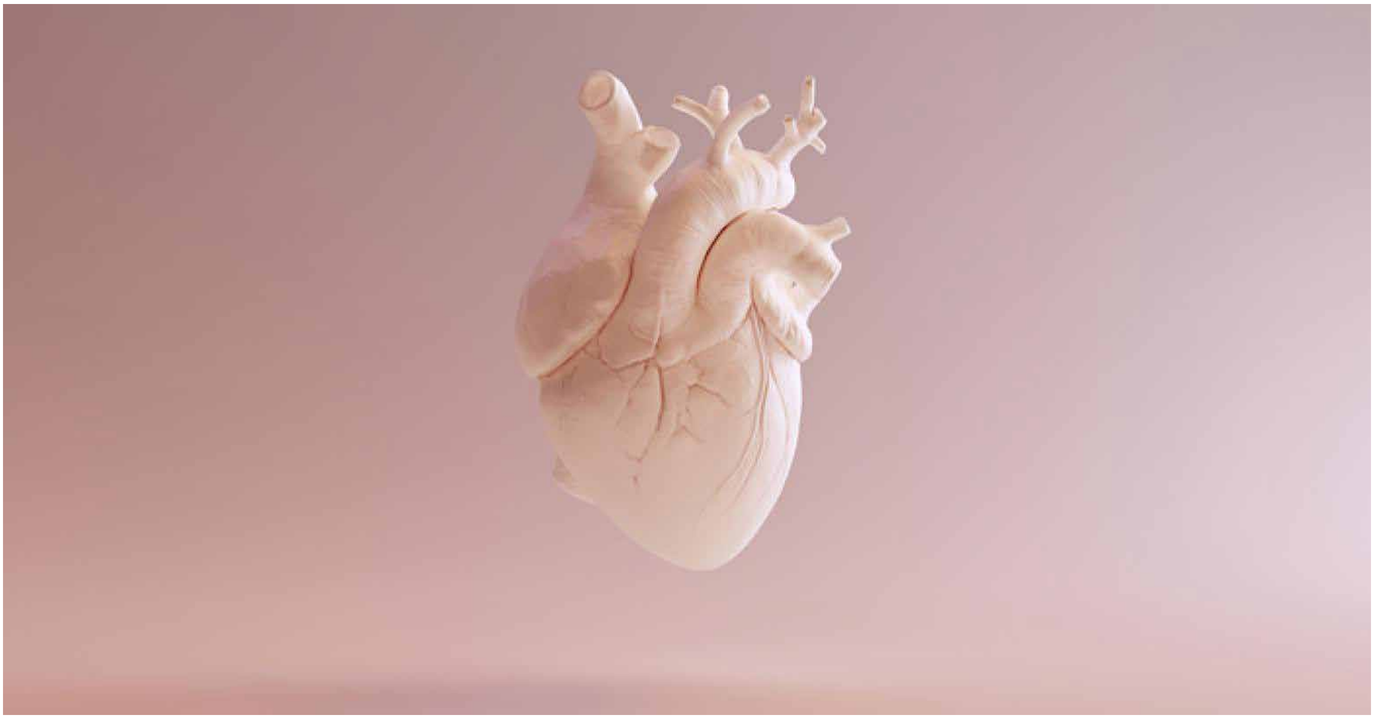
MEDICAL DEVICE AND DIAGNOSTIC INDUSTRY

Can a Robot Make a Better Heart Valve?

How to develop heart valves during a pandemic.

By Jason Beith; Peter Cavallo; David Robers | Oct 30, 2020



Calcification is the bane of the human heart valve. Human heart valves are plagued by stenosis[1] – or the thickening or stiffening of the valve leaflets caused by a build-up of calcium. Millions of patients are affected each year.[2] A patient with a stenotic valve needs a replacement valve at some time in their life or their heart valve will fail and they will die.[2] This issue has driven the growth of the artificial heart valve industry over the last several decades.

Several types of prosthetic valves have been invented over the last 70 years, but none have adequately resolved the problem of heart valve calcification without significant trade-offs.

Types of prosthetic heart valves

Mechanical heart valves – commonly made of carbon today – were invented in the 1960's. While very durable, often lasting throughout a patient's lifetime,[3] they require open-heart surgery and the carbon surface attracts blood clots.[4] As a result, patients with mechanical valves must be on lifelong blood-thinning medication[5] (anticoagulants) to prevent the development of blood clots that can cause a heart attack or stroke. This use of blood thinners puts patients at a high risk of bleeding[6] and they must often compromise their lifestyle to accommodate it.

To reduce this risk of valve thrombosis and lifelong use of blood thinners, tissue heart valves were invented, commonly using bovine (cow) or porcine (pig) tissue for valve leaflets. While reducing the risk of thrombus,[4] the animal tissue proved far less durable than mechanical valves, often requiring a re-operation to replace the valve within 10 to 20 years.[3] Tissue valves are also complicated to manufacture. According to Edwards Lifesciences,[7] one of the world's largest heart valve manufacturers, making just one of their tissue valves takes 150 employees, 40 days of production, and 5-6 weeks of testing and packaging, with each assembler requiring 6 weeks of training.

As an alternative, polymer valves have been explored over the years. However, polymer valves have been unable to demonstrate that they can withstand the stresses of a human heart valve and have suffered from calcification, thrombosis, and lack of durability.[8]

So, there exists a conundrum in current commercial heart valves – making tradeoffs in durability for patient quality of life – resulting in no heart valve that checks all the boxes.

Making a better heart valve

What if, rather than iterating off existing ideas to solve the challenges around heart valves, you instead decided to rethink everything about a heart valve from scratch…what would you end up with?

To start with, you would simultaneously think about material, design, and manufacturing to optimize everything about the device and its production.

You would start with finding or inventing a material and design that could resist calcium and withstand the stresses and strains of the human heart for a lifetime. One that virtually eliminated thrombus accumulation and pannus formation on leaflets. One that required only one surgery for any given patient. And one that matched or improved upon the performance of today's standard-of-care heart valves.

At the same time, you would identify a manufacturing process that could accommodate that material and design while improving uniformity and precision, streamlining the process, and reducing costs associated with tissue valve manufacturing. Oh, and you would also want to be able to run the line 24 hours a day, 7 days a week, and not be sidelined by pandemic concerns.

Purpose-built material and design

Carbon, tissue, and polymer have all shown weaknesses as surrogates for the human heart valve. All of these approaches have used existing materials and altered them to withstand the significant pressures of the human heart.

Only by creating a brand-new material can we hope to finally solve the historical heart valve conundrum. By engineering a biopolymer at a molecular level specifically for use in the human heart (LifePolymer™*) we can finally end up with a valve that can withstand and even go beyond the substantial stresses the human heart can produce.

With a proprietary biopolymer, you can design ultra-thin yet strong leaflets that can rapidly open and close, enabling excellent hemodynamics.[9] You can also computer-design the leaflet shape and stent design uniquely for the aortic and mitral positions to accommodate the different opening and closing dynamics for each position. This approach is designed to optimize the distribution and absorption of stress in a bid to enhance durability.

Using this novel biopolymer and valve design, early animal studies and bench testing have shown promising results. Animal studies have shown no calcification,[9] virtually no platelet aggregation,[9,10,11] negligible fibrin deposition,[9,10,11] no pannus formation on leaflets,[9,10,11] and excellent hemodynamics.[9] Internal bench testing has shown resistance to catastrophic valve deterioration (even to deliberately-damaged leaflets).[12,13,14,15]

A Breakthrough in Heart Valve Manufacturing… Robotics

The unique material and design enable robotic manufacturing of an artificial heart valve for the first time in history. Using robotics, you open up the door to levels of precision, stability, reproducibility and efficiency that could have never been imagined with existing heart valve production.

The robotic valve dipping process using a biopolymer creates an entire heart valve leaflet and frame structure in one step. This revelation was a turning point in the commitment to robotic manufacturing. The integrated material-design-manufacturing approach also enables the design of one valve base and universal tooling for all sizes of valves, which enhance the ability to robotically produce the valve.

Think about what it takes to manufacture tissue valves today. Animal tissue is first collected from slaughterhouses and then must be cleaned, sorted and sterilized. Production is done in vast rooms with hundreds of human assemblers sitting elbow to elbow, painstakingly hand-sewing leaflets to valves. Now, envision what robotic heart manufacturing looks like in the real world. Imagine three small robots with the capability to manufacture enough valves to accommodate an entire year's worth of U.S. surgical heart valve demand (100,000 valves, to be specific).

Robotic heart valve manufacturing benefits from decades of robotics experience spent assembling miniature components for the electronics and automotive industries. The same requirements for electronics components – precision, cleanliness, efficiency – translate well to the needs of the medical device industry, where tiny devices are being manufactured to be used inside the human body.

Robots can be small in stature and are capable of very fine movements, beyond what a human can produce in the way of precision and repeatability. Considering a human hair is approximately 75 microns in width[16], when you are dealing with ± 20 micron adjustments to a device, this is difficult for a human to achieve but quite easy for a robot. With human assembly, things can get missed toward the end of a shift when completing complex tasks, while robots are consistent, every single time.

Remember we talked about dipping of leaflets as a turning point in the ability to robotically manufacture heart valves? Dipping of polymer leaflets by hand is a highly variable process – getting uniform leaflet thicknesses within specification every time is nearly impossible. Robotic manufacturing adds more precision and repeatability to the process, with automated systems controlling the dipping, measuring leaflet thickness, and visually inspecting the biopolymer leaflets. Once the dipping quandary was solved, robotics could be embraced for virtually every step in the manufacturing process.

Ultimately, the robotic manufacturing design will encompass two clean room-style robots with dual articulating arms in the actual manufacturing cell, and one small load/unload robot that supplies the other robots with materials. The robots are pre-designed specifically for a clean room environment, with medical-grade material, paint, seals, wiring, and joint architecture borrowed from the automotive industry.

The human component in robotic manufacturing will be minimized as much as possible to remove subjectivity and enable efficiency. No human hands will touch the valve. Humans input the raw materials and supplies and monitor the robots, and the robots take it from there. The ultimate goal is complete automation and machine repeatability all the way through.

You might be wondering how tissue valve manufacturing could benefit from robotics. Tissue valves require more than 1,000 hand sutures each, which would not be compatible with a robot. Because the animal tissue itself and design are not optimized for robotics, there would not be the same opportunity to go robotic. There would be few tasks in manufacturing that could be automated, and thus, the economics would not be the same. Only by rethinking everything at the same time – material, design and manufacturing – does robotics make sense.

Technology in robotics

Robotics enable minute, precise and real-time trackability and digital data collection at every step, for every valve. Each robotic movement can be measured and recorded, from timing down to the 10th of a second to temperature to location. This rigor in tracking enables identification of important trends and assists with rapid troubleshooting. The QR code, invented by DENSO Robotics 25 years ago[17] for NASA satellites, is utilized in tracking each valve through the manufacturing cycle.

The economics of robotics

When first considering robotic manufacturing of heart valves, one might think it would be expensive. In fact, the costs are quite shocking, but pleasantly so. The upfront cost of each robot is actually less than the annual minimum wage for most workers.

As far as overhead, the robotic manufacturing facility to produce a year's worth of surgical heart valves comprises less than 4,000 square feet for everything, including storage. Compare that to an approximately 300,000 square foot tissue valve manufacturing facility, and add in the cost of utilities, gowns, laundry, and the like.

All in all, the upfront capital investment to robotically produce a biopolymer heart valve is under $2 million as a one-time cost to produce all the surgical heart valves needed in any given year, which is what most companies spend on just one clean room with nothing in it.

How robotics help in a pandemic

COVID-19 has created a great deal of angst and disruption for companies large and small. Valve manufacturing has faced challenges with protecting workers and social distancing in an assembly environment, meeting supply demands with fewer workers on the assembly line, training of new operators, and significant bioburden concerns.

As robots do not carry viruses and do not need time off, robotic manufacturing can ensure that not one day of manufacturing is missed in the event of a pandemic. It is also notable that the digital data recording even eliminates risks from paper from the system.

The future of robotic heart valve manufacturing

The pandemic has highlighted the peril of American manufacturers' dependence on offshore manufacturing and foreign goods. As companies seek to bring manufacturing back to the U.S., robotics will play a larger role in their consideration. The robotically manufactured heart valve has been entirely manufactured in the U.S. since inception due to the improved economics offered by robotics.

Because of the efficient set-up of a robotic manufacturing pod, they can easily be replicated, based on demand. The manufacturing process is already set and the robots are already programmed; it is as easy as finding another facility and purchasing additional robots. Once set-up, the robotic manufacturing facility is adaptable, easy to learn, and user-friendly.

Over time, robotic manufacturing will continue to be economically attractive, as robots have a long lifespan and require minimal maintenance over the long term.

Robotic manufacturing of a heart valve – combined with a novel material and design - has shown that it can help solve the historical heart valve conundrum. As part of a novel approach of reinventing material, design and manufacturing, robotics has proven that it can be instrumental in producing a better artificial heart valve.

*Tria LifePolymer heart valves are for investigational use only and not available for sale.

References:

1. World J Cardiol. 2010 Jun 26; 2(6): 135–139. Published online 2010 Jun 26. doi: 10.4330/wjc.v2.i6.135
2. Nat Rev Cardiol 2011;8: 162–72.
3. American Heart Association website. Types of replacement heart valves page. https://www.heart.org/en/health-topics/heart-valve-problems-and-disease/understanding-your-heart-valve-treatment-options/types-of-replacement-heart-valves
4. Heart 2007;93:137–42.
5. JACC. 2017 Jul 11;70(2):252-89 DOI: 10.1016/j.jacc.2017.03.011
6. J Thromb Thrombolysis. 2013 Apr; 35(3): 312–319.
7. Edwards Lifesciences. LinkedIn post. https://www.linkedin.com/company/edwards-lifesciences/
8. Expert Rev Med Devices. 2012 Nov; 9(6): 577–594. doi: 10.1586/erd.12.51
9. Data on file at Foldax.
10. Data on file at Foldax.
11. Data on file at Foldax.
12. Data on file at Foldax.
13. Data on file at Foldax.
14. Data on file at Foldax.
15. Data on file at Foldax.
16. Bacteria-World.com website. Home page. http://www.bacteria-world.com/how-big-micron.htm
17. QRcode.com website. History of QR code page. https://www.qrcode.com/en/history/

Authors:

Jason Beith, Vice President, R&D, Foldax, Inc.

Jason has over 20 years of experience in the medical device industry and is a major contributor to the invention of the Tria aortic and mitral surgical valve platforms, leading the development of the novel manufacturing and production system. Previously, he was Senior Principal Engineer in R&D with Medtronic, where he was the technical lead and inventor of the Avalus pericardial tissue valve. Earlier, Jason was involved in synthetic heart valve development for several years after receiving his PhD from the University of Glasgow. He was also a Principal Engineer within Edwards Lifesciences' Advanced Heart Valve R&D, where he led the company's efforts on polymer heart valve design and development. Jason has eight issued U.S. patents and numerous applications worldwide.

Peter Cavallo, Senior Manager, Robot Division, DENSO Robotics, Inc.

Peter has worked for DENSO Robotics for more than 40 years, in various capacities including sales, planning, and currently, as manager of the company's Robot Division. Peter founded the robot sales division in 1999 when Denso decided to expand its robotic offerings to the U.S. and grew that business by almost 50x. Peter will retire this year after helping DENSO Robotics become a market leader.

David Robers, Vice President, Sales - Americas, Robot Division, DENSO Robotics, Inc.

David has been with DENSO for almost 10 years, rising from Business Development Manager to his current role leading robot sales throughout North, Central, and South America. Prior to joining DENSO, he founded three start-up companies, including Diversified Design Dynamics (engineering and machine design services), Diversified Manufacturing (parts manufacturing, product assembly, and machine build), and Robotic Systems Group (focused on robot sales and service). David began his industrial career in the aerospace division of Cincinnati Milacron.