At Mayo Clinic the foundational approach to complex medical problems has been a multidisciplinary collaborative approach, and this is certainly embraced in the setting of the adult congenital heart disease practice. In the current era, multimodality imaging techniques are being used more frequently as their utility is better appreciated. There are several choices available when it comes to detailed imaging. Echocardiography has been the mainstay approach, has a long history in the practice and remains uniquely poised to delineate complex hemodynamic abnormalities non-invasively. Cardiac computed tomography (CT) and magnetic resonance imaging (MRI) provide a good imaging alternative in patients in which echocardiography is problematic or inconclusive which can be common in patients with multiple complex surgeries. Currently both cardiac CT and MRI are regarded as standard adjunctive imaging approaches to help with diagnosis, stratification of prognosis, surveillance for complications and as an alternative when standard echocardiography is inadequate. Furthermore, as these techniques are becoming more mainstay in contemporary practice, the stance in the Mayo Clinic Adult Congenital Heart Center is (1) to critically appraise their utility, (2) to help understand congenital heart disease and post-operative changes and (3) to approximate the clinical, surgical and imaging practices when it comes to planning future procedures for our patients in need.

Advanced imaging has been central to the continued advancement of the contemporary cardiovascular practice in the adult congenital heart center. “3D imaging provides a detailed understanding of the complex spatial relationships in the heart and vascular system that is required by cardiac surgeons, cardiologists, cardiac radiologists, and the cardiovascular device industry to successfully manage these complex diseases,” says Nandan S. Anavekar, MB BCh, cardiologist and imaging specialist at Mayo Clinic in Rochester, Minnesota. In congenital heart disease, the 3D relationships of cardiovascular structures can vary greatly from patient to patient and are often not immediately intuitive from two-dimensional (2D) images. To address this dilemma, 3D printing of life-size, patient specific models can help improve the understanding of cardiac and vascular anatomy.

3D printing, an exciting, relatively new addition to the imaging armamentarium, is the process of creating a physical model based on a digital file using a 3D printer, a machine which...
lays down multiple layers of material guided by the model file. Medical 3D printing allows volumetric imaging data sets (most commonly CT, MRI, or ultrasound images) to be converted into physical 3D replicas of anatomy (Figure). While this technology has been available since the early 1980’s and has been used for planning dental and craniofacial surgery for over 25 years, 3D printing for cardiovascular applications has seen a significant growth only over the last several years. This technology not only shows promise as a cardiovascular diagnostic tool, but also has implications in therapies as 3D bioprinting may be useful for the creation of living 3D printed implants. Congenital heart defects are the most common type of birth defects occurring in about 1% of all live births. A large number of these defects require surgery for management with a significant number, especially those in the category of complex congenital heart disease, requiring multiple operations. While there have been great advances in surgical technique and outcome, there still remains significant morbidity and mortality, especially in the setting of those requiring multiple operations. A major reason for this is the significant variation in anatomic abnormalities in patients with congenital heart disease, especially in those individuals requiring repeated procedures. At the Mayo Clinic practice, 3D printing has seen a rapid growth in use for planning treatments for patients with congenital heart disease and carries hope in improving quality, efficiency and outcomes of these procedures. The current paradigm of the practice is to identify those individuals with complex anatomy who may require repeated procedures that carry significant risk. These individuals are discussed in a conference forum and all imaging materials are carefully reviewed ahead of time by cardiac imagers with specialization in congenital heart disease. With the advancement of 3D printing at the Mayo practice, life-size models using different materials can be held by the surgeon who can then immediately contemplate the approach and the technical feasibility of the anticipated procedure.

“The use of 3D printed models can be used to tailor education to different learners,” says Thomas A. Foley, MD, radiologist at Mayo Clinic in Rochester, Minnesota. “3D printed models are being used to effectively teach complex cardiac anatomy to radiology, cardiology, and cardiovascular surgery fellows.” Training procedural techniques has been traditionally time consuming and has the potential to be implicated in procedural complications. Simulation using 3D models is emerging as a fundamental resource for teaching advanced skill sets in the field and is similarly being used within the Mayo Clinic practice as a new standard of care. Finally, we have found that 3D printed models are also effective tools for communication within healthcare teams and with patients. Within the practice, specific 3D models used to explain disease processes and planned procedures enhanced patient understanding and facilitated shared decision making and informed consent, which ultimately improves patient satisfaction.
Yogesh Reddy, MBBS, Vaibhav Vaidya, MBBS, and William Miranda, MD bested 35 other teams to win the American College of Cardiology Fellows-in-Training Jeopardy competition during the 67th Annual Scientific Session in Orlando, Florida. The team from Mayo Clinic in Rochester, Minnesota won nine preliminary rounds, the semi-finals and the final round, answering questions from categories based on the American Board of Internal Medicine Certification Examination Blueprint. Dr. Reddy is a senior fellow in the advanced heart failure and transplant training program, Dr. Vaidya is a senior fellow in the electrophysiology training program, and Dr. Miranda has joined the Mayo Clinic in Rochester, Minnesota cardiovascular staff specializing in structural heart disease.

Fletcher A. Miller, MD, cardiologist at Mayo Clinic in Rochester, Minnesota and emeritus director of the Mayo Clinic Echocardiography Laboratory, presented the 2018 Tajik-Seward Echo Lecture, entitled “Echoes from the Past – And a Few Thoughts for the Future.” Dr. Miller (center) is pictured with the lectureship namesakes, A. Jamil Tajik, MD (left), past chair of the Mayo Clinic Division of Cardiology and past director of the Mayo Clinic Echocardiography Laboratory and currently president of Aurora Cardiovascular Services in Milwaukee Wisconsin, and James B. Seward, MD, (right) past director of the Mayo Clinic Echocardiography Laboratory and currently president of EchoMetrics in Rochester, Minnesota.

Michael J. Ackerman, MD, PhD, pediatric cardiologist at Mayo Clinic in Rochester, Minnesota, received the 2018 Distinguished Scientist Award at the annual scientific sessions of the Heart Rhythm Society held in May in Boston. Dr. Ackerman is the director of both the Windland Smith Rice Sudden Death Genomics Laboratory and the Long QT Syndrome Clinic at Mayo Clinic.

Yogesh Reddy, MBBS was awarded the 2018 Donald C. Balfour Alumni Award for Meritorious Research. This award recognizes outstanding research by a resident of the Mayo School of Graduate Medical Education. Dr. Reddy graduated with honors and a full scholarship from Madras Medical College in India. He completed his Internal Medicine Residency at Case Western Reserve University in Cleveland, where he received the Norman Goodman Award for clinical excellence. Dr. Reddy is currently pursuing advanced training in heart failure and cardiac transplant at Mayo Clinic in Rochester, Minnesota, and will complete his Masters in Clinical Investigation this year.

John F. Bresnahan, MD, interventional cardiologist at Mayo Clinic in Rochester, Minnesota, has received the 2018 Interventional Fellows’ Teacher of the Year Award. This award is presented annually by the trainees for professionalism and for providing an outstanding educational experience throughout the year.

Krishnaswamy Chandrasekaran MD, cardiologist at Mayo Clinic in Rochester Minnesota, is the recipient of the 2018 Mayo Clinic Career Contribution to Cardiovascular Medicine Award. This award is presented annually by the Department of Cardiovascular Disease to honor career contributions in clinical practice, education, and research.
Congenital Heart Disease: The First Fifty Years ... The Next Fifty Years

The First Fifty Years

There were three major revolutionary innovations and paradigm shifts in congenital heart disease (CHD) interventions over the last half-century. These innovations were the heart-lung (cardiopulmonary bypass) machine, neonatal cardiac surgery, and transcatheter therapy.

Heart-Lung Machine

The advent of the heart-lung machine in the mid-1950s marked the birth of cardiac surgery and the genesis of CHD as a subspecialty. Prior to this, there had been several successful extracardiac CHD interventions such as the first ligation of patent ductus arteriosus by Dr. Robert Edward Gross in 1938, repair of coarctation of aorta by Dr. Clarence Crafoord in 1944, subclavian to pulmonary artery (Blalock-Taussig) shunt performed by Dr. Alfred Blalock in 1944, and the first pulmonary artery banding by Dr. William H. Muller Jr. in 1951.

Dr. F. John Lewis performed the first intracardiac surgical procedure in 1952 when he repaired an atrial septal defect using moderate hypothermia and caval inflow occlusion technique. This was immediately followed by repair of several moderately complex CHD diagnoses such as the first ligation of patent ductus arteriosus by Dr. Robert Edward Gross in 1938, repair of coarctation of aorta by Dr. Clarence Crafoord in 1944, subclavian to pulmonary artery (Blalock-Taussig) shunt performed by Dr. Alfred Blalock in 1944, and the first pulmonary artery banding by Dr. William H. Muller Jr. in 1951.

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The first successful application of the heart-lung machine was by Dr. John Gibbon Jr. when he repaired an atrial septal defect in a young woman in 1953. Unfortunately, subsequent attempts to replicate this operation all resulted in surgical mortality over the next two years. However, the tides turned when Dr. John Kirklin used a modification of this heart-lung machine (Mayo-Gibbon’s pump oxygenator) in a series open-heart operations from 1955 with some success (Figure). Subsequent modifications of the heart-lung machine such as the DeWall bubble oxygenator, which was cheap and easy to assemble, catalyzed the proliferation of open-heart surgical centers in the United States and throughout the world. The next decade witnessed the emergence of new surgical techniques for more complex lesions such as the Senning operation in 1957, Mustard operation in 1963 and the Fontan operation in 1968.

The Arterial Switch Operation

The arterial switch operation was first introduced by Dr. William Mustard in Toronto in 1952 although the patient did not survive. The first successful switch was performed by Dr. Adib Jatene of Brazil in a 42-day-old infant with transposition of the great arteries and ventricular septal defect in 1975. This marked the beginning of an era of early primary repair of complex congenital heart defects.

Neonatal Cardiac Surgery

The next revolutionary innovation in CHD interventions was the advent of neonatal cardiac surgery. Prior to this, neonates and young infants with complex CHD had to undergo a palliative procedure as a bridge to corrective surgery later in life. In the late 1960s and early 1970s, Dr. T. Horiuchi and colleagues from Japan and Dr. Brian Barrat-Boyes from New Zealand were reporting good results with primary repair of tetralogy of Fallot in infants. The Boston Children’s Hospital followed this trend under the leadership of Dr. Aldo Castaneda, and accumulated a large and satisfactory experience with open-heart operations in neonates and infancy including the first arterial switch operation in an 11-day-old neonate in 1983. Neonatal cardiac surgery changed the CHD landscape by reducing the need for
staged surgical repair (palliative surgery followed by corrective surgery) and its associated morbidity and mortality, and increased the population of CHD patients that were eligible for heart surgery. The first successful transcatheter cardiac procedures were balloon atrial septostomy by Dr. William Rashkind in 1966, patent ductus arteriosus closure using Ivalon plug in 1967, and atrial septal defect closure by Dr. Terry Dean King in 1975. A new frontier in CHD interventions emerged after the first successful transcatheter aortic valve replacement in an inoperable patient by the French cardiologist Dr. Alain Cribier in 2002. This paved the way for the development of Melody transcatheter valve, which has become the workhorse of transcatheter pulmonary valve therapy for nearly a decade.

In addition to these revolutionary interventions, the field of congenital cardiology also witnessed several other important milestones such as significant improvement in perioperative anesthesia and monitoring, neonatal and pediatric critical care, fetal echocardiography and interventions, and improved patient survival resulting in the emergence of the Adult Congenital Heart Disease subspecialty.

The Next Fifty Years
Despite the landmark innovations of the first 50 years, the next 50 years appear even more promising. There are multiple evolving areas of expertise that will potentially shape congenital cardiovascular specialty over the next half-century. The first is the creation of the Adult Congenital Heart Disease subspecialty. With up to 90 percent of CHD patients surviving to adulthood in the current era, the next fifty years will likely see a significant increase in the prevalence of acquired heart disease in this population. Well-coordinated specialized multidisciplinary care from providers with skills in both pediatric and adult medicine will become critical for the prevention and management of acquired heart disease as well as the long-term sequelae of CHD in this population.

Second, one of the downstream problems of an aging CHD population is an increase in the average number of surgical reinterventions in a lifetime, and the need for multiple reoperations in patients with complex anatomy will invariably result in an increase in surgical morbidity and mortality. Transcatheter valve therapy is now increasingly being used to mitigate or delay the need for multiple high-risk surgical reoperations. Although transcatheter valve therapy was an innovation of the first 50 years, the application of this therapy is significantly limited by the anatomic variability of the CHD population making most patients ineligible candidates. The ongoing improvement in the design of valve prostheses and delivery systems specifically engineered to accommodate the anatomic variability of this population will potentially increase the number of patients eligible for this therapy in the next half century.

Third, the advances in imaging techniques (CT, MRI, echocardiography) that include 3-dimensional imaging and the ability to print models and evaluate anatomy in a virtual environment allows a more thorough preparation for a complex intervention. In addition, the ability to practice the actual procedure in advance of the operation provides an effective model for education and may help reduce morbidity and mortality for complex or infrequently performed percutaneous or open surgical procedures.

Fourth, the demand for cardiac replacement therapy will continue to rise as the CHD population ages and the prevalence of end-stage heart failure increases. Unfortunately, the limited availability of donor heart organs and pre-sensitization from prior operations have resulted in a huge mismatch between the supply of cardiac allografts and the rising demand due to end-stage heart failure. With the ongoing improvements in the newer generation of ventricular assist devices we anticipate that the use of ventricular assist device as destination therapy for CHD patients with end-stage heart failure may become the standard of care in the near future.

Lastly, stem cell therapy is an emerging field with many exciting ongoing research studies. The clinical application of stem cell therapy, though still at the preliminary stage, is very promising for slowing down the progression to end-stage heart disease or even potentially reversing myocyte damage from previous insult.

At the turn of the twentieth century, complex CHD was uniformly fatal with no meaningful treatment options. The last 50 years have witnessed the birth and exponential growth of CHD interventions. More importantly the next 50 years will likely see more revolutionary innovations in this field.
Juan A. Crestanello, MD, has joined the Department of Cardiovascular Surgery at Mayo Clinic in Rochester, Minnesota. Dr. Crestanello earned his medical degree from the University of the Republic of Uruguay Medical School. He trained in General Surgery at Hahnemann University and the University of Maryland. Dr. Crestanello completed his cardiothoracic residency at Mayo School of Graduate Medical Education in Rochester, Minnesota. He then practiced cardiac surgery at The Ohio State University before returning to Mayo Clinic. At Ohio State, Dr. Crestanello was Director of the Division of Cardiac Surgery and was the G.S. Kakos, MD and T. E. Williams, Jr. MD, PhD Endowed Professor in Cardiac Surgery.

Dr. Crestanello’s main clinical interests are conventional and minimally invasive valve surgery and transcatheter valve procedures. Other interests include complex cardiac re-operations, heart valve repair, endocarditis surgery, adult congenital heart surgery, hybrid coronary revascularization, surgery for hypertrophic obstructive cardiomyopathy, and aortic surgery. Dr. Crestanello’s research interests are focused on clinical outcomes after cardiac surgery procedures. They include the effect of lung disease on outcomes after heart valve surgery or TAVR, reoperations for endocarditis, and the effect of hyponatremia on outcomes after cardiac surgery.

Arman Arghami, MD has joined the department of Cardiovascular Surgery at Mayo Clinic in Rochester, Minnesota. Dr. Arghami received his medical education in Mashhad University of Medical Sciences in Mashhad, Iran. He completed his general surgery residency followed by cardiothoracic surgery training at Mayo Clinic in Rochester, Minnesota. Dr. Arghami’s interest is in a wide range of adult cardiac surgeries, with focus on minimally invasive and robotic procedures.

Phillip G. Rowse, MD has joined the Department of Cardiovascular Surgery at Mayo Clinic in Rochester, Minnesota. Dr. Rowse completed his medical education at Ross University School of Medicine in Dominica, West Indies. He has spent the last eight years at Mayo Clinic in Rochester, Minnesota completing his residencies in general surgery and cardiothoracic surgery, including a one-year fellowship in surgical simulation with the American College of Surgeons Education Institutes. Dr. Rowse has an interest in treating all aspects of adult cardiovascular disease including arrhythmias, valvular heart disease, ischemic heart disease, and re-operative surgery with a focus on the use of minimally invasive techniques including robotically-assisted procedures.

**Announcement**

**Simon Dack Award**
Barry A. Borlaug, MD, cardiologist at Mayo Clinic in Rochester, Minnesota has been chosen to receive the Simon Dack Award for Outstanding Scholarship from The Journal of the American College of Cardiology. Named for the founding editor of the journal, the Simon Dack Award recognizes the contributions and accomplishments of outstanding peer reviewers who assist the journal in its mission of publishing important new clinical information.