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Patient Care • Teaching • Research

Childhood vascular malformations: The most common cause of pediatric stroke

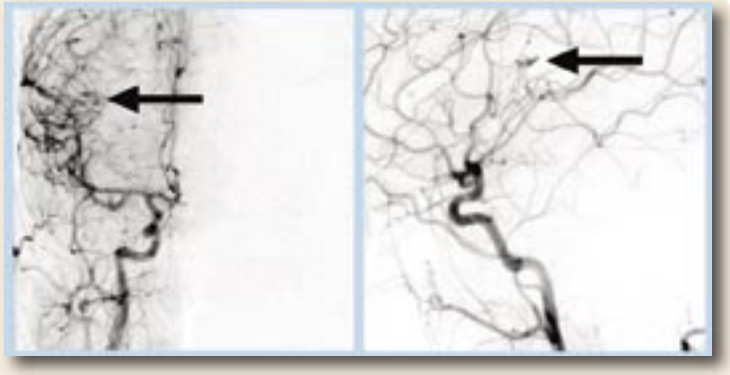
by Douglas Kondziolka, MD
Professor of Neurological Surgery

Stroke is not just for adults. When an intracerebral hemorrhage occurs in a child, the usual cause is an arteriovenous malformation (AVM). Whereas adults often present with hemorrhage, seizures, headaches, and/or progressive neurologic deficits, the majority of children suffer a bleed. Because of this risk for hemorrhage and its attendant morbidity and mortality, as well as the life-long risks of the AVM should it go untreated, the majority of children with brain AVMs undergo some form of therapy. Approaches include microsurgical resection, embolization, or stereotactic radiosurgery, alone or in combination.

Although considered to be congenital, it is unclear when brain AVMs actually develop. They are thought to develop in the fetus, but the rarity of presentation during the neonatal period has prompted some investigators to question whether AVM development only begins first in utero, but progresses during the first years of life. This possibility also has been raised by various authors who have noted the recurrence of childhood AVMs despite total resection confirmed by angiography.

Since most children with AVMs undergo treatment, there are too few reports of untreated patients to fully understand the natural history of untreated pediatric AVMs. I reviewed the 40-year Toronto experience with 132 children, and found a mortality rate of 4% for hemispheric AVMs, and over 50% for posterior fossa AVMs. When conservative management was chosen in 27 children, 13 of these later died after catastrophic hemorrhage. A simple risk prediction formula for natural history data that maintains each year of risk as independent can be used. This formula is: risk of hemorrhage = 1-(risk of no hemorrhage)$^{\text{expected years of remaining life}}$. An approximation of this formula is 105 minus age for lifelong risk of AVM hemorrhage.

The factors of brain location, arterial supply and suitability for embolization leading to volume reduction, lack of relationship with critical functional brain, and appearance of the AVM nidus must all be understood before management is selected. For patients with a hematoma associated with a deep AVM, resection of the blood clot may be indicated, leaving the AVM behind for radiosurgery. Although



Stereotactic angiograms during Gamma Knife Radiosurgery in a 12 year-old girl with a deep left frontal lobe AVM, found because of headache related to a motor vehicle accident.

Angiogram during radiosurgery in a 13-year-old girl found to have an incidental AVM. She had headaches following a motor vehicle accident that prompted the MRI.

our understanding of the potential risks and benefits of these different procedures has improved, dilemmas remain for patients and physicians in the choice of specific therapies.

Recently we evaluated our experience in pediatric AVM radiosurgery. Gamma Knife radiosurgery has allowed us to care for children with deep-seated malformations in high-risk locations. During a 17-year interval, we performed Gamma Knife radiosurgery on 159 children with brain AVMs. There were 85 boys and 74 girls, with a mean age of 12 years (range, 2-17). Many of these children had small AVMs that posed potential difficulties in locating the nidus during resection. Most children under the age of 13 years will receive general anesthesia for radiosurgery. The AVM is targeted with a combination of stereotactic MRI and angiography.

For follow-up, we obtain MRI scans at six to 12 month intervals after radiosurgery in order to assess the brain response. An angiogram is requested in all patients beginning three years after radiosurgery. When complete obliteration or only an early draining vein is identified on the follow-up angiogram, no further care is necessary. For patients who have small residual AVM nidus more than 3 to 3.5 years following radiosurgery, then an additional procedure is usually required to complete the obliteration. In our series, 60% presented with a hemorrhage, 19% complained of headache, and 18% had sustained prior seizures. A neurologic deficit was present in 38%. Prior subtotal surgical resection (range, 1-4 operations) had been performed in 19% of children. Embolization was performed in 16% in an attempt to reduce the size of the AVM prior to radiosurgery. In an analysis of 50 children who had post-radiosurgery

*(see **Childhood** on page 8)*

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Whenever a new discovery...

One of my favorite quotes is attributed to Michel D. Montaigne, a French philosophist of the 17th century. The quote goes like this. "Whenever a new scientific discovery is reported to the scientific world, their first reaction is to say 'it cannot be so'. When the truth is fully established, they say 'it may be true, but it is not important'. When its importance is established, the scientific community now says 'it may be important, but it is no longer new.'" This aphorism seems to reflect much of our inherent tendency as medical scientists to be skeptical about advances in science, especially if those advances differ from our own perception of reality. As we grow older, we become confident, perhaps overly confident, in our own perceptions and our own methods and our own approaches. It becomes increasingly challenging to adopt new postures, investigate new paradigms, and search for new truths.

Recently, at the Society of Neurological Surgeons, I heard an entertaining talk by a neurobiologist who defined our inability to make significant transitions in our life after a certain age. As an example, he performed a poll of all the Midwestern U.S. sushi bars. He showed that unless you had eaten sushi by the age of 30, you would never eat sushi. Similarly, a poll of San Francisco tattoo parlors showed that unless you had a tattoo by the age of about 25, you would probably never get a tattoo. Human nature is often questioning and probing in youth, but occasionally reluctant to adopt change as we age.

Neurosurgery as a field is continuing to probe, evaluate, and institute change. One such example is the tremendous push towards minimally invasive and multi-disciplinary surgery. Previously, we would have thought that a single gifted surgeon would be the only answer that an individual patient might need to handle their neurological condition. Unfortunately, no single individual can master all of the data, technology, and surgical skills necessary to generate alone the best results. Instead, the new paradigm requires intra and multi-disciplinary referral and communication, discussions of various therapeutic options, and reliance on intricate technologies to facilitate the best patient outcomes.

For example, some patients may be better off with a subtotal microsurgical or endoscopic removal of their tumor, relieving some symptoms while preventing complications. In such patients, additional strategies, such as radiosurgery, radiation therapy, or new molecular or genetic approaches may be better options. In the 1950's and 60's, a neurosurgical outcome statistic might reflect survival. In the 70's and 80's, survival became less of an issue and quality of life issues emerged. In the 90's and in the early part of the 21st century, a patient with neurological symptoms often wants to know not whether he or she will survive or get worse, but will I get better? In order to meet these rising expectations, multi-disciplinary groups working in centers of excellence with special expertise are essential for the patients with increasingly challenging disorders of the brain and spine. Centers of excellence are critical to provide the highest level of care and best outcomes for patients with rare, difficult, and critically located neurological lesions. We need to recognize not only what's new, but what's important, and what's true. •

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Minimally Invasive Spinal Surgery:

Percutaneous Discectomy Using Coblation® Technology

By Peter C. Gerszten, MD, MPH
Assistant Professor of Neurological Surgery

The general trend in spinal surgery has been one of reductionism and minimalization, and has been driven by a number of factors, including surgeons' desires to reduce surgery-related trauma, patients' awareness of alternatives to open surgical procedures, and the development of new technologies. To this end, new techniques have been developed that are applicable to the treatment of lumbar disc herniation and discogenic pain due to degenerative disc disease.

Discogenic leg pain affects nearly 10 million persons a year in the United States, with an estimated cost of over $20 billion. Disc decompression procedures for treating symptoms associated with disc herniation have been performed with excellent success for more than half a century. Open discectomy reduces pressure within the intervertebral disc and adjacent nerve root. While clinical success in eliminating radicular symptoms following microdiscectomy is excellent, postoperative sequelae include reherniation in approximately 10% of patients, residual back pain, and other complications.

The surgical treatment of intervertebral lumbar disc herniation via open discectomy is often targeted at patients with uncontained or large herniations, and/or sequestered discs. Patients presenting with small, contained herniated discs who have not responded to conservative noninvasive treatment are often not considered as candidates for open surgical procedures. Carragee et al. reported that patients with contained disc herniations measuring less than 6 mm (anterior-posterior measurement) had a success rate of only 24% after discectomy compared to a success rate of 98% for patients with disc herniations measuring more than 9 mm.

Over the last decade, minimally invasive percutaneous techniques using an intradiscal approach have been developed in an effort to minimize trauma to normal tissues and improve patient recovery and clinical outcomes. These techniques have been designed either to shrink or remove disc material believed to be causing lumbar pain and/or radiculopathy. The most commonly examined and applied percutaneous techniques include arthroscopic microdiscectomy, automated percutaneous lumbar discectomy, and chymopapain, as well as other procedures.

In recent years, members of the Department of Neurological Surgery have championed innovative minimally invasive surgical procedures of the spine at the University of Pittsburgh Medical Center in hopes of developing the field and finding new treatment options for patients. One of these procedures is the percutaneous microdiscectomy or nucleoplasty. Nucleoplasty is a minimally invasive surgical procedure for disc decompression developed to treat patients with symptomatic contained disc herniations. Nucleoplasty involves the percutaneous removal of disc material by using Coblation® technology (ArthroCare Corporation, Sunnyvale, CA). Coblation® consists of a low-temperature resister probe being used to disintegrate and evacuate disc material, followed by thermal treatment of adjacent residual disc material. The procedure is based on the principle that inducing a small reduction of volume in a closed hydraulic space, such as an intact (contained herniated) disc, can promote significant relief of pressure, and therefore reduce or eliminate pain. Once intradiscal pressure is relieved, the disc is believed to down-regulate inflammatory mediators, reduce in size, and initiate a healing process, thereby alleviating chemical, mechanical, and neural genesis of discogenic pain.

We have engaged in several research studies to determine the outcomes, quality of life, and comparative efficacy associated with nucleoplasty and are currently conducting a prospective, randomized, multi-center study of the nucleoplasty procedure compared with selective nerve root injections. For more information, please contact us at (412) 647-9786. •

Photos courtesy of ArthroCare®

(Top of page) Nucleoplasty catheter within the disc space demonstrating treatment of the ipsilateral side; (above), diagram demonstrating the proper lateral approach to the disc space within Kambin's triangle

Post-concussion migraines

Young athletes with migraine headache characteristics may have increased neurocognitive impairment

by Susan Manko
UPMC News Bureau

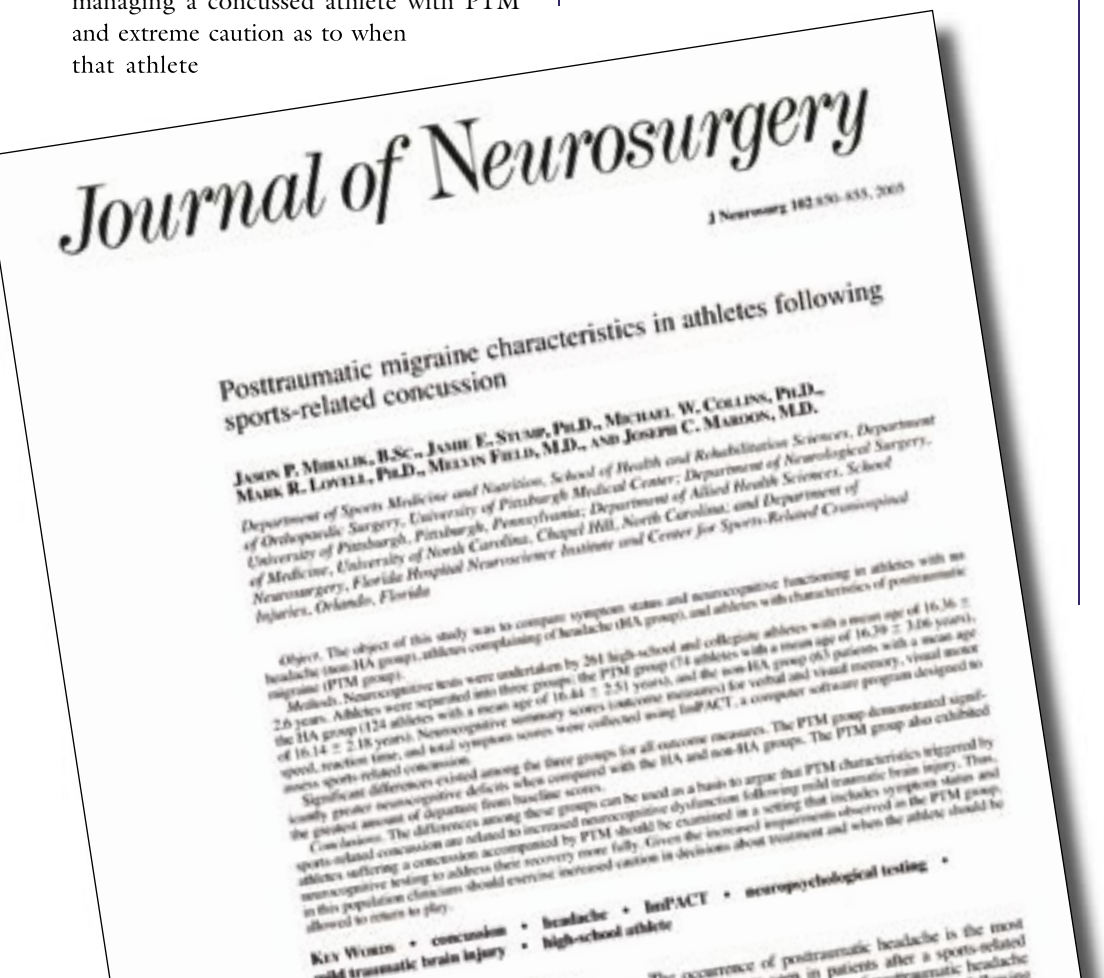
High school and college athletes with migraine headache characteristics after a concussion may have increased neurocognitive impairment, suggests a University of Pittsburgh Sports Medicine Concussion Program study published in the May issue of the *Journal of Neurosurgery*. The study results speak to the need for extreme caution in clinical evaluation and return-to-play decisions, say the authors.

In the study, athletes who had characteristics of post-traumatic migraine (PTM) headache following a concussion also showed increased neurocognitive function impairment and related symptoms compared to concussed athletes with no post-injury headache or non-migraine headache.

"The findings of our study strongly support the need for clinicians to exercise increased vigilance in making decisions about managing a concussed athlete with PTM and extreme caution as to when that athlete should be allowed to return to play," said the study's lead author, Jason Mihalik, CAT(C), ATC, who now is a doctoral student working in the Sports Medicine Research Laboratory at the University of North Carolina at Chapel Hill.

"This research is important because headache is the most common reported symptom after a sports-related head injury. As many as 86 percent of these injuries are accompanied by some type of headache," commented study co-author Joseph Maroon, MD, clinical professor of neurological surgery at the University of Pittsburgh School of Medicine.

"We are concerned because even though headache may be noted as a symptom in the young athlete with a concussion, he or she may be allowed to return to play before the headache resolves and later may suffer from second-impact syndrome, which, although rare, may be catastrophic," Dr. Maroon stressed.


Journal of Neurosurgery

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Posttraumatic migraine characteristics in athletes following sports-related concussion

JASON P. MIHALIK, B.SC., JAMIE E. STUMP, PH.D., MICHAEL W. COLLINS, PH.D., MARK R. LOVELL, PH.D., MELVIN FIELD, M.D., AND JOSEPH C. MAROON, M.D.

Department of Sports Medicine and Nutrition, School of Health and Rehabilitation Sciences, Department of Orthopaedic Surgery, University of Pittsburgh Medical Center; Department of Neurological Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania; Department of Allied Health Sciences, School of Medicine, University of North Carolina, Chapel Hill, North Carolina; and Department of Neurosurgery, Florida Hospital Neuroscience Institute and Center for Sports-Related Craniospinal Injuries, Orlando, Florida

Key Words • concussion • headache • ImPACT • neuropsychological testing • mild traumatic brain injury • high-school athlete

University of Pittsburgh researchers were the first to study the relevance of headache in the recovery of concussed high school athletes. That study, published in the March/April 2003 issue of the American Journal of Sports Medicine, concluded that headache, even one week after a concussion, is likely associated with incomplete brain recovery, indicating the need to keep the athlete out of the game until the headache and other symptoms are resolved.

"Our ongoing research with younger athletes has increasingly suggested that kids are particularly at risk for neurocognitive decline following concussion, and this group also appears to be particularly vulnerable to post-traumatic migraine," said study co-author Mark Lovell, PhD, a neuropsychologist and director of the University of Pittsburgh Sports Medicine Concussion Program.

"Although it is estimated that up to 300,000 athletes sustain a concussion each year, the injury is still not well understood, the symptoms are not always straightforward and there is not one standard concussion severity grading scale or return-to-play protocol that has been scientifically validated as the best one to use. In fact, there is notable variability in the several injury severity scales and return-to-play guidelines that are in use today," added study co-author Michael Collins, PhD, a neuropsychologist and assistant director of the University of Pittsburgh program.

Concussion is any change in mental status caused by a sudden violent rocking back and forth of the brain inside of the skull due to a blow to the head or upper body. Symptoms can include headache, amnesia, dizziness, confusion, lack of hand-eye coordination, and in some cases, loss of consciousness. Generally, an athlete can safely recover from an initial concussion as long as the brain has had time to heal. Returning an athlete to play before the brain has had time to heal places that athlete at risk for a second concussion and further, more serious injury. First-ever research involving high school athletes published by the University of Pittsburgh in recent years has shown that even seemingly mild concussions may be more serious than previously thought. These studies have suggested that currently-used return-to-play guidelines relating to symptoms, including headache, may be too lenient, often allowing athletes to return-to-play too soon, placing them at risk for more serious injury, according to study authors.

"One statistic we have discovered is that for every one concussion that occurs in the National Football League, more than 5,200 occur in our youth in the United States alone," said Melvin Field, MD, study co-author who now is co-director of the Florida Sports Concussion Program and a neurosurgeon at the Orlando Neurosurgery and Florida Hospital Neuroscience Institute.

"This is a particularly important focus of study because symptoms of post-traumatic migraine are a complication of sports-related concussion that is often misunderstood," Mihalik said. "A specific diagnosis is often not assigned and an optimal course of therapy is often not provided."

The International Headache Society defines migraine as an episodic disorder characterized by acute attacks of pain with associated symptoms that often result in disability. These symptoms include but are not limited to headache, nausea, photophobia and phonophobia (hypersensitivity to light and sound).

The current University of Pittsburgh study is the first to compare acute neurocognitive impairments after sports-related concussion in athletes who exhibited migraine characteristics, those who complained of headache, and those who did not complain of headache.

In the study, 261 high school and college athletes who sustained a concussion underwent post-injury neurocognitive testing as part of a clinical evaluation through the University of Pittsburgh Sports Medicine Concussion Program. The athletes were separated into three groups: 74 athletes who had PTM; 124 athletes with headache complaints; and the non-headache group of 63 athletes. Neurocognitive outcome summary scores for verbal and visual memory, visual motor speed, reaction time and total symptom scores were collected using ImPACT® (Immediate Post-Concussion Assessment and Cognitive Testing), a scientifically validated computer software program developed years ago by the University of Pittsburgh team and widely used today as an objective assessment tool to help determine neurocognitive effects of concussion and measure recovery.

Significant differences existed among the three groups for all outcome measures, Mihalik reported. The PTM group demonstrated significantly greater neurocognitive deficits when compared with the headache and non-headache groups. Specifically, the PTM group had significantly lower verbal and visual memory, motor speed and reaction time scores than the other two groups. The researchers also observed significantly higher self-reported symptom scores in the PTM and headache group compared to the non-headache group.

Photo courtesy of University of Pittsburgh Media Relations

"Given the significantly greater neurocognitive impairments observed in the PTM group in our study, any athlete with a concussion accompanied by characteristics of PTM should be examined in a setting that includes symptom status and neurocognitive testing to address their recovery more fully," asserted the study's authors. "Clearly, sports-related concussion is related to increased cognitive impairments, regardless of the presence of headache. It is critical that any athlete sustaining a concussion be followed up to not only assess lingering symptoms, but also to evaluate cognitive impairments. Symptoms may resolve before their neurocognitive deficits do."

Another investigator in the study was Jamie Pardini, PhD, neuropsychology fellow at the University of Pittsburgh Sports Medicine Concussion Program.

The University of Pittsburgh Sports Medicine Concussion Program is an ongoing clinical service and research program focusing on the diagnosis, evaluation and management of sports-related concussion in athletes of all levels. The program's internationally known team of clinicians and researchers are world leaders in studying the neurocognitive effects of sports-related concussion and pioneering the development of better methods of post-injury evaluation to better determine when it is safe for concussed athletes to return to play. •

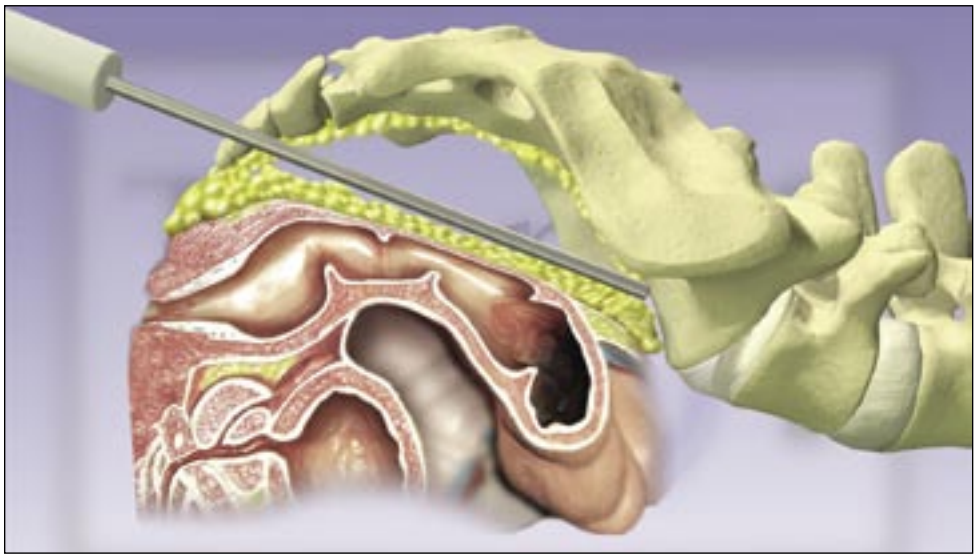
New minimally invasive approach to L5-S1 level allows quick recovery; low post-operative pain

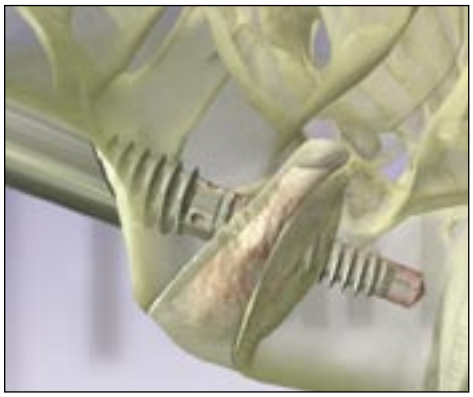
By Peter C. Gerszten, MD, MPH
Assistant Professor of Neurological Surgery

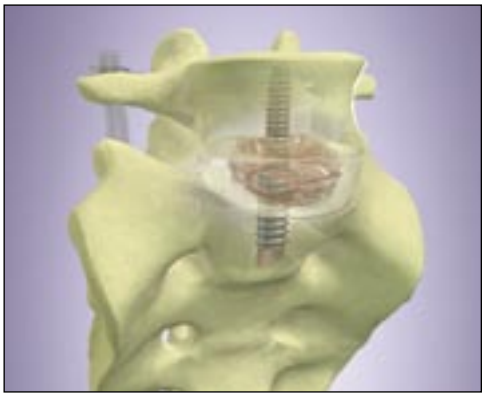
For some patients requiring an interbody fusion device at the L5-S1 level (where the lumbar spine meets the sacrum) surgery can be a major undertaking, associated with risks as well as patient discomfort. A new technique has been developed with excellent results that obviates the need for large incisions and lengthy stays in the hospital. Such techniques usually involve an incision in the abdomen or the back that allow for the placement of metallic cylinders within the disc space. Such surgeries may last for several hours and are associated with risks of vascular and nerve root injury. Patients usually recover in the hospital for several days.

The Axial Lumbar Interbody Fusion-System (Axial LIF™) is a new minimally invasive approach to the L5-S1 disc space being utilized by spine surgeons at the University of Pittsburgh. The point of access for placing this new system is just lateral to the coccyx. This point of access alleviates the need for the surgeon to cut through soft tissues such as muscles and ligaments, thus lessening patient pain and the likelihood of complications. This minimally invasive approach allows patients to be discharged from the hospital the day after surgery. Patients can return to work within weeks instead of months.

The AxialLIF System includes devices used to access the spine, remove the diseased disc material, re-establish normal disc height and stabilize the spine to enable lumbar fusion to occur. The procedure is performed via an incision of only 1 cm in length, with complete preservation of all native paraspinal soft tissue structures including the disc annulus. So far, experience with the AxialLIF system with patients at the University of Pittsburgh has been very positive. The patients have been extremely pleased with the results and surprised at how little post-operative pain they have experienced. •







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New Operating Suite Opens

A new operating room designed solely to accommodate a novel surgical procedure for removing brain tumors through the nose opened recently at UPMC Presbyterian. The Endonasal Surgical Suite will house the latest technological tools to facilitate the Expanded Endonasal Approach, an innovative minimally invasive technique refined by UPMC surgeons **Amin Kassam, MD**, Carl H. Snyderman, MD, and Ricardo L. Carrau, MD.

The operating suite is the result of a collaboration between UPMC and Karl Storz Endoscopy-America, Inc., which worked closely with the surgeons in the design and fabrication of special endoscopic instruments. These custom instruments enable the surgeons to see inside the skull and remove tumors without damaging delicate blood vessels and nerves. Surgeons utilize computerized mapping systems, similar to GPS, enabling them to more assuredly navigate the brain through the nasal opening. The facility is believed to be the first of its kind in the United States.

Spine Lab Begins Studies

A spine research laboratory featuring state-of-the-art biomechanics equipment and focusing on stem cell research and therapies for radio-oncology began operations recently in the University of Pittsburgh's Scaife Hall. The Spinal Biomechanics Laboratory, under the direction of **William Welch, MD**, and **Boyle Chen, PhD**, will host research projects designed for many levels of backgrounds and interests. Initial projects underway at the lab include second generation cervical motion preservation devices, spinal hardware effects on radiation treatments, rehabilitation therapies and adipose-derived stem cells.

Work is also underway to completely renovate the lab area with completion scheduled in January of 2006. ZimmerSpine has contributed to the completion of this project.

New Research Grants

• "Survey of Injury Prevention Activities in PA ED: Successes, Barriers and Opportunities." **Harold B. Weiss, MS, MPH, PhD**, American College of Emergency Physicians Award, ($37,000).

Visiting Scholar/Professor

• **Anthony Fabio, RD, MPH, PhD**, was a visiting scholar at the University of Cambridge, England in September. He studied with David Farmington, MD, examining "novel methods for separating age, period and cohort for understanding the causes and correlates of violence trends."

• **Douglas Kondziolka, MD**, served as visiting professor at the University of Florida in Jacksonville, FL, August 30-31.

Awards

• **Anand V. Germanwala, MD**, chief resident, won first place for presentations at the Pennsylvania Neurological Society meeting in Hershey, PA on July 16 for his presentation, "The Use of Gamma Knife Radiosurgery in the Multi-Modality Treatment of Medulloblastoma in Adults: A Long-Term Follow Up." **Costas G. Hadjipanayis, MD, PhD**, chief resident, won second place for his presentation, "Optimal Delivery of Herpes Virus Vector to Enhance to Radiosensitivity of Intracranial GBM Xenografts in a Mouse Model."

Annoucements

• **Peter Gerszten, MD, MPH**, was chosen to serve on the board of directors of WQED Multimedia.

• **Pat Karausky,** research nurse for Dr. Welch**,** passed the certification exam for research coordinator and is now a certified clinical research coordinator.

• The Think First For Kids program, under the sponsorship of **P. David Adelson, MD**, received $75,000 in funding from Kohl's Cares For Kids® through the Children's Hospital of Pittsburgh Foundation. This is the second year that Kohl's has funded the program.

• **L. Dade Lunsford, MD**, was the honored guest at the Young Neurosurgeons Luncheon at the American Association of Neurological Surgeons meeting in New Orleans, April 20.

Congratulations

• **Debra Jennette**, Gamma Knife nurse, received the UPMC 'Above & Beyond' award for her work with patients.

• **Kevin Walter, MD**, completed the Ironman USA Triathlon in Lake Placid, NY, July 24 in a time of 13 hours and 39 minutes. The event consisted of a 2.4 mile swim, a 112 mile bike ride and a 26.2 mile run.

• The team of **Dr. Walter**, **Elle Carson-Walter, PhD**, **Paul Gardner, MD**, **Brain Jankowitz, MD**, and **Jason Voorhies** took first place in the health care division of the City of Pittsburgh's 10k 'Great Race,' September 25. Their combined time was 2:16:36.

• **Jocelyn Koessler**, clinical secretary to Richard Spiro, MD, was married to William H. Cornelius on October 8.

Welcome

• **Ajith Thomas, MD**, clinical instructor; **Boyle Chen, PhD**, director, Spinal Biomechanics Laboratory; welcome back to **Elizabeth Tyler-Kabara, MD, PhD**, assistant professor of neurological surgery.

Upcoming Events

• November 7-11: **Principles and Practice of Gamma Knife Radiosurgery**. Training course targeted at neurosurgeons, radiation oncologists and medical physicists interested in Gamma Knife radiosurgery certification. Next course is January 9-13. Contact Charlene Baker at (412) 647-7744 for more information.

• November 15: **CIRCL Web Seminar**, "The Role of the Injury Professional on the Child Death Review Team: Translating CDR Findings to Injury Prevention Policy and Practice." Theresa M. Covington, director, National MCH Center for Child Death Review, Michigan Public Health Institute, and Vick Zittle, program director, PAAAP/PA CDRT, 2:00 p.m., www.circl.pitt.edu.

• December 7: **Stuart Rowe Society Lectureship**. Gary Steinberg, MD, PhD, service chief and professor of neurosurgery, Stanford University Hospital & Clinics. Contact Mary Ann Vincenzini at (412) 647-6781 for more information.

• December 13: **CIRCL Web Seminar,** "Turning Point: Rethinking Violence. An Evaluation of Program Efficacy in Reducing Adolescent Violent Crime Recidivism." Kamela K. Scott, PhD, Department of Surgery, University of Florida at Jacksonville, and Joseph J. Tepas, III, MD, professor, surgery & pediatrics, University of Florida, College of Medicine, 2:00 p.m., www.circl.pitt.edu. •

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Childhood vascular malformations: The most common cause of pediatric stroke

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angiography, 35 children had complete obliteration identified on their angiogram (70%), and the rest showed a significant decrease in AVM volume.

Cavernous Malformations

Cavernous malformations are common in the general population and most cause no symptoms. They can occur as sporadic lesions or as an autosomal dominant, familial disorder. Children with a cerebral cavernous malformation usually are symptomatic. Related symptoms can include brain hemorrhage, seizures or focal neurologic deficits. In one family we found increasing numbers of malformations within different generations when they were studied with MRI. Generally, cavernous malformations incidentally recognized maintain a low annual rate of bleeding. We conducted a large prospective natural history study, and found a 0.6% annual hemorrhage rate in patients without a prior symptomatic hemorrhage. However, in patients who had sustained a prior symptomatic hemorrhage, the subsequent annual hemorrhage rate was a magnitude higher, with a 4.5% annual risk of bleeding. Thus, children who are found to have a cavernous malformation may require management. For a single symptomatic lesion, surgical resection should be performed when the malformation is located in a brain region where resection is feasible. If contained entirely within the substance of the thalamus or brainstem, resection may not be appropriate. We have used Gamma Knife radiosurgery in both children and adults where prior multiple hemorrhages and deep brain location mandated a procedure. In this setting, radiosurgery was associated with a significant reduction in the hemorrhage rate over time, especially after a two-year latency interval. To date, 12 children with cavernous malformations have had radiosurgery at our center (mean, 11 years of age), with an average of two symptomatic hemorrhages per patient.

Venous Malformations

Venous malformations are congenital anomalies of the venous circulation. Although they represent developmental anomalies, they provide drainage of normal brain tissue. Common brain locations include the cerebellar hemispheres, brainstem, basal ganglia, frontal lobe and parietal lobe. Often they are diagnosed as an incidental finding on CT scan, MRI scan or angiogram. There has been no consistent relationship between venous malformations and headaches. Even in patients who present with seizures and are found to have a venous malformation, a causative link is difficult to identify. Natural history studies have shown extremely low annual hemorrhage rates, and when hemorrhage does occur, it may be from an adjacent cavernous malformation. In general, these functional venous anomalies should be observed despite their clinical and imaging appearance. •