has, entirely on its own without any manipulation, shot through the RV, out into the PA, and wedged securely in a distal pulmonary vessel.

Jeremy encourages George and me to test the balloon catheter in our MIRU. Because institutional review boards do not exist, George and I simply sterilize our catheter and go directly to our patient's bedside. We insert the catheter through a cutdown on an antecubital vein (subclavian insertion had not yet been developed). As the first-ever balloon catheter in acute MI enters the RV, we are met with a furious, horrifying run of ventricular tachycardia, induced by the catheter’s stiff tip flailing against the endocardium. In that terrible moment, I envision a catastrophe that sticks with me to this day: that my desire to do groundbreaking research has injured my patient, perhaps fatally. The arrhythmia subsides spontaneously as the catheter flips into the PA. Later that day, we share our near-disaster experience with Jeremy and Willie. We agree to move the balloon from its position on the distal shaft all the way out to the catheter tip.

GOOD LUCK

In attaching a latex cylinder to form his prototype balloon at the catheter tip, Edward's David Chonette folds both ends of the tubing back onto the shaft of the catheter. To our surprise, the inflated balloon bulges beyond the tip without obstructing the lumen. Spectacular good luck or David's profound prior wisdom? Whichever, David has created a soft “pillow” that forever eliminates tip-induced ventricular arrhythmias.

Within a few months, George and I catheterize the pulmonary arteries of 70 patients in the MIRU, and Harold Marcus tests another 30 catheters in the cath lab (1). In the MIRU, George and I see that PCW changes almost immediately with drug therapy, many hours before we see any change in rales or the chest x-ray (2). Comparing alternative drugs, we find our treatment decisions are repeatedly modified by bedside hemodynamics.

STROKE OF CHANCE

Without doubt the most profound stroke of chance in the catheter's development comes, not from medicine, but from politics. In Prague, Czechoslovakia, while Jeremy is contemplating sailboats on Santa Monica's beach, Willie Ganz is plotting his family's escape from Communist oppression. Granted permission to take a family vacation in Europe, Willie abandons all his worldly possessions in Prague. Forty-nine years old and unknown in the academic West, with just 9 publications, Willie's prospects seem bleak. With Jewish community support, he ultimately lands a job in cardiovascular research at Cedars of Lebanon Hospital as a penniless refugee.

But what Willie brings with him is beyond imagining. In their Prague animal laboratory, Willie and physiologist Arnost Fronèk had developed a method for measuring blood flow by thermodilution. The technique requires 2 thermistor wires and a mixing chamber. Cardiac output (CO) can be measured by injection of a cold solution in the RA, which mixes with blood in the RV. The time course of temperature change in the PA is then used to calculate flow by the Fick Principle. Willie brings his knowledge of this arcane technique to Los Angeles.

THE TRIPLE-LUMEN CATHETER: PERSISTENCE REVISITED

As we use the double-lumen catheter to measure PCW in the MIRU, Willie proposes that his 2 thermistor wires can be used to measure CO. Neither Willie
nor Jeremy ever pass our catheter in patients, so it falls to George and me in the MIRU to pass the 2 thermistor wires. But 2 devils lurk in the details. The temperature of the injectate changes as it passes from the external injection site through the catheter to the RA, so Willie wants us to pass a thermistor wire through the catheter to the RA delivery site. But it proves impossible. The wire twists and buckles with friction against the inner surface of the catheter, and in addition, when we rarely do succeed, the wire leaves no room for the injectate. Willie’s dream of a single catheter to measure PCW and CO is shattered.

**OUTSIDE-THE-BOX REVISITED**

But now George, a quintessential out-of-the-box thinker, has an idea. Perhaps he can create an algorithm that predicts the temperature of the injectate delivered into the RA, given the temperature of the injectate outside the body, the patient’s blood temperature, and the catheter length. George develops his algorithm in bench testing, and cath lab director Harold Marcus validates George’s method by simultaneous measurement of cardiac output by thermodilution and indocyanine green in the cath lab. The 2 methods correlate ±5%.

**PERSISTENCE REVISITED**

To create a single catheter, incorporation of the PA thermistor wire into the catheter itself now falls to David Chonette. He easily embeds the wire in a catheter by creating a separate third lumen through which he threads the wire. At end of the catheter, where the thermistor tip is insulated and sealed, the second devil appears. Too much sealant blunts the thermistor’s temperature sensitivity. Too little sealant allows seepage of blood through the sealant, disabling its function after in-dwelling overnight in the MIRU. Sealant after sealant fails until finally David finds the cure. For the first time, we can reproducibly measure PCW and CO (3).

**ACHIEVING OUR ORIGINAL GOAL: BEDSIDE HEMODYNAMICS**

In the MIRU, increased PCW precipitates pulmonary congestion, and decreased CO induces signs of peripheral hypoperfusion. We realize that cardiac index and PCW are surrogates for the x- and y-axes of the Starling curve, allowing us to bring together cardiac function, hemodynamic cutpoints, and clinical presentation in 4 subsets (Figure 1) (4).

In-hospital mortality among each of the subsets is statistically significant (at that time, approximately 1%, 10%, 20%, and 60%, respectively). Our hemodynamic cutpoints become widely used internationally throughout critical care as the Forrester classification, but to our disappointment, our parallel clinical classification is ignored. The Killip classification, which does not relate directly to hemodynamics, nor identify the critical subset of hypoperfusion without congestion, remains widely used for 30 years until Lynne Stevenson, MD, revives that link using the appealingly pithy descriptive terms dry, wet, warm, and cold.

Using our subsets, we define the acute effect of all our therapies on cardiac function. The pressure waveforms themselves allow us to identify often unrecognized or misdiagnosed complications of MI including mitral insufficiency, pericardial tamponade, acute ventricular septal defect, and RV MI (5). The catheter ushers in the era of monitoring in all forms of critical care units and in general anesthesia.

**DENOUEMENT**

Medical breakthroughs have shelf lives. Thrombolytic therapy and angioplasty for acute MI in the 1990s lead to a dramatic decline in heart failure and cardiogenic shock. Bedside echocardiography leads to far less need for invasive hemodynamics. But in its era, >25 million Swan-Ganz catheters were used worldwide since that first MIRU patient experienced life-threatening iatrogenic ventricular tachycardia in 1969. The pathophysiological lessons learned from the correlation of CO and PCW with clinical
presentation, and with the acute response to pharmacological therapy stand as a landmark in critical care, and as a foundation of modern patient management. Although its era has passed, the insights into the creative process, and the knowledge from bedside hemodynamics live on.

**REFERENCES**


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