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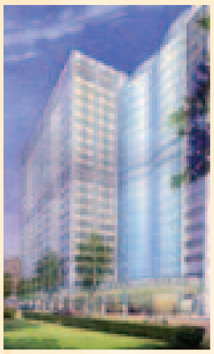


Inside This Issue

New Hyperbaric and Altitude Medicine Program at Mayo Clinic Rochester

Raymond C. Shields, MD

In January 2008, Mayo Clinic Rochester launches a clinical and research hyperbaric and altitude medicine program. The multidisciplinary efforts of the Division of Preventive, Occupational, and Aerospace Medicine, the Division of Cardiovascular Diseases, and the Gonda Vascular Center focus primarily on the management of chronic nonhealing wounds. "This program is an important extension of the Wound Center as an additional tool in managing problem wounds, with the goal of providing comprehensive care and further improving limb salvage rates," says Raymond C. Shields, MD, Mayo Clinic Rochester cardiologist and member of the staff of the Gonda Vascular Center.

Mechanisms of Action

Hyperbaric oxygen therapy is defined as exposure to 100% oxygen at a pressure greater than atmospheric pressure. The modern clinical and scientific use of hyperbaric oxygen started in 1955 as an adjunct to cardiac surgery before the wide availability of cardiopulmonary bypass machines.

Under conditions of normal perfusion at rest, tissues extract between 5 and 6 mL of oxygen per deciliter of blood. Based on Henry's law (the partial pressure and concentration of a gas dissolved in a liquid are determined by the partial pressure of the gas on the surface of that liquid), at sea level while breathing ambient air (1 atmosphere = 1 kg/cm^2, 760 torr, or 760 mmHg), the plasma oxygen concentration is 0.3 mL/dL. At sea level, this concentration increases 5-fold to 1.5 mL/dL with administration of 100% oxygen. At 3 atmospheres of pressure, the dissolved plasma oxygen content approximates 6 mL/dL; this level allows for sufficient oxygenation of resting tissues, regardless of the oxygen-hemoglobin content. At the tissue level (muscle and subcutaneous tissue), the partial pressure of oxygen at 2 atmospheres of compression while breathing 100% oxygen approximates 300 mmHg.

Based on Boyle's law (the volume of a confined gas is inversely proportional to the pressure at a constant temperature) and Laplace's law, the primary effects of increased pressure and levels of oxygen are reduction in bubble size and bubble dissolution.

Indications and Secondary Effects

These mechanisms of action (changes in pressure and oxygenation) are particularly applicable in the urgent management of arterial gas embolism and decompression illness. Indeed, hyperbaric oxygen is the primary therapy for arterial gas embolism and decompression illness. Other important indications for hyperbaric oxygen therapy are listed in the Table.

Secondary effects of hyperbaric oxygen therapy are diverse and include the following:

1. *Increased leukocyte oxidative intracellular killing*. Leukocyte phagocytosis is improved with increased tissue oxygen levels (Po_2 of 45 to 150 mmHg) achieved with hyperbaric oxygen versus decreased tissue oxygen levels (less than 30 mmHg). Clinical applications include necrotizing soft tissue infections and chronic refractory osteomyelitis.
2. *Toxin production, inhibition, and inactivation*. Hyperbaric oxygen therapy is effective for inactivat-

ing clostridial toxins and is directly bactericidal to *Clostridium perfringens*. This effect is applicable in the management of clostridial gas gangrene.

3. *Osteoclast stimulation*. Osteoclast function is stimulated by hyperbaric oxygen, which is elemental in the management of chronic refractory osteomyelitis and osteoradionecrosis.
4. *Fibroblast proliferation and collagen synthesis stimulation*. This process is also oxygen dependent and is important in the proliferative and remodeling stages of wound healing.
5. *Angiogenesis stimulation*. Tissue oxygen gradients generated by hyperbaric oxygen stimulate capillary formation. This is particularly applicable to graft salvage, soft tissue radionecrosis, and osteoradionecrosis.
6. *Vasoconstriction*. Vasoconstriction with hyperbaric oxygen results in tissue edema reduction while ameliorating ischemia, which is particularly important in the management of crush injuries and acute thermal burns.

Contraindications

Absolute contraindications for hyperbaric oxygen therapy include concurrent use of doxorubicin (due to possible increased cardiotoxicity). The cytotoxic effect of *cis*-platinum may be enhanced with hyperbaric oxygen therapy, thereby diminishing wound healing. Disulfiram inhibits superoxide dismutase production, the major defense against oxygen toxicity. Untreated pneumothorax is also an absolute contraindication for hyperbaric oxygen therapy.

Hyperbaric oxygen therapy has the following relative contraindications: upper respiratory infection, chronic sinusitis, seizure disorder, emphysema with CO_2 retention, heart failure, high fever, history of spontaneous pneumothorax, history of thoracic surgery, viral infection, congenital spherocytosis, and history of optic neuritis. The benefit of instituting hyperbaric oxygen therapy should be weighed against the risk of adverse reactions. Tumor growth does not appear to be stimulated by hyperbaric oxygen therapy, and pregnancy is not a contraindication for emergent indications.

Conclusions

Hyperbaric oxygen therapy administered according to standard protocols is considered safe (Figure). Middle ear "squeeze" or barotrauma is the most common complication of hyperbaric therapy. The risk of barotrauma can be minimized with appropriate screening, patient education, and monitoring. Patients who receive a prolonged course of normobaric increased FIO_2 therapy and then undergo repeated exposure to hyperbaric oxygen are at the greatest risk for pulmonary oxygen toxicity. Generalized seizures may occur in patients during hyperbaric oxygen therapy but are considered rare and self-limiting, with no subsequent neurologic sequelae reported.

Mayo Clinic Rochester has an important place in history with altitude physiology research and training dating back to 1939, preceding World War II. "Many of the currently available aircraft oxygen and antigravity systems were developed in the Mayo Clinic Aeromedical Unit," says Dr Shields. "The current hyperbaric and altitude medicine program will also include opportunities for altitude physiology training and research."

Table. Evidenced-Based Indications for Hyperbaric Oxygen Therapy

Primary Therapy	
Cerebral arterial gas embolism	Decompression illness
Adjunctive Therapy	
Selected problem wounds	Refractory osteomyelitis
Osteoradionecrosis	Necrotizing infections
Osteoradionecrosis prophylaxis	Crush injuries
Radiation tissue damage	Clostridial gangrene
Carbon monoxide poisoning	Acute thermal burns
Compromised skin grafts or flaps	Acute exceptional blood loss

Figure. Dr Shields demonstrating use of the oxygen hood used by patients during hyperbaric therapy.

Prosthetic Perivalvular Leaks Repaired by New Percutaneous Technique

Charanjit S. Rihal, MD, Paul Sorajja, MD, and Allison K. Cabalka, MD

Perivalvular regurgitation is a long-standing complication of prosthetic valves. Long-term studies suggest that perivalvular leaks occur in 3% to 7% of aortic and mitral prosthetic valves. Although many patients with prosthetic valves are asymptomatic, severe perivalvular regurgitation may result in heart failure, infective endocarditis, or hemolytic anemia. Reoperative mortality in these patients has been reported to be between 6% and 15%; perioperative morbidity is likewise high.

Interventional cardiologists at Mayo Clinic Rochester are investigating the feasibility of treating perivalvular leaks with percutaneous techniques that avoid the risks of operation. "Catheter-based technologies provide an innovative approach to this increasingly common clinical problem," says Paul Sorajja, MD, an interventional cardiologist at Mayo Clinic Rochester.

To date, 23 patients have undergone perivalvular repair with a ductal occluder or septal occluder device. The majority involved a prosthetic mitral valve; a small number involved a prosthetic aortic valve, and there were 2 left ventricle–to–right atrial fistulas in patients with prosthetic mitral valves (Figures 1 and 2). All patients had developed either heart failure thought to be primarily due to valve regurgitation or transfusion-dependent hemolytic anemia. All patients were deemed to be at high risk for severe morbidity or mortality at reoperation (many had undergone prior attempted operative procedures), and all clearly understood that this was an investigational, off-label use of these devices.

Periaortic defects were imaged with transthoracic echocardiography in addition to fluoroscopy. Vascular plugs were not feasible because of the lack of a retention disk, but small septal occluder devices could be seated without impinging on the prosthetic valve.

Perimitral positioning of these devices is more difficult. "Many of these patients have severe left atrial enlargement and/or severe mitral annular calcification, making transseptal puncture and catheter manipulation challenging," says Charanjit S. Rihal, MD, director of the Cardiac Catheterization Laboratory at Mayo Clinic Rochester. Patients had transesophageal echocardiographic imaging done under general anesthesia in addition to fluoroscopic visualization.

Various guide catheters were used to engage mi-

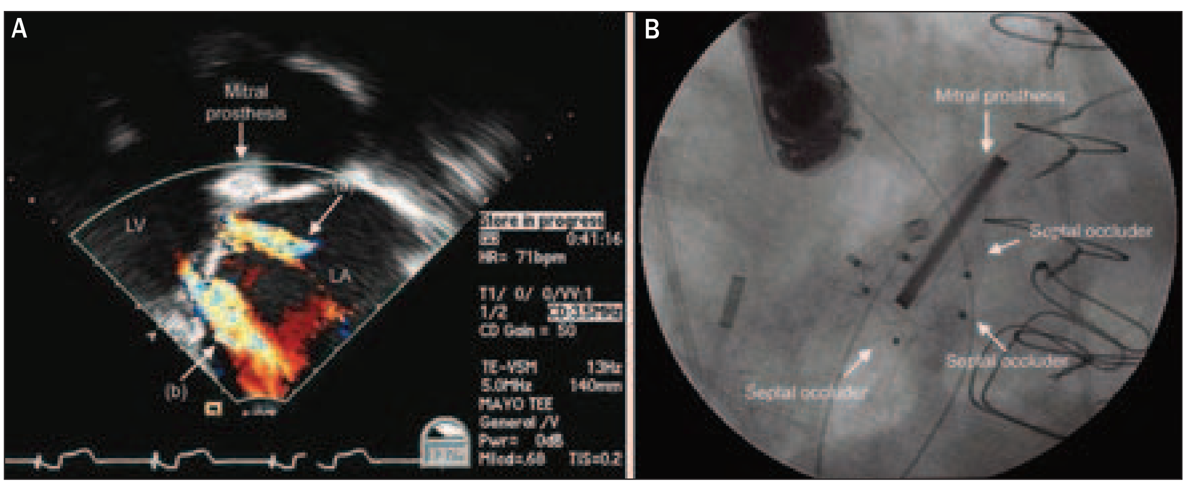


Figure 1. This 74-year-old woman underwent percutaneous repair of a perivalvular leak of her St. Jude mechanical mitral prosthesis. A, Transesophageal echocardiography shows multiple regurgitant jets involving the prosthesis (a) and (b). B, Fluoroscopy showing multiple septal occluders deployed around the mitral prosthesis. LA, left atrium; LV, left ventricle.

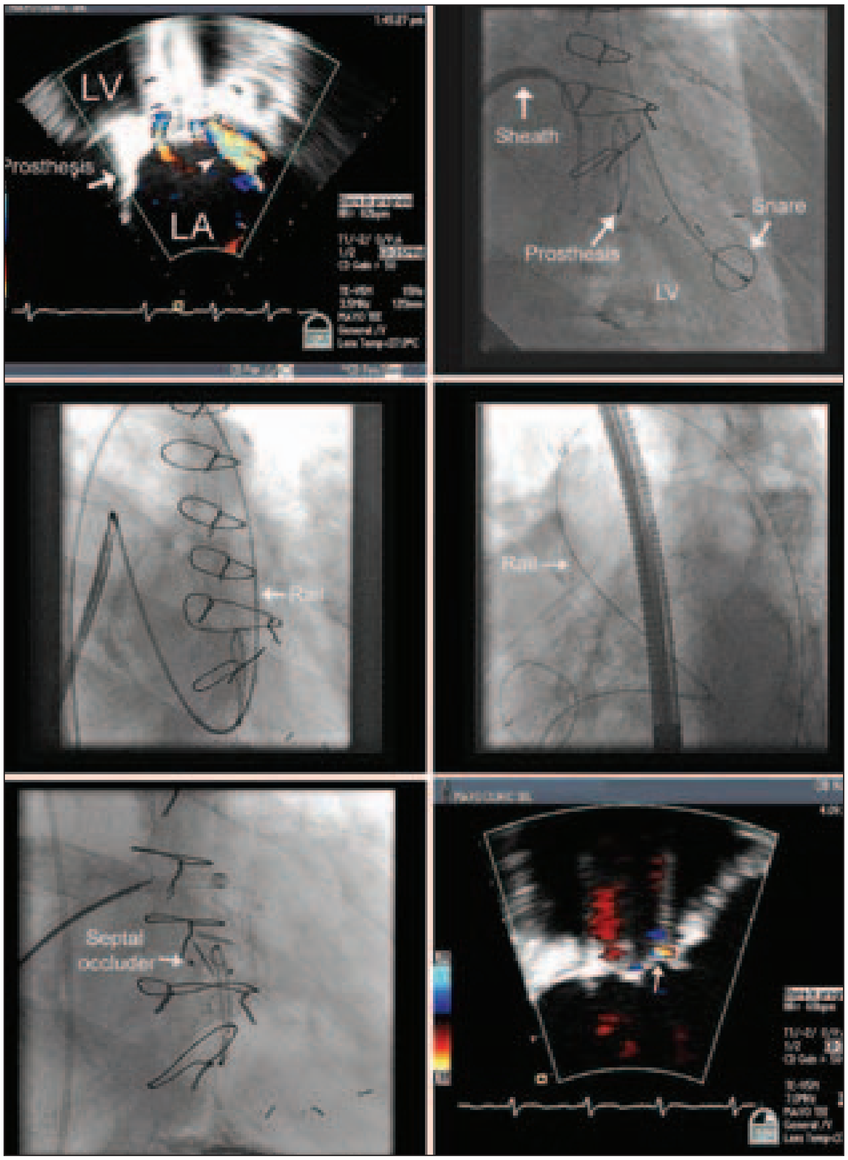


Figure 2. This 64-year-old woman underwent percutaneous repair of a perivalvular leak of her St. Jude mechanical mitral prosthesis. An arteriovenous rail was constructed to deliver the septal occluder. Top left, Transesophageal echocardiography shows the perivalvular regurgitant jet (arrowhead). Top right, A snare is placed across the aortic valve into the left ventricle. Middle left and right, A guidewire is advanced from the left atrium through the defect into the left ventricle, where it is snared to create the arteriovenous rail. The arteriovenous rail provides strong support for delivering devices across the perivalvular leak. Bottom left, A septal occluder has been deployed. Bottom right, Repeat transesophageal echocardiography shows trivial residual regurgitation after placement of the septal occluder (arrow). LA, left atrium; LV, left ventricle.

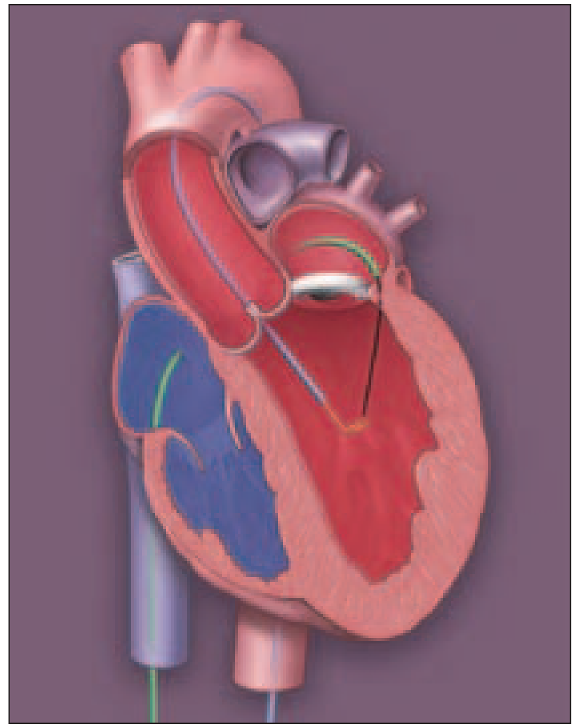


Figure 3. Diagram of arteriovenous rail. The blue catheter is advanced retrogradely through aortic valve; the advanced snare then grabs the wire within the green catheter, which has been advanced through the venous system and passed through an atrial transseptal puncture.

tral valvular defects; nevertheless, some lesions could not be crossed because of poor guidewire support. In patients with difficult-to-engage lesions and native aortic valves, an arteriovenous rail was created. The arteriovenous rail was developed in 1 of 2 ways: antegradely through the septal puncture, through the periprosthetic defect into the left ventricle, advanced across the aortic valve, and exteriorized through the femoral artery; or retrogradely from the left ventricle, across the periprosthetic lesion, through the left atrium, and then snared and exteriorized through the femoral vein (Figure 3). Additionally, in patients with mechanical aortic valves, left ventricular puncture was performed in selected cases, and the arteriovenous rail was created retrogradely to provide a stable catheter position for approach of a perimitral defect (Figure 4).

Although the procedure was a technical success in nearly all patients, 4 patients died during follow-up: 1 of pneumonia, 2 of progressive heart failure, and 1 suddenly 4 weeks after the procedure. One patient had successful placement of 2 types of closure devices, but the large defect was too close to the prosthetic leaflet; and each device caused leaflet impingement so was removed percutaneously.

In summary, the present experience has demonstrated that current catheter-based technology is a reasonable approach to repair of perivalvular leaks in patients who are at high risk for operative repair. Improvement in New York Heart Association class was notable, and patients with hemolytic anemia had reduced need for transfusion.

"Our experience has demonstrated the importance of a multidisciplinary team of both congenital and adult interventional cardiologists, anesthesiologists, and echocardiographers in these procedures,"

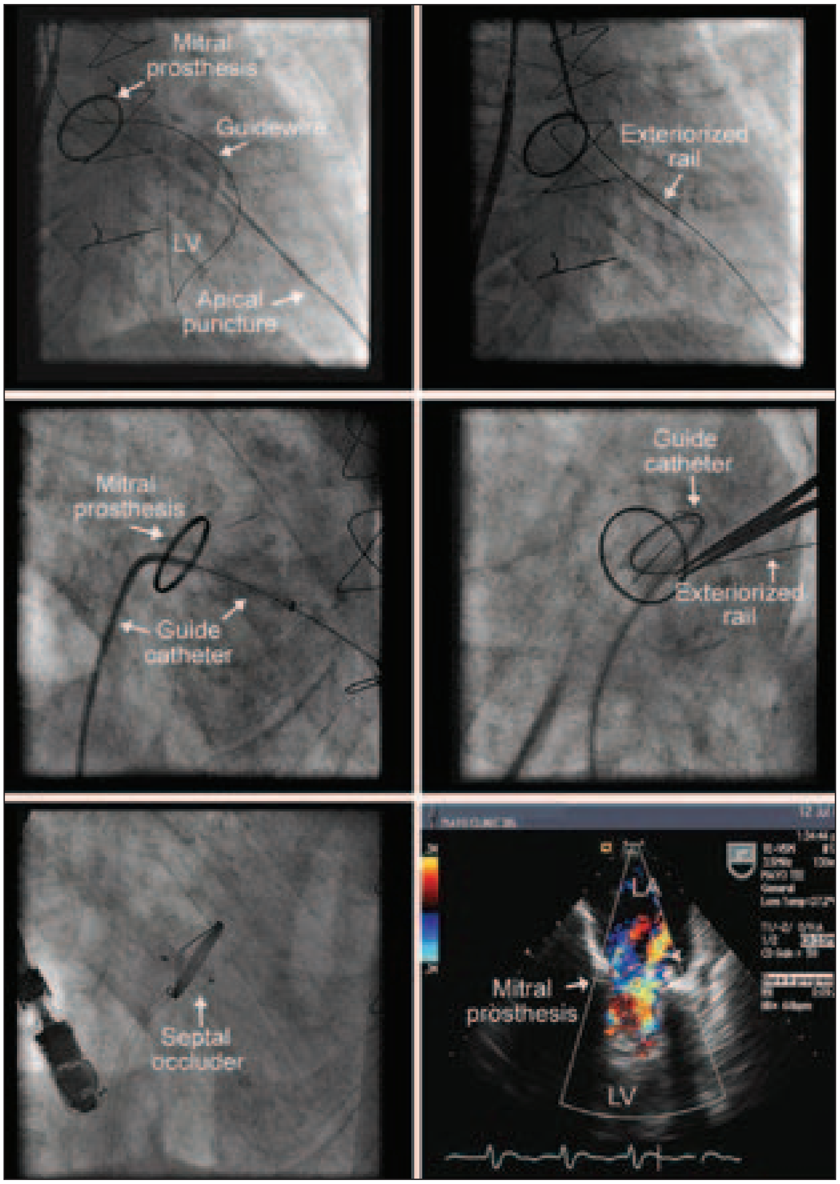


Figure 4. This 74-year-old man underwent percutaneous repair of a perivalvular leak of his St. Jude mechanical mitral prosthesis. Top left, An apical puncture is performed to snare the guidewire, which has been passed across the leak from the left atrium into the left ventricle. Top right, This snaring allows creation of an exteriorized wire rail, which provides strong support for placing devices across the perivalvular leak. Middle left and right, The guide catheter is advanced through the leak over the rail. Bottom left, A septal occluder is deployed across the leak. Bottom right, Transesophageal echocardiography shows occlusion of the leak with only mild central regurgitation through the septal occluder. This central regurgitation resolves with subsequent endothelialization of the septal occluder. LA, left atrium; LV, left ventricle.

says Allison K. Cabalka, MD, a pediatric cardiologist at Mayo Clinic Rochester. "It has also demonstrated the need for innovative use of current technology, and the need for the development of specialized devices to expand utilization of this technique." Additional studies are needed to define appropriate patient selection criteria and assess long-term patient outcomes.

IN THE NEWS

Division of Cardiovascular Medicine Receives Minnesota Council for Quality Award

The Minnesota Council for Quality has announced the recipients of the 2007 Quality Award. The Mayo Clinic Rochester Division of Cardiovascular Medicine was 1 of 8 award recipients, receiving an Advancement Level Award. The primary objective of the award, established in 1991, is to help organizations improve performance results and to recognize excellence.

Participating organizations receive a comprehensive evaluation and feedback that outlines organizational strengths and opportunities for improvement. This feedback can be used by organizational leadership for purposes of organizational learning, planning, and improvement. Processes evaluated include leadership, strategic planning, customer focus, market focus, information and knowledge management, human resource focus, process management, and results. Team leaders on this project were Robert P. Warda, Jonathan W. Curtright, and Douglas A. Parks, all of Mayo Clinic Rochester Administrative Services, and cardiologists W. Bruce Fye, MD, Robert L. Frye, MD, David L. Hayes, MD, David A. Foley, MD, Wayne L. Miller, MD, PhD, and Henry H. Ting, MD, clinical practice director of the Division of Cardiovascular Medicine.

"We began this journey toward performance excellence in 2004, using the Baldrige Process," says Mr Warda. "We have created quality improvement projects that have improved the care we are able to deliver to our patients." Some of those quality improvement projects include FAST TRACK for patients with acute myocardial infarction, increasing efficiency and decreasing wasted resources in the echocardiography and cardiac catheterization laboratories, redefining staff roles in the Heart Rhythm Services section, and cross-training of paramedical staff to level workloads in the cardiology outpatient clinic.

Areas for additional improvement were identified, including a process to diffuse innovation throughout the Division of Cardiovascular Medicine, developing outcome metrics that assess success of the strategic plan, and recalibrating strategic plan as necessary. "We will continue this process to achieve and maintain the highest standards of quality throughout the division," says Mr Warda.

Pediatric Cardiologists Help Develop Congenital Heart Center in Russia

Frank Cetta, MD

Heart-to-Heart (H2H), based in Oakland, California, was founded in 1989 to establish and support congenital heart surgery centers in Russia. Only 10% to 15% of Russian children with congenital heart disease have access to modern surgical care. H2H has worked to establish facilities for state-of-the art congenital cardiac surgery and to train pediatric cardiologists and cardiovascular surgeons. “The mission of H2H is to develop self-sustaining programs that provide modern and compassionate care for children and adults with congenital heart disease,” says Frank Cetta, MD, director of pediatric cardiology at Mayo Clinic Rochester and a member of H2H.

The first trip by H2H physicians 18 years ago was to Children’s Hospital No. 1 in St Petersburg. The medical facilities at that time could not provide any meaningful care to infants with congenital heart disease. Today a state-of-the-art congenital heart surgery facility exists in St Petersburg, and complex neonatal procedures are performed, including arterial switch operations, truncus arteriosus repairs, and Norwood operations for neonates with hypoplastic left heart syndrome.

The initial work that H2H performed in St Petersburg at Children’s Hospital No. 1 involved training local staff in advancements in surgical care and helping to fund and establish a postoperative intensive care unit. Today, that unit has 6 beds with state-of-the-art ventilatory and hemodynamic support equipment. In addition, H2H, with the help of private philanthropy, has established a congenital cardiac catheterization laboratory in Children’s No. 1. Now many complex interventional cardiac catheterization procedures can be performed on children with congenital heart disease in St Petersburg.

H2H has expanded its role in Russia in an attempt to deliver quality pediatric cardiac care to other regions of the country. For sev-

Figure. Dr Cetta demonstrating echocardiography in a patient with congenital heart disease to health care workers in Russia. Photo by Joye Photography.

eral years, H2H medical teams have been sent to the Samara region. More recently, medical teams under the Dr Cetta's direction have gone to the city of Tomsk in Siberia.

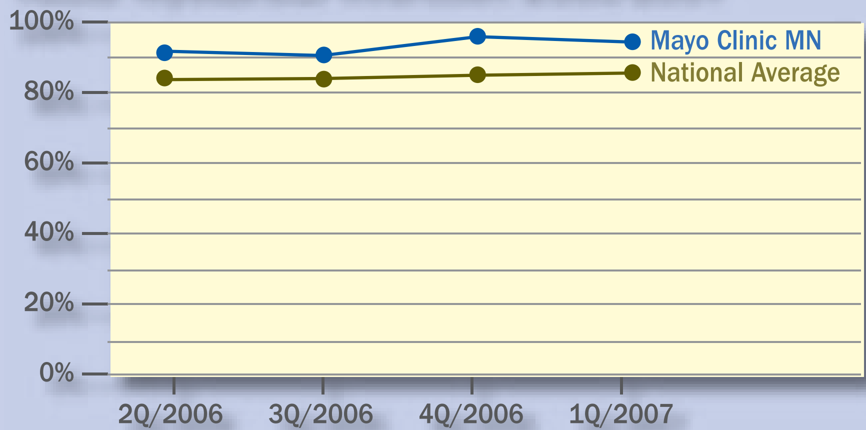
Because of excellent surgical outcomes over the past 18 years, the St Petersburg area has an ever-increasing population of adults with congenital heart disease. Mayo Clinic Rochester has played a major role in the development of an adult congenital heart center to serve these patients. During the past 3 years, Dr Cetta and Heidi M. Connolly, MD, a cardiologist at Mayo Clinic Rochester specializing in adult congenital heart disease, have facilitated training of Russian physicians in the clinical recognition, echocardiographic assessment, interventional catheterization, and other therapeutic techniques required for the ongoing care of these patients.

In addition to on-site patient care, during every H2H mission, H2H medical volunteers also participate in an extensive educational program, including lectures and demonstrations provided by the American medical specialists (Figure). "The true success of this program is not measured by the number of surgical procedures or interventional catheterizations that are performed during each mission, but by the number and outcomes of procedures performed by our Russian colleagues after the H2H team leaves," says Dr Cetta. Members of the H2H teams find these trips personally invigorating and educational, and they have developed a profound respect for Russian colleagues who deliver dedicated care to their patients, despite outdated and underserviced equipment and facilities. "Our Russian colleagues are truly the heroes of this endeavor, and the children of Russia reap the benefits," says Dr Cetta.

For additional information about H2H, please see its Web site, http://www.heart-2-heart.org/index.html.

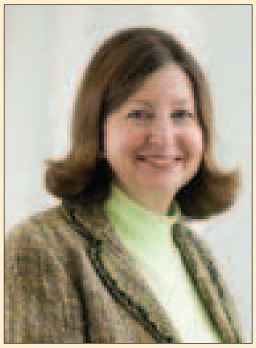
QUALITY

Acute Myocardial Infarction 2006-2007

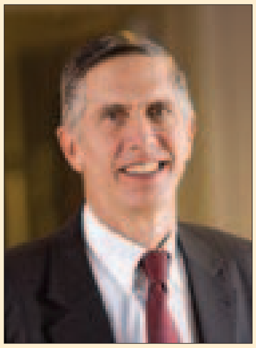


This graph displays the percentage of eligible Mayo Clinic Rochester patients diagnosed with acute myocardial infarction in whom all mandated quality care measures were achieved. For more information, see the Mayo Clinic Rochester quality Web site: http://www.mayoclinic.org/quality/ami.html.

RECOGNITION



Carole A. Warnes, MD, has received the Mayo Clinic Rochester Department of Medicine Leadership in Education award.



Hartzell V. Schaff, MD, has received the Mayo Clinic Rochester Distinguished Clinician Award.

Dalene M. Bott-Kitslaar, NP, of Mayo Clinic Rochester, Women's Heart Clinic, received a Wenger award for "Excellence in Healthcare" at the WomenHeart 2007 meeting.

Beth L. Heim de Bera, Kathleen K. Zarling, and Tammy F. Adams won a 2007 Gold Award from the National Health Information Center for "Steps to Heart Health," a patient education booklet they produced. This is the most comprehensive competition of its kind.

Upcoming Courses

Continuing Medical Education, Mayo Clinic

To request additional information or to register, unless noted otherwise, please call 800-323-2688, e-mail cme@mayo.edu, or visit www.mayo.edu/cme.

Ethical Dilemmas Throughout the Medical Spectrum
Feb 6-8, 2008, Rochester, MN

Mayo Clinic Interactive Surgery Symposium
Feb 10-15, 2008, Wailea, Maui, HI
Phone: 480-301-4580; e-mail: mcs.cme@mayo.edu

33rd Annual Cardiovascular Conference at Snowbird
Feb 19-23, 2008, Snowbird, UT

Arrhythmias and the Heart
Mar 10-13, 2008, Kauai, HI
Phone: 800-283-6296; e-mail: cvcme@mayo.edu

Mayo Echocardiography Review Course
Mar 15-18, 2008, Rochester, MN

Menopausal Medicine: Care for the Mature Female
Mar 27-29, 2008, Albuquerque, NM

18th Annual Advances and Controversies in Clinical Nutrition
Apr 25-27, 2008, Scottsdale, AZ
Phone: 800-462-9633; e-mail: cme-jax@mayo.edu

Controversies in Cardiovascular Disease: Practical Approaches to Complex Problems: Medical and Surgical
May 3-4, 2008, St Paul, MN

Valvular Heart Disease: New Strategies
May 5-7, 2008, Las Vegas, NV
Phone: 507-266-0677; e-mail: cvcme@mayo.edu

Current Topics in Noninvasive Cardiovascular Imaging
Jun 22-27, 2008, La Jolla, CA

Success With Failure: New Strategies for the Evaluation and Treatment of Congestive Heart Failure
Aug 3-6, 2008, Whistler, BC
Phone: 800-283-6296; e-mail: cvcme@mayo.edu

Mayo Interventional Cardiology Board Review
Sep 19-21, 2008, Rochester, MN

Mayo Cardiovascular Review Course for Cardiology Boards and Recertification
Sep 20-25, 2008, Rochester, MN

Continuing Medical Education, Cosponsored With American Society of Echocardiology

To request additional information or to register, unless noted otherwise, please phone 507-266-6703 or e-mail echocme@mayo.edu.

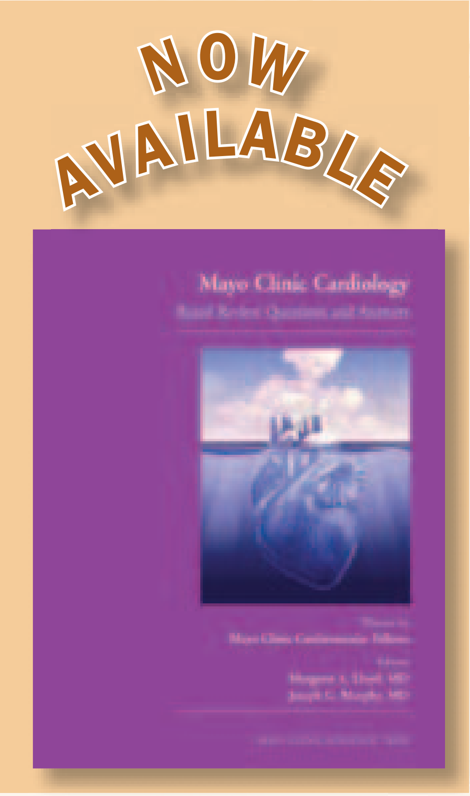
18th Annual Echo Hawaii 2008
Jan 28-Feb 1, 2008, Big Island, HI

13th Annual 2008 Cardiology at Cancun
Feb 25-29, 2008, Cancun, Mexico
Phone: 507-284-9032, e-mail: echocme@mayo.edu

21st Annual State-of-the-Art Echocardiography
Mar 2-6, 2008, Phoenix, AZ

15th Annual Echocardiographic Workshop: 2-D & Doppler Echocardiography at Vail
Mar 9-13, 2008, Vail, CO

5th Annual Team Echocardiography: The Heart of Cardiovascular Disease
Apr 24-27, 2008, Hilton Head Island, SC
Phone: 336-716-4505; e-mail: cmu@wfubmc.edu



Echocardiography in the Nation's Capital: Focus for the Physician
Apr 28-30, 2008, Washington, DC
Phone: 507-266-0677; e-mail: cvcme@mayo.edu

Other Educational Opportunities

ACC.08: 57th Annual Scientific Session of the American College of Cardiology and 3rd Annual Innovation in Intervention: i2 Summit
Mar 29-Apr 1, 2008, Chicago, IL
Phone: 202-375-6000

Heart Rhythm 2008
May 14-17, 2008, San Francisco, CA
Web site: www.hrsonline.org/Sessions/HR2008/

American Society of Echocardiography 19th Annual Scientific Sessions
Jun 7-11, 2008, Toronto, ON
Web site: www.asecho.org

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