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EDITOR’S NOTE

In this issue of CNSQ, we reflect on only a few of the many advances that have been afforded to our specialty and patient care through the use of technology. During my training, I was provided insight into the rapid advances of our field by William Buchheit, MD, former Chairman of Neurological Surgery at Jefferson Medical College. He noted, at the time of his retirement, that all the operations and procedures he trained for as a resident and during the beginning of his career were no longer being performed (i.e., direct carotid puncture for arteriogram). He was a pioneer of innovation and welcomed “new” technology such as the operating microscope. This is just one example of the technological advances that have enabled neurosurgery to improve patient outcomes and increase their quality of care. We therefore dedicate this issue of the CNSQ to specifically examine the use of robotics in neurosurgery as a whole, as well as in several subspecialties.

Elad Levy et al. examine robotic advancements in the field of endovascular neurosurgery, while Dale Horne contrasts these achievements to how these devices have improved spinal surgery. Nick Boulos and Jason Taub discuss how they implemented robotics to overcome obstacles for delivering biologics to the human spinal cord. Specifically, they discuss the recent clinical trials and onset of stem cell therapies for neurosurgical diseases. Francesco Cardinal and Roberto Mai examine the use of robotics for improved implantation of intracerebral electrodes for epilepsy surgery. Timothy Lucas details the computer brain interface and Darlene Lobel discusses robotics and technology in education. A futuristic look in the use of robotics in neurosurgery is provided by Michael Lang and Garnette Sutherland. Edward Benzel and his laboratory discuss the use of MEMS technology in the use of robotics in neurosurgery. Finally, rounding out our theme, Pascal Jabbour provides an insight of how telemedicine with the use of robotics is enabling the expansion of cerebrovascular surgery.

We are further fortunate to have a featured article by Zoe Ghogawala and Sepideh Amin-Hanjani discussing comparative effectiveness research. In this article, they explain the principle of comparative effectiveness research and how this may impact both academic and general practitioner neurosurgical practices. Additionally, Jason Sheehan, Nader Pouratian and Zach Litvack discuss the newest addition to the SANS Lifelong Learning family – SANS Neurotrauma. In addition, we have an informative report from the pain section, as well as an instructive analysis of the legislative agenda from Katie Orrico.
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Images in Neurosurgery
The incorporation of new technological advances in patient care is nothing new to medicine. However, the challenges are increasingly diverse and complex and often represent a continuation of the issues facing our predecessors. How technology affects the doctor-patient relationship, how technology drives the delivery of patient care, how physicians manage rapid advances in technology when the science to utilize them lags behind, and how physician-industry relationships are managed to promote invention and innovation of new medical devices and not stifle them are just some of the questions facing us in the 21st century.

With the increasing complexity of medical technology and science, new devices, techniques and technology have been successfully introduced for the advancement of patient care over the past several decades. Dr. George Godber, chief medical officer for the British Ministry of Health wrote in an article in The Lancet in 1964, “but though mechanical aids and measuring devices extend the capacity of the doctor to serve the patient, they do not replace him. They are adjuncts to the human relationship between doctor or nurse and the patient; they cannot replace the art.” The advancement of these new technologies has to be developed in parallel with the growing body of scientific knowledge. Without the science, there is a potential threat to the human side of the doctor-patient relationship. The introduction of robotic devices to procedural medicine removes the physician one more degree as the device now becomes an extension of the surgeon’s hands. How patients and physicians manage this change has yet to be determined.

Rapid advances in technology have also changed the practice of medicine for physicians. The expanding role of technology has given rise to the necessity of specialists and then again subspecialists being driven by the complexity of the devices and techniques to use them. The expansion of neurointerventional techniques and devices and the emergence of subspecialist physicians trained to perform these procedures is a clear example of the force exerted by the adoption of new technology.

The medical landscape has also been altered directly by the cost of incorporating new devices and techniques and has contributed to the movement toward regionalization of care and competition in the marketplace to develop centers of excellence. Who will be responsible for paying for new technologies that increase the cost of health care with yet unproven effectiveness or efficacy? This is directly affecting physician to physician relationships in communities locally and is part of the national debate on health care and its cost. Additionally, more recently the issue of physician-industry relationships and the potential for conflict of interest in the development and clinical evaluation of new medical devices has become front and center. It is an absolute necessity that physicians are involved in the development and evaluation of new device technology. Furthermore those same physicians have to be involved with training and education because of the technique specific nature of these new devices. Physicians are the only ones who have the insight, understanding and expertise to de-
velop new health care technology, techniques and science to improve the outcomes for patients. To remove them altogether eliminates a necessary element to the innovative process for advancing the science of medicine. While improved oversight and protection should be a part of this process and the AdvaMed guidelines are a step in the right direction to provide these protections, it is up to the physicians and industry leaders to step forward now and defend and positively shape this relationship. If they don’t, protections and oversight will be mandated without understanding of the potential impact of cost and constraint.

The value of preserving the essential elements of invention and innovation is incalculable, particularly in neurosurgery and neuroscience. It draws young, bright medical students, bioengineers, as well as others to our specialty. The benefits and resulting challenges that technology places before us are a part of the medical landscape and cannot be underestimated. But in the end, any obstacles are not insurmountable – it is our future.

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Modern endovascular techniques complement or supplant open surgical approaches for the treatment of various cerebrovascular and cardiovascular diseases, including abdominal aortic aneurysms, coronary artery disease, carotid stenosis, cerebral aneurysms and cerebral arteriovenous malformations. The experience of the operating physician is changing and the technology supporting the development of endovascular devices is growing at a rapid pace. This has mandated a higher level of precision for manipulation of these devices and has resulted in a higher level of radiation exposure to the operator. Developments in robotic technology for manipulation of endovascular devices and computer-assisted visualization of the vascular anatomy may help the operator deal with some of the limitations associated with the treatment of complex lesions as well as improve the safety and precision of endovascular treatments and reduce the level of radiation exposure to the operator. Following the success of telerobotic surgery for minimally invasive procedures using the da Vinci™ surgical system, several similar surgical systems are under various stages of commercialization or development.

Current Commercially Available Endovascular Robotic Catheter Systems

Hansen Medical has introduced the Sensei X system, which provides a platform that combines an articulated robotic catheter with 3D visualization for planning and performing procedures. Their Artisan Extend™ Control Catheter accommodates pre-FDA approved mapping catheters and provides six degrees of freedom (ability to move forward/backward, up/down, left/right) through its steerable inner and outer guide catheter design. The complementary CoHesion™ 3D Visualization Module integrates the 3D motion control of the Sensei X System (below the screens) with the 3D visualization of the EnSite® System to allow precise placement of the catheter. The IntelliSense® Fine Force Technology with Tactile Vibration interface measures forces on the working catheter and provides immediate tactile and visual feedback to the operator. Although Hansen Medical is currently the market leader for such robotic solutions, the dependence of their system on the proprietary articulated catheter is a weakness because it limits the surgeon’s choice of catheter and devices.

Stereotaxis offers a guidewire that can be navigated using magnetic forces. The CARDIO-DRIVE™ Catheter Advancement System (Figure 1a) is a remote device manipulation system that is used to advance and retract a catheter in the patient’s heart. NIOBE® magnets (Figure 1b) precisely steer the working tip of the catheter advancer. Similar to the Hansen Medical system and other commercial robotic systems, Stereotaxis offers the advantage of remote manipulation (i.e., telemanipulation) of tools. However, the use of the NIOBE® magnets precludes the system’s compatibility with certain imaging modalities and other medical devices.

Catheter Robotics has Amigo™, yet another teleoperated catheter steering system that is undergoing preliminary evaluation.

Corindus has the CorPath® 200 System (Figure 2a and 2b), for coronary intervention with an integrated-ergonomically designed interventional cockpit. Both Corindus and Catheter Robotics offer systems that are compatible with currently used interventional devices and could potentially be integrated into existing therapeutic techniques. Both offer the benefit of not requiring proprietary catheters or guidewires. However, these systems are currently being tested only for percutaneous coronary interventions, and it is not known whether they will easily scale down for application to neuroendovascular procedures.

The Hansen Medical and Stereotaxis systems are currently being used for therapy at selected sites. These two systems have been subjected to multiple studies, and their efficacy in reducing fluoroscopy time and radiation dosage has been validated.

Compared with manual interventions, robotic systems seem to cause complications and result in slightly higher complication rates. These complications may be occurring due to a lack of adequate training on the new technology platforms. However, these systems cost more than current endovascular devices and...
DEVELOPMENTS IN ROBOTIC TECHNOLOGY FOR MANIPULATION OF ENDOVASCULAR DEVICES AND COMPUTER-ASSISTED VISUALIZATION OF THE VASCULAR ANATOMY MAY HELP THE OPERATOR DEAL WITH SOME OF THE LIMITATIONS ASSOCIATED WITH THE TREATMENT OF COMPLEX LESIONS AS WELL AS IMPROVE THE SAFETY AND PRECISION OF ENDOVASCULAR TREATMENTS AND REDUCE THE LEVEL OF RADIATION EXPOSURE TO THE OPERATOR.

Figure 2. A) Setup of the Remote Navigation System (RNS, NaviCath, Haifa, Israel), which was adapted by Corindus as the Corpath 200 system, during pilot clinical experiments. The operator control unit of the RNS was placed at the catheterization laboratory. The bedside unit was attached to the table side and adjusted to the groin position. Standard imaging screens were used for guiding the navigation process. B) A prototype of the bedside unit attached to the patient table, loaded with a wire and device. A standard guiding catheter and Y-connector are hooked to a special holder on the base. With permission from Beyar R, Gruberg L, Deleanu D, et al. Remote-control percutaneous coronary interventions: concept, validation, and first-in-humans pilot clinical trial. J Am Coll Cardiol. Jan 17 2006;47(2):296-300.
Cercenelli et al.\textsuperscript{10} (University of Bologna) developed a robotic system to steer standard electrophysiology catheters. Their system did not feature any force-dependent or controlled manipulation, and sensors were used to passively monitor proximal forces on the catheter. The system was briefly evaluated using animal models, and the benefits of having force-sensor information to increase the safety of the procedure were reported.

Jayender et al.\textsuperscript{11} (University of Western Ontario) used an articulated industrial robotic manipulator to advance catheters remotely. They developed novel image-processing algorithms that were used to prevent catheters from buckling or bunching. The group has also developed an active catheter equipped with shape-memory alloys to dynamically shape the catheter head during a procedure. A force-torque sensor was mounted directly on the wrist of the robot to obtain proximal forces during catheter insertion. This manipulation set-up was integrated with a camera-based tracking system to create a semi-autonomous system that could automatically reach specified points in a vascular phantom. This system has not been evaluated in clinical studies.

Guo et al.\textsuperscript{12} (Kagawa University, Japan) developed a teleoperated system for steering interventional devices. The system consisted of a slave capable of providing linear and rotary movements to a catheter. A miniature force sensor was mounted on the catheter head and distal forces were communicated to the operator through a force feedback device. They tested the system in vitro using vascular phantom and reported good results in being able to position the catheter accurately.

Srimathveeravalli et al.\textsuperscript{13} (University at Buffalo) developed a novel, teleoperated system, called the System for Endovascular Teleoperated Access (SETA), that was designed based on an in vivo study of surgeon manipulation forces on interventional devices. SETA features force monitoring and feedback to the remote operator and is the only system that allows simultaneous manipulation and control of both the guidewire and the catheter. This feature preserves the natural manipulation techniques of the surgeon. SETA was evaluated for precision positioning (Figure 3), using in vitro vascular phantoms and by a group of endovascular surgeons using the Procedicus Vascular Intervention Simulation Trainer (VIST) vascular simulator (Mentice AB, Gothenburg, Sweden) as a patient surrogate (Figure 4). The surgeons were asked to use SETA and navigate a guidewire and catheter into a stenosis in the right internal carotid artery. It was reported that all surgeons using the system were able to safely navigate the tools to the desired location on
the carotid artery. Two metrics were recorded during the experiments conducted using VIST to obtain a preliminary quantitative comparison of manual and SETA-assisted interventions. These metrics were (1) time taken to complete the procedure and (2) the amount of contrast material used during the course of a procedure. Surgeons took slightly more time to complete SETA-assisted procedures (SETA–mean: 87.42 seconds, manual–mean: 80.57 seconds); however, no statistically significant difference was observed for this metric. Similarly, slightly more contrast material was used for SETA-assisted procedures (SETA–mean: 7 ml, manual–mean: 5.75 ml); but again, with no statistically significant difference for this metric. This study confirmed the feasibility of SETA as being at least equivalent to manual intervention for the attempted procedure. Animal studies and clinical trials are being planned.

Future

Given that endovascular robotics is in its infancy, we presage that there will be rapid advancements in robotic endovascular technology and widespread testing of this technology in the clinical setting. The possibility of adoption in the endovascular field requires improved technology and user-interface and well-defined studies evaluating precision, radiation exposure, complications and cost-effectiveness in which this technology is compared with manual endovascular techniques in multicenter randomized controlled trials. Future technologies must focus on reducing the tedious telemanipulation required by most current systems and allow the use of non-proprietary components that will afford the flexibility that is needed. Robotic systems should have built-in intelligence and safety mechanisms that will enable the surgeon to focus more on the outcome of the procedure than on the technology. User interface must also be more intuitive and appropriate for operating room or catheterization laboratory settings. Rigorous human factor studies must be performed to validate the efficacy of interface design. This technology has the potential to increase the scope of the application of endovascular procedures, especially in settings where complex and long endovascular maneuvers are required to achieve the desired results.

References:

Disclosure: Dr. Elad Levy has an ownership interest in Intratech Medical Ltd. and Mynx/Access Closure.
ROBOTIC ASSISTANCE IN SPINE SURGERY

The implementation of surgical robots in the operating room has given surgeons in a number of specialties the advantage of increased accuracy while performing minimally invasive procedures. This means better localization of surgical targets with less damage to surrounding tissues and, ultimately, better outcomes. In spine surgery, a number of computer-assisted surgery (CAS) spinal navigation systems are commercially available that aid in the placement of spinal implants. These systems require “line of sight” between the tracking camera and surgical tool and accuracy is limited, in part, by the surgeon’s ability to freehand match the trajectory in three planes to the plan on the monitor. Since these systems are complicated and often increase surgical time, many surgeons have given up or avoided stereotactically placing implants.

SpineAssist (Mazor Robotics) takes stereotactic guidance to the next level by eliminating the line of sight constraint and freehand skills of the surgeon and providing for a simpler and more consistent and accurate means of placing hardware while exposing patients to less X-ray radiation. What sets SpineAssist apart from conventional CAS techniques is that a robot, about the size of a soda can but capable of six degrees of freedom, is rigidly mounted to the patient, either on a spinous process clamp or on a platform secured to the posterior superior iliac spines (PSIS) and a spinous process (Figure 1). As the robot moves, it guides an arm to a fixed location that provides the preplanned trajectory and entry point without requiring anatomic visibility. Although a main focus of the robot is for the placement of pedicle screws, the system is also able to place facet screws, translaminar screws and translaminar facet screws, and has been used in Europe for vertebralplasties, kyphoplasties and biopsies and to place Guided Oblique Lumbar Interbody Fusion (GOLIF) screws. This ability to target easily, accurately and efficiently allows the surgeon to perform minimally invasive or open procedures in a wide range of patients and is especially useful in degenerative spine procedures, spinal deformity cases, patients with anatomically small pedicles (Figure 2), thoracolumbar fracture stabilization, and patients with elevated BMI. The SpineAssist is FDA approved and is currently in clinical use in multiple centers around the world including the US.

The flow of a SpineAssist case is straightforward. Each patient receives a preoperative CT scan in Digital Imaging and Communications in Medicine (DICOM) format at the time of preadmission testing. In our facility these images are loaded to a virtual drive accessible over the internet from a virtual private network. The scan is then loaded into the proprietary planning software on a PC or Mac running Microsoft Windows. The program reconstructs the raw CT data into three-dimensional virtual X-rays for each individual vertebra in the region of interest. In the operating room on the day of surgery, the surgeon mounts the SpineAssist platform to the patient, either a clamp on a spinous process for short segment cases, or the Hover-T frame to the PSIS and a spinous process in long segment cases. Two intraoperative fluoroscopic images are acquired, one in the anterior-posterior (AP) plane and one 60° oblique plane, using a registration device mounted to both the image intensifier and SpineAssist platform. These images are used to create a segmental registration match of each vertebra to the virtual X-ray images from the preoperative CT plan. The system has several checkpoints along the registration process to ensure accuracy.

Once the registration device is exchanged for the robot on the SpineAssist platform, the surgeon chooses the vertebral body and side of the patient to begin placing screws. The

Figure 1: Mazor SpineAssist Robot
workstation sends the robot to the preplanned position. For pedicle screws, the workstation designates one of three robotic arms that are easily secured to the top of the robot and provide the support for the drill guides, which are used to access the pedicle at the exact location and with the precise trajectory planned. Although no further fluoroscopy is required, an image in the lateral plane may be taken to confirm that the drill guide is in line with the pedicle to be accessed. Once the pedicle is drilled, a K-wire is placed through the drill guide, down the pedicle and into the vertebral body. Once the K-wire is in place, the pedicle is tapped and the screw placed using standard minimally invasive techniques. This process is quick and typically takes only a few minutes per screw.

Whether there is sufficient benefit to using robotic and CAS techniques to place pedicle screws in lieu of open anatomical landmarks is controversial. Studies to examine the rate of misplaced pedicle screws suggest the rate can be as high as 4.2% in degenerative spinal diseases and 25% in patients with scoliosis. A recent multicenter retrospective study examining the accuracy of 3271 pedicle screws placed with the SpineAssist demonstrated that 98% of the screws placed were acceptable. No permanent neurological deficits were noted in any of the 635 cases evaluated, of which half were performed percutaneously.

The Mazor SpineAssist robot is a well-designed, easy to use, accurate positioning device for placing spinal implants in minimally invasive and some open procedures, especially in cases of deformity or small pedicles. In addition to the increased safety of physically placing pedicle screws, there is a significant reduction in the amount of X-ray radiation to patients and staff. Furthermore, with the increased ability to precisely match a preplanned trajectory, screw diameter can be more accurately matched to the width of the pedicle, thereby increasing the pull-out strength of the screw. The end result is to make spine surgery safer for patients, reduce the chance of revisions and complications and improve outcomes.

References:
CONCUSSION AND APPLIED
KINEMATIC MONITORING
TECHNOLOGY: THE MISSING LINK

Concussion is currently a topic of great clinical and research interest as reports of athletes suffering long term neurologic deficits as a result of these injuries continue to make headlines. For both athletes and soldiers, the lack of quantitative data about impacts transmitted to the brain has undermined efforts to determine the relationship between concussion and the risk for long term cognitive, psychological and motor dysfunction. To better understand the threshold required to produce the clinical symptoms associated with concussion, head impact dose data have been collected through instrumented helmets and headgear known as the Head Impact Telemetry System (HITS) in American football, boxing, hockey, equestrianism and the military.

While data from several million head impacts have been collected from these instrumented helmets, definitive diagnostic and treatment algorithms related to concussion have yet to be established. And research continues into the development and implementation of protocols for imaging studies, laboratory tests to identify blood biomarkers, and clinical diagnostic tools such as neurocognitive testing, and balance and motor assessment. Contributing to the difficulty of accurately collecting real-time data during practice and competition is the finding that concussion is also common in unhelmeted contact sports—e.g., collegiate women’s soccer outpaces concussive rates for collegiate football.

The Intelligent Mouthguard is a recent innovation in head kinematic monitoring that provides accurate real-time head impact dose data related to concussion. Through the use of micro-electrical mechanical systems (MEMS), microprocessors, Bluetooth data transmission and miniature batteries, the Intelligent Mouthguard may provide a means to collecting real-time in vivo impact dosage data for unhelmeted athletes and soldiers. It also complements current concussion data-gathering that employs helmet-mounted systems.

As early as 1975, Colonel John Paul Stapp MD, PhD, a pioneer of injury biomechanics, proposed to study football players with subminiature sensors. Based on Colonel Stapp’s idea, hard wired intra-oral and extra-oral in vivo head impact telemetry system arrays of six (6) to fifteen (15) subminiature strain-gage linear accelerometers were developed to calculate head center of gravity (cg), linear and rotational kinematics. However, these sensors needed to be positioned in precise locations and orientations to permit kinematic calculation at the head cg. Further, these systems were impractical when used on live humans due to the need to screw accelerometers into the skull in order to capture data accurately.

More recently, wireless MEMS-based linear accelerometers have been developed. The helmets of the aforementioned HITS system have a specified array of six (6) uniaxial MEMS linear accelerometers positioned tangentially to the head that calculate head cg linear acceleration and angular acceleration. As with all head-mounted sensors, in order to calculate head cg kinematics, HITS uses an optimized data algorithm as a function of helmet size; these calculations are not currently tailored to each user’s unique head anthropometry.

Though prior methods have provided a strong foundation for in vivo head impact monitoring, present day MEMS sensor innovations allow for a breakthrough in impact monitoring in order to capture the head impact dosage responsible for concussion. Inexpensive rotational, position, velocity and acceleration MEMS sensors are available that can simplify high-g head impact measurement. This breakthrough strongly indicates that using intraoral sensors for all helmeted and unhelmeted sports will be possible. Rotational MEMS sensors, when paired with existing MEMS linear accelerometers, permit direct measurement of rotational head kinematics and make head cg linear acceleration calculations simpler and less error prone. This type of six degree of freedom (6DOF) inertial measurement unit (IMU), with on-board three-axis linear accelerometer and three-axis angular velocity sensor, is currently available in applications like smart phones and handheld video gaming systems. When this 6DOF MEMS high-g IMU is paired with diminutive batteries, Bluetooth data transmission and tiny analog-digital converters, the entire package is on the order of one cm³ or less and able to be molded into any custom intra-oral appliance.
Intelligent Mouthguard prototypes are currently being developed and validated experimentally at the Cleveland Clinic. As testing is ongoing with robust laboratory prototypes [Figure 1 – (A)-(C)] the first fully functional in vivo prototypes [Figure 1 – (D), (E)] are being constructed. In 2011 it is anticipated that the first batch of high 6DOF IMU Intelligent Mouthguard prototypes will be produced for in vivo use.

After efficacy of these prototypes is validated in both laboratory and human subject testing, the stage will be set to manufacture and distribute the Intelligent Mouthguard for pilot concussion studies nationwide. After collecting head cg linear acceleration, angular acceleration and angular velocity data from these in vivo studies, kinematic data will be compared to known head injury metrics. Peak brain stress and strain related to energy transmission during impact will be obtained using finite element models, such as SIMON. These data will be instrumental in developing head protection to reduce energy transmission to the skull and brain.

Human subjects will also be clinically examined for signs and symptoms of concussion. This clinical examination will include on-site physical evaluation and balance testing, Imaging (MR diffusion tensor, fiber tracking, CT and PET scans), neurocognitive and motor testing with computerized assessment systems, and blood biomarker analysis such as s100ß and Apo lipoprotein E epsilon-4 will be considered as well. When all of these data—kinematic head impact dosage and clinical diagnostics—are collated, a clearer picture of concussion should emerge. With a better understanding of the relationship between head impact dosage and clinical signs of concussion, strategies to reduce the factors that contribute most to concussion can be developed through improved helmet design or behavior modification.

Finally, investigators will be able to correlate the relationship between impact characteristics and clinical outcomes with this wealth of quantitative and clinical diagnostic data. As these patients with concussion are followed over time, much will be learned with regards to the long term cognitive and psychomotor effects of concussion.

References
The promising results achieved with stem cells in animal models have increased interest in the targeted delivery of biologic payloads to the human spinal cord. Our group, and others, have designed and implemented technologies and techniques aimed at safe and accurate spinal cord injections. Currently, spinal cord injury (SCI), motor neuron diseases (ALS and SMA), and demyelinating diseases (MS) are the obvious targets for translational research and trials. Repetitive improvements in design have reduced incision size and invasiveness, improved targeting and accuracy, and decreased overall procedural complexity.

Human spinal cord injections have historically been performed using free-hand syringe injections. The potential for sheering long tracks, imprecise targeting, and poor reproducibility associated with the free-hand method provide an eloquent argument for innovation. Equally important, the lack of stability of free hand injections promotes rapid infusion which can create local pressure in the cord and promote reflux of the biological therapy into the CSF. Table-mounted injectors eliminate many of these drawbacks, providing a stable platform to allow for controlled slow infusion, and allowing for accurate and reproducible targeting. Table-mounted platforms are also easy to use and can be deployed quickly.

However, these systems fail to prevent movement of the patient in relation to the injection platform. Two forms of cord movement exist: microscopic and macroscopic. Microscopic movement occurs within the spinal canal in synchrony with cardiovascular pulsation, ventilator-associated respiration likely due to changes in arterial and venous pressure in the CNS. Macroscopic movement occurs with movement of the spine during ventilation due to changes in thoracic volume, as well as inadvertent patient movement associated with bumping the patient or bucking under anesthesia. The former can be eliminated by holding ventilation during injection. However, the potential for hypercarbia and hypoxia limits the duration of injection, and the devices remain vulnerable to intraoperative mishaps. With these limitations in mind, we have introduced a spine mounted platform that moves with the patient, eliminating these risks.

Early versions of our spine mounted platform utilized spinous process clamps. Application of these clamps required an incision long enough to accommodate the entire device, often spanning multiple levels both rostral and caudal to the laminectomy site. Likewise, the bony fixation pressure clamps attached at the midline failed to provide at least three-point fixation. The two-dimensional axis of the injection stage and limited angles of rotation greatly re-
restricted its usability. Lastly, early systems which employed a rigid cannula did nothing to prevent relative micromovement.

The current version of the device solves these problems. It incorporates a platform entirely affixed to the patient’s bony spinal column with a cannula system that allows for both continued ventilation during injection and the prevention of shear injury in the case of patient or apparatus movement. The laminar support posts, placed percutaneously outside the laminectomy incision, provide greater stability through an increased number of fixation points. A tissue retractor system, also incorporated into the device, enables further stability through opposing forces on the fascia and musculature. The remaining rail system and injection platform now reside above the incision and laminectomy site, thereby offering greater accessibility to the surgeon.

These new additions can accommodate unlevel placement of laminar posts, junctional levels of the spinal column, scoliotic and kyphotic deformities, and eccentric laminectomies. The delivery platform is now capable of movement in the x, y, and z planes, and hosts a full locking articulation bearing that permits 360 degrees of rotation for greater adaptation. Lastly, the rail system is fitted with markings to allow for precise spacing between injections without multiple manipulations.

These advances allow for the micromanipulation needed during biologic payload delivery to the human spinal cord. The “floating” cannula component utilizes a rigid construct for pial and parenchymal penetration, and then exposes flexible tubing that can absorb motion placed upon the entire system during injection. In addition, the needle is outfitted with a proximal flange that helps support the inserted needle during the injection phase, while also increasing accuracy and targeting during penetration.

While many advances have been made toward perfecting biologic delivery, there has been no objective data to support one device and technique over another. We are currently attempting to procure funding to conduct head to head comparisons and “crash tests” that examine the impact of inadvertent patient movement.

In January of 2010, we initiated the first human spinal cord stem cell transplantation trial for the treatment of ALS using this optimized device under the sponsorship of NeuralStem Inc. A variety of groups, including the teams of Angelo Vescovi (Milan), Clive Svendsen (Cedar Sinai), Nick Maragakis (Johns Hopkins), and Lawrence Goldstein (UCSD/Salk/California Institute for Regenerative Medicine) are working towards trials to treat ALS with spinal cord transplantation. In addition, we are beginning to develop a gene therapy strategy that will leverage these techniques. Geron Inc, NeuralStem, and the Miami Project are conducting and preparing transplantation trials for spinal cord injury. While no approach has shown efficacy in humans yet, this fertile environment will continue to drive innovation in the arena of safe and accurate spinal cord surgery.

Disclosure: Dr. Nicholas Boulis has a financial relationship (category: other) with NeuralStem.
"Robotics," a term originally coined by Isaac Asimov in 1941 in his short story “Liar!” describes the science and technology of robots. A newly emerging field, medical robotics, is gaining momentum both in the practice of medicine and as an educational tool. Medical robotics has evolved to include telepresence surgery and robotic telemonitoring. Telepresence surgery or “robotic surgery” involves the implementation of a surgical robot that is a computer-controlled device programmed to assist the surgeon in the placement and manipulation of surgical instruments. This device, or “robot,” through the use of motion scaling and tremor filters, enables the surgeon to increase precision of tool manipulation and carry out tasks of a complexity that would be challenging based on the limitations of human hands. Telemonitoring involves remotely monitoring patients, often using a robot, when the patient is not in the same location as the physician.

Neurosurgery seems ideally suited to robotic surgery both to improve precision in performance of technically challenging procedures and to enhance neurosurgical training of residents. While significant advancements in robotics for neurosurgery have been made in the last 25 years, the greatest development in medical robotics has been in the areas of general surgery, obstetrics and urology. Despite the increasing prevalence of robotic technology in these fields, surveys of surgical residents suggest that although 57% of residents demonstrate significant interest in robotic surgery, the majority (80%) do not have a robotic training program in their institutions. While a few neurosurgical residents may have some exposure to robotic surgery at a handful of institutions where robotic technology is routinely used, no formal surveys have been conducted to assess neurosurgical resident exposure to this emerging technology.

So how do we integrate robotic surgery into neurosurgical training programs? When considering methods of implementing new technology into education, it is important to avoid the temptation to provide exposure to the new technology without formally integrating it into the curriculum. The concept of a curriculum which teaches defined fundamental skills is essential to graduate medical education. Furthermore, validation parameters for any new technology must be established. This is essential to show that the implementation of the new technology provides objective evidence that the established goals of the training program are being met. From such an evaluation, it may be possible to assess the effect of the new technology on the overall learning curve of trainees, as well.

While there are a few FDA approved “robotic surgery” training centers in the US, these are currently utilized mainly by practicing surgeons. Certain centers, such as Hackensack University Medical Center, have even defined criteria to grant operative privileges to surgeons who wish to perform robotic surgery. There is, however, no formal robotic curriculum established for neurosurgical residency programs to date. To fully integrate this burgeoning technology into the future of neurosurgery, we must assimilate robotic surgery into the residency curriculum and ensure that training with such systems meets the goals of the ACGME core competencies. Furthermore, we must establish parameters to validate the efficacy of robotics in training our young neurosurgeons.

Few validation studies of robotic surgery currently exist; however, the published studies suggest that training with robotic technology may shorten the learning curve for students and residents. In one study, medical students...
on a general surgery rotation were left alone in the operating room and then exposed to anatomy, surgical principles and adjunct surgical techniques via a remote telepresence operator. The students felt the experience was better than traditional surgical observation. Among the reasons cited was better visibility as the operating surgeon was not blocking the surgical field. Furthermore, this approach required precise verbal accuracy in describing the procedures, which facilitated students’ learning.9 Another study which evaluated residents and practicing surgeons at East Carolina University in the use of a da Vinci™ robot demonstrated a significant reduction in both knot-tying time and overall procedure time for the last half of the surgeries during the study period.10 Other studies have confirmed that training using robotic surgery decreases the learning curve for residents in acquisition of new surgical skills.11,12

While the benefits of integrating robotics into a neurosurgical curriculum are vast, including decreased operative time, shorter patient stays and improved training for residents, the cost of implementing should also be considered. Typically, robotic systems carry a price tag of over $1 million and require significant funds for annual maintenance.

As a final note, robotic technology must be integrated into a multi-modality approach to residency training. While new technology can be exciting to both educators and students, the importance of training using classic techniques should not be underestimated. Thus, comparative studies which assess resident training using traditional methods vs. robotics will be essential to determine the benefit of training using this new technology.

While robots don’t share the fallibility of the human physician, we recall an interesting literary parallel and are reminded that it is the surgeon who is ultimately responsible for the care of the patient, with or without the use of technology:

“A robot may not injure a human being or, through inaction, allow a human being to come to harm.”

-Asimov, 1st law of robots in “Runaround”

“I will prescribe regimens for the good of my patients according to my ability and my judgment and never do harm to anyone.”

-“Hippocratic Corpus”

References
THE VISION OF ROBOTIC NEUROSURGERY

To project the future of neurosurgical robotics, a careful balance must be struck between the expanse of possibility and the practical limitations of technology development. Advocates envision a coming era of micro-invasiveness, but often neglect justifiable concerns regarding efficacy, utility or even the essential importance of a surgeon’s touch. In addressing both opportunity and challenges, we have found robotic-assisted neurosurgery to be of ever-growing scope and complexity.

Project neuroArm at the University of Calgary began not as a dedicated undertaking in surgical robotics, but as an outgrowth of previous work in intra-operative MRI (iMRI). In order to operate under real-time image guidance, the natural conclusion of the iMRI concept, an MR-compatible robot was deemed a more advantageous solution than contorting the surgeon into the closed bore of a high-field magnet. Given the intended use for both microsurgical and stereotactic applications, the neuroArm system was designed with image guidance and haptic capability, so as to integrate vision with touch, both indispensable for microsurgical dissection. The technical specifications of the neuroArm system, pre-clinical validation, and initial clinical experience have been previously described. It is our intent here to describe the infrastructure created around neuroArm and the processes towards the ongoing and future development of neurosurgical robots.

The creation of neuroArm occurred within a collaboration between the University of Calgary and MacDonald, Dettwiler and Associates Ltd. (Brampton, ON, Canada). It was however, not simply a collaboration between a university and industry, but rather the establishment of a comprehensive academic medical robotics program for the optimal integration of technology with surgery. The University of Calgary robotics program now includes a lab dedicated to the study of haptics, where the basic elements governing digital touch recreation are being evaluated. Electrical and mechanical engineers are examining sensor and hand-controller design, while software engineers are addressing robotic control programming so as to optimize force transmission while in contact with soft tissue or harder surfaces, like bone or calcified tumor. The lab will come to incorporate research from basic neuroscientists, such that an understanding of neural touch transmission and integration with other sensory feedback can be incorporated into more sophisticated haptic systems.

In addition to the haptics lab, an advanced engineering and prototyping lab was also established. In this environment, innovations in surgical tools can be guided through initial design to rapid fabrication. From there, they can be evaluated in an adjacent research operating room, identically equipped as the clinical iMRI/neuroArm OR.

The history of neurosurgery has repeatedly demonstrated that technological innovation begets further innovation. The continued use of robotics will make new instrument designs apparent, similar to the process that followed the introduction of the operating microscope. Notwithstanding challenges related to force sensing, equipping a robot with MR compatible drills may be an exceptional advance for skull base surgery. Furthermore, the addition of contact laser technology (Photomedex Inc., Montgomeryville, PA, USA) provides a multi-purpose tool that retains the sense of touch. The ability to rapidly translate ideas into testable prototypes expedites the creation of technology and its translation into clinical medicine.

The importance of connecting engineers with medical personnel and the operating room environment cannot be understated. Software design and the interface between it and the surgeon are essential if the surgeon is to take full advantage of robotic technology. For example, the ability to digitize force data from the surgical field will allow the surgeon to quantify, in standard units, the forces associated with tissue deformation and dissection. Paired with finite element analysis studies of cadaveric tissue, such data will form the basis of future patient specific haptic-enabled surgical simulators. This could become an essential component in gaining experience in the performance of surgery and perhaps reducing time required to master surgical techniques. Additionally, the creation of virtual fixtures, alternately known as ‘no-go zones’ or ‘virtual highways,’ will improve the ability to protect vital structures and provide a safe and more precise surgical corridor. To accelerate commercialization and future technology creation, neuroArm technology was transferred to an industrial partner, IMRIS Inc. (Winnipeg, MB, Canada). Industrial influence on development provides value engineering and economy of scale through negotiation, which are difficult to achieve within an academic environment.

The robotics research infrastructure also includes a laboratory for surgical debriefing and global connection. In this environment, it is feasible to play back or play forward surgical procedures, thereby providing a unique venue for learning and sharing surgical experience. Connecting this environment through a web-based forum dedicated to the advancement of informatic neurosurgery provides the opportunity of linking research being conducted in Calgary with other centers throughout the world.

While still in its infancy, an increasing number of robotic systems have been designed for and integrated into neurosurgery. Analogous to
the evolution of personal computer technology, medical robotic systems are increasingly incorporating new advancements, such that the union of surgeon and machine exceeds either individually. With the potential of surgical robotics now demonstrated, compounding knowledge will inevitably drive the production of new robotic systems and related technologies into clinical medicine that may ultimately change how surgery is performed and taught.

References

Disclosure: Dr. Garnette Sutherland has an ownership interest in IMRIS.
BRAIN COMPUTER INTERFACE DEVICES ON THE NEUROSURGICAL EVENT HORIZON

Technological advances in the disciplines of electrical engineering, computer science and neurophysiology will increasingly influence neurosurgical care. This is because the nature of the ‘excitable tissue’ of the nervous system. The ability to record and stimulate the nervous system provides an avenue of nervous system modulation. Properly targeted nervous system modulation affords relief from disease symptoms (e.g. tremor, pain), augments sensory systems (e.g. cochlear implants) and—within the foreseeable future—will replace lost motor function following stroke, trauma, tumor and neurodegenerative disorders such as amyotrophic lateral sclerosis.

The concept of nervous system modulation is not new. Indeed, clinicians have utilized deep brain stimulation for decades while physiologists have stimulated the nervous tissue experimentally for over a century. What is new is the tempest of interest which has developed around novel methods of nervous system modulation utilizing brain-computer interface (BCI) devices. BCI neuromodulation technologies are evolving too rapidly for most clinicians to stay informed. The field of neuromodulation is a $4.5 billion industry, with projected annual growth rates between 15-26%. The purpose of this article, therefore, is to provide neurosurgeons with an overview of the basic concepts surrounding BCI technologies and provide examples of human applications.

An understanding of brain computer interface (BCI) devices begins with brain signals. Brain signals, of course, consist of fluctuating electrical fields developed within the dendrites of the cortical neurons. Analogue voltage changes are recorded with electrodes with varying spatial and temporal resolution, depending on the type and location of the electrode. Non-invasive BCI devices record integrated voltages in the form of electroencephalogram (EEG) from thousands to millions of cortical cells spatially averaged over centimeters of cortex. The non-invasive nature of these recordings permits extensive study of these devices in normal control subjects. These methods are safe, relatively cost-effective, and have been demonstrated to work with modest efficacy. The disadvantage of such systems is that they require substantial signal averaging to boost the signal-to-noise ratio above the background noise related to the scalp, muscle, bone and dura. Nevertheless, EEG-based systems which measure P300 responses have been shown to permit ‘locked-in’ patients to communicate by generating letters and words on a computer monitor.

Invasive BCI devices, on the other hand, consist of epidural, subdural and intracortical electrode arrays. The signal-to-noise ratio of these arrays benefits from the closer proximity to the current source by detecting voltages at a much higher resolution than non-invasive techniques. Subdural systems, which record electrocorticography (ECoG), and intracortical systems, which record local field potentials (LFP) and unit spike activity, have been successfully used in humans. ECoG systems from grids in epilepsy patients have been shown to drive a cursor along a single dimension. Microelectrode BCI systems inserted into the visual cortex have been used to partially restore light perception in blind individuals. And, in nonhuman primates, motor cortex BCI implants have been used to reanimate temporarily paralyzed limbs by directly stimulating arm muscles to produce arm movements, bypassing damaged neural pathways. Indeed, a variety of non-invasive and invasive BCI technologies are being developed in parallel, with different patient populations and clinical indications in mind.

Once the brain signal is acquired by a recording electrode, the signal is amplified, filtered and digitized. The signal must then be ‘decoded.’ Decoding algorithms extract selected features from the recorded signal before transforming it into some form of a command. Different signals (i.e. EEG, ECoG, LFP) require different signal processing systems. For instance, intracortical recordings may extract the frequency of spike activity as the appropriate feature for signal extraction, while recordings of local field potentials from ECoG may extract the power of a specific frequency band as the appropriate feature for signal extraction. The decoded signal is then transformed into output commands that drive cursors on a monitor, servos and motors on robotic limbs, or switches to turn on or off the room lights.

This is the step where most BCI technologies meet their greatest challenge. Closed-loop decoding requires a priori knowledge of what the signal translates to in functional terms. In other words, when a subject closes his hand to form a fist, an ECoG electrode may measure a shift in the power of a given frequency band of motor cortex LFP. One might surmise that this...
shift is the neural code which signals the hand muscles to contract; a code for making a fist. Accordingly, the BCI controlling a robotic arm is programmed to close the mechanical hand when the fist signal appears. Unfortunately, such training is not possible in a patient who cannot close his fist in the first place—there is no functional output to correlate with the various brain signals. Complicating the issue further is the fact that the brain signal may vary for the patient depending on a host of uncontrollable variables like the level of alertness of the individual.

An alternative strategy to decoding neural signals to drive BCI devices is to use BCI to promote changes in the nervous system. The concept of BCI-induced neuroplasticity is possible because the functional organization of the brain is inherently dynamic, adapting throughout life. Our group and others have explored the use of BCI technology to induce plasticity in a targeted fashion. Autonomous, implantable computer circuits induce long term plasticity of motor output in primates. Targeted plasticity could condition normal brain regions to alter their output and augment damaged pathways following stroke, traumatic brain injury and tumors. Active research is exploring these areas currently.

Emerging BCI technologies will undoubtedly impact neurosurgical practice, paralleling the course of cochlear implants, which now number over 188,000. Neurosurgeons are uniquely qualified to bring BCI technology to the clinical arena with their understanding of neuroanatomy, neuropathology and technical expertise. Neurosurgeons versed in the burgeoning discipline of neuromodulation will be increasingly sought after.

> BCI NEUROMODULATION TECHNOLOGIES ARE EVOLVING TOO RAPIDLY FOR MOST CLINICIANS TO STAY INFORMED. THE FIELD OF NEUROMODULATION IS A $4.5 BILLION INDUSTRY, WITH PROJECTED ANNUAL GROWTH RATES BETWEEN 15-26%. <

References
Introduction

Amputation of an upper extremity is a devastating loss, both functionally and psychologically. Currently, there are two types of prosthetic limbs commercially available: body powered and myoelectric. Body powered systems employ cables driven by shoulder motion to effect movement in the prosthetic elbow or terminal device. Conventional myoelectric technology translates the EMG signals generated by residual arm musculature into specific forearm or hand motions. For example, in order to allow the prosthetic fingers to move, a transhumeral amputee wearing a conventionally-controlled myoelectric device will contract his biceps muscle. The resulting surface EMG signal will be detected by sensors within the socket of the prosthesis, and a signal processor will command the device to perform a single action, such as finger extension. Neither type of device is intuitive (imagine trying to pick up a pencil using only muscles meant for shoulder or arm movement). Moreover, neither allows simultaneous control of multiple prosthetic “joints” and therefore the user must toggle between hand, wrist and elbow motion, markedly decreasing the speed and efficiency of task performance. It is not surprising that many amputees functionally abandon their prostheses, wearing them only for cosmetic purposes.\(^1\)

One of the most important advances in prosthetic rehabilitation of the upper extremity amputee since World War II\(^2\) was first reported in 2004. Targeted Reinnervation (also known as TR, and the “Bionic Arm procedure”) uses novel nerve transfers to amplify the information still present in the residual nerves that once controlled arm, elbow and hand movement, thereby allowing intuitive control.

Figure 1. Transhumeral amputee with her prosthesis controlled using TR.
of the prosthetic limb. All the patient has to do is think of performing a hand, wrist or elbow motion, then the target muscle contracts and the action is performed by the device.

Who is a Candidate for the Procedure?
Upper extremity amputees at or above the elbow level are candidates for the procedure. In order for nerve transfers to be possible, the nerves that had once served the upper extremity must still be in continuity with the brain, without a higher level injury. Therefore, patients with brachial plexus injuries or spinal cord injuries are NOT candidates for TR. For amputees who have undergone the procedure, sharp rather than avulsive injury patterns have had more straightforward procedures, because the amputated nerves are located more distally in the residual limb. Electrical injuries have also been successfully treated with TR. The two published types of TR procedures are for shoulder disarticulation patients and transhumeral amputees. A video demonstrating the technically easier transhumeral procedure is located on the Rehabilitation Institute of Chicago web site.

How Does it Work?
Nerves proximal to an amputation are still capable of transmitting information from the brain, despite having lost their distal muscle targets. Unfortunately, these nerve signals are diminutive and cannot be picked up on the skin surface. Targeted Reinnervation solves this problem by providing the amputated nerves endings with a megaphone. By transferring the end of one of these nerves to a neighboring muscle’s motor point, after regeneration, the signal present in that transferred nerve is amplified and can be readily picked up by skin surface EMG sensors. For example, after transfer of the median nerve to the medial head of the biceps brachii, contraction of this muscle when the median nerve depolarizes will generate an EMG signal. Using myoelectric technology, the terminal device translates that EMG signal into device closure. It takes three to six months after nerve transfer for regeneration to occur which results in contractions that generate useful EMG signals. In some patients, a sensory nerve can be coapted end-to-side to either the median or ulnar nerve for targeted sensory reinnervation. Stimulation of the resulting reinnervated skin results in the sensation of the patient’s hand being touched. Analysis of these patients has revealed an ability to discriminate between gradations of force that matched their uninjured skin. This feature not only improves the utility of the prosthetic device (patients don’t drop or crush objects because they are able to sense what degree of force is being applied), but may allow the patient to integrate the prosthetic into the user’s self-image.

Another advantage of TR is that it requires only a slight modification of the existing prosthetic device to optimize electrode fitting. Occupational therapy and training is minimal after TR because control of the device is more intuitive than with conventionally controlled prostheses.

Outcomes
The TR procedure has been performed in over 30 patients worldwide (11 shoulder disarticulation-level amputees and 19 transhumeral amputees). Results have been published on a small subset of patients (3 TH and 3SD), and indicate marked improvement (up to 271%, average 198%) in manual dexterity tasks. Assessment of Motor and Process Skills (AMPS) testing (a measure of performance of activities of daily living) revealed a statistically significant improvement when conventionally-prostheted prostheses were compared to TR-controlled prostheses. Most striking is the smooth coordination of complex tasks. Our internal database of procedures performed worldwide show a success rate of 96% gaining a useable EMG signal after nerve transfer in 94 of 98 nerves.

Summary
Targeted reinnervation is a practical application of the brain-machine interface. By allowing amputees to regain intuitive control over their limbs, it works to restore both the functional and psychological losses associated with limb amputation.

References:
STROKE AND TELEMEDICINE

Stroke is the second leading cause of death worldwide and the third leading cause in the US. New endovascular techniques offer better alternatives to patients with acute stroke; however, these techniques are not available everywhere. Most hospitals in rural areas do not have the capabilities of patient assessment on a 24/7 basis, and they also lack the emergency department support to be able to administer IV Tpa. In addition, very few hospitals have a neuroendovascular team. Therefore, many candidates for IV Tpa or IA procedures are not getting state-of-the-art care. Many of these patient candidates are either immediately transferred without proper evaluation or they go untreated.

For these reasons the Neurosurgery Department at Thomas Jefferson University Hospital has developed a telemedicine stroke consulting network using robots placed in different remote emergency rooms where 24/7 stroke coverage is not available.

The objectives of the program include:

a) Timely delivery of appropriate state-of-the-art treatment.
b) Elimination of inappropriate patient transfers.
c) On-demand access 24/7 to tertiary care and stroke expertise.
d) Access to stroke awareness and education programs.
e) Recognition of Thomas Jefferson University Hospital and Jefferson Hospital for Neuroscience as the Stroke Center of Excellence of the Delaware Valley.

> THE PHYSICIAN IS ABLE TO CONDUCT AN ACUTE STROKE CONSULT ON DEMAND, IMMEDIATELY, FROM ANYWHERE AT ANY TIME. <

Figure 1. A physician remotely assessing a potential stroke patient.
Stroke expertise is delivered using Remote Presence (RP) robotic technology (In Touch Health, Santa Barbara, CA). When a stroke patient presents to the emergency room, the emergency room physician calls a toll-free number paging the physician who is on-call for telestroke. The telestroke physician logs on to a mobile laptop and wireless internet to connect to the RP Robot and is virtually within the emergency room in minutes.

The RP system is unique compared to traditional telemedicine systems in that it affords the physician complete autonomy and reliability to initiate a connection without the need for support from either ED nursing or information technology staff. The physician is able to conduct an acute stroke consult on demand, immediately, from anywhere at any time. Physicians are able to drive and maneuver the robot around the ED, essentially giving them mobility at the remote site. The consultant uses the two-way audio and video capability to conduct neurological assessments with patients, read data visually off monitors and devices in the room by zooming in, and interact with patients, family and ED staff.

This program was recently initiated at Thomas Jefferson University Hospital, and we will analyze our data in 6 months to evaluate the effect it has on stroke care in the Delaware Valley. The program has been operating in the State of Michigan by a hub-hospital, which recently analyzed its results after 18 months. The facility had more than 300 stroke consultations from all over the State of Michigan. Eighty-three percent of eligible patients received intravenous tPA. The program enabled stroke patients to have faster access to medical expertise; average time interval from the patient’s arrival at the emergency room to consultant callback was 8.5 minutes. Eighteen hospitals gave IV tPA for the first time. The hub hospital saw their volume double compared to the previous year, and at the same time participating community hospitals were able to keep more patients by being selective and avoiding unnecessary transfers. The program received the 2007 Detroit “Health Heroes” award. Other specialties like cardiology are interested in adopting similar programs.

In addition to its use for acute stroke, this technology has also been utilized to provide remote presence in intensive care units. Timely assessment and treatment of ICU patients can be difficult given the shortage of intensive care physicians and surgeons as well as the unavailability of ICU beds. Delays in both patient assessment and physician response can result in lost opportunities to improve patient outcome and also in increased morbidity and length of stay. Vespa et al. performed a prospective study using a before-after, cohort-control design to test the effectiveness of the telemedicine program. Physicians used the robot to make rounds in the ICU in response to nursing pages. The use of the robot reduced the latency of attending physician face-to-face response for both routine and urgent pages. There was an increase in ICU occupancy by 11% compared with the pre-robot era, and also a cost savings of $1.1 million.

It is our hope that this telemedicine stroke program gives stroke patients everywhere a better chance of survival by delivering faster and more efficient access to state-of-the-art expertise and care. Yet the long term sustainability and growth of telestroke practice remains threatened by unresolved legal, economic and market factors.

Figure 2. A physician using the special laptop and joystick to manipulate a robot at a remote site to assess a potential stroke patient.
Introduction

The Epileptogenic Zone (EZ) was originally defined by Talairach and Bancaud as “the site of the beginning and of primary organization of the epileptic discharge.” Its resection (or disconnection) is the most common and effective surgical option in cases of partial drug-resistant epilepsy. Non-invasive investigations (accurate anamnesis, neurological examination, high quality MRI and long-term scalp Video-EEG monitoring) are enough to suggest the surgical strategy in about two-thirds of the subjects. In the remaining one third, intracerebral recordings are necessary for the definition of the EZ.

StereoElectroEncephaloGraphy (SEEG) is a diagnostic stereotactic procedure aimed at placing recording multi-lead electrodes directly within brain structures, with a patient-tailored exploration strategy on the basis of noninvasive studies. By means of this methodology it is possible to implant recording leads in the dorsal, basal and mesial aspects of the hemispheres, on the cortical surface, in the fundus of sulci, and in the white matter. During long term Video-SEEG monitoring, it is possible to record spontaneous seizures, or to provoke them via low- and high-frequency stimulations. These electrical stimulations, together with evoked potentials, allow the epileptologists not only to elicit seizures, but also to map brain function. Finally, in well-selected cases, when a very small epileptogenic lesion is demonstrated, the same electrodes can be used for radio-frequency lesioning (therapeutic SEEG option).

Surgical Technique

Tele-stereoscopic radiology and the Talairach frame are the key elements of traditional methodology. The planning of the trajectories on the basis of stereoscopic stereotactic pairs of angiographic images permitted the implantation of the electrodes along pre-planned pathways, using the Talairach double grid as a frame-attached tool holder. In our Center, we have been performing SEEG implantations by means of these traditional imaging and surgical tools for many years, progressively supported by new technologies (3D MRI, fMRI, DTI-FT, 3D rotational imaging, stereotactic robot). The workflow has changed throughout the years; since September 2009 all SEEG procedures were planned and carried out entirely with the current technique.

The imaging needed for planning is obtained in frameless and markerless conditions, with the patient awake (except for children). The images can be acquired weeks or months before surgery, so that all the time needed for post-processing and planning can be freely taken. For every subject a 3D T1-FFE MRI sequence is obtained, and this dataset will be coregistered to the space of 3D cerebral angiography. The latter dataset is acquired with the O-arm™ 1000 System by Medtronic, a mobile robotic radiographic device for intraoperative
imaging. This 3D rotational angiography (the reconstructed volume is a 200 x 150 mm cylinder, 192 slices, 512 x 512 matrix, 0.4 x 0.4 x 0.8 mm anisotropic voxels) will be the reference space for planning. Other structural and functional MRI scans are optionally acquired.

The day of surgery a new dataset with the Talairach frame is obtained, so that the pre-planned trajectories can be transferred from the scanner space to the frame one. The tool holder for percutaneous drilling is fixed onto the arm of neuromate® (Renishaw) (Figure 1), a mobile image-guided robotic device developed specifically for neurosurgical procedures, in use in our center since 2001. This passive robot has an arm with five degrees of freedom that allows for aligning the tool holder along a trajectory previously planned with the Voxim® (IVS Technology GmbH) software (Figure 2). High accuracy and precision, the stiffness of the arm and the possibility of virtually infinite trajectories with any desired obliquity make this device particularly appropriate for SEEG planning and implantation.

The guiding screws are fixed into the skull holes previously performed percutaneously with a 2.1 mm drill. Drilling is aligned with the vector of pre-planned trajectories by means of the tool-holder of the neuromate®. The multi-lead electrodes (Microdeep Intracerebral Electrodes D08®, Dixi Medical - or Depth Electrodes Range 2069®, Alcis) are semirigid, with 0.8 mm external diameter and have no stylet inside. Every contact is 2 mm long, with 1.5 mm inter-leads gap. These electrodes are available with 5, 8, 10, 12, 15, and 18 contacts.

Case Series
In the period between May 1996 and December 2010 we performed 462 SEEG procedures in 447 patients (265 males, 182 females). We implanted 5,999 electrodes (mean 12.98 ± SD 2.49, range 3 - 20). Mean age of the patients was 25.62 ± 12.13 years.

Since September 2009, 40 SEEG procedures (557 electrodes) were planned and carried out entirely with the current technique. The median value for targeting error at the cortical entry point (measured comparing original plans with post implantation O-arm imaging) was 0.82 mm (Interquartile range 0.53 - 1.17).

Out of the 5,999 implanted electrodes, we had five major intracranial bleedings and two intracranial infections. We report one death of a 3-year-old child, probably due to an impairment of the hydro-electrolytic balance. None of these major complications occurred in the case of electrodes implanted with neuromate®.

Illustrative Case
In Figures 4 and 5 anatomy and peculiar SEEG data of a patient with a large Focal Cortical Dysplasia (FCD) affecting right hemisphere
are depicted. Video-SEEG monitoring allowed for planning a resection of the anterior part of the lesion, suggesting its more important epileptogenic role. The sensori-motor cortical and white matter structures, mapped by means of the electrical stimulations, were preserved. One year after surgery the patient is still seizure-free.

Note: in Figure 5 SEEG electrodes allow the epileptologists to record crucial information not only from the surface of the hemisphere, but also from deeper gray and white matter structures.

Conclusion
SEEG monitoring is the only invasive technique for direct recording and stimulating of electrical activity from any desired gray and white matter structure. Despite the large number of electrodes per patient, this technique has a very low rate of complications.

The image-guided robotic system allows the surgeon to implant intracerebral electrodes very accurately, along any desired trajectory.

References

Disclosure
The first Author is a consultant to Renishaw Mayfield, the manufacturer of neuromate, and a former consultant to Medtronic, the manufacturer of O-arm.
Noteworthy News from the CNS

The Congress of Neurological Surgeons continues to provide neurosurgeons from across the country and around the world with the tools and resources necessary to enhance health and improve lives worldwide through the advancement of education and scientific exchange.

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Connect with the leaders who are moving our specialty forward in Washington, DC, October 1-6 for the 2011 CNS Annual Meeting. Our exciting theme, E Pluribus Unum: The Specialty of Neurological Surgery, recognizes the tremendous impact we have on the public through the synergies within organized neurosurgery. Log on to http://w3.cns.org/meetings and register for this pivotal meeting today!

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FEATURED ARTICLE

COMPARATIVE EFFECTIVENESS RESEARCH – WHAT DOES IT MEAN FOR YOU AND YOUR PRACTICE?

Zoher Ghogawala, MD Sepideh Amin-Hanjani, MD

Comparative effectiveness research (CER) is currently a hot topic; it is not new, but the government’s interest in driving it might change its overall emphasis. In 2003, the AHRQ was given a congressional mandate to support CER. Today, the US government has committed enormous financial resources to this type of practical clinical research. The American Recovery and Reinvestment Act of 2009 allocated 1.1 billion dollars for new CER in the US. The NIH (400 million dollars) and AHRQ (300 million dollars) have stepped up requests for proposals that either develop CER methodology or propose actual comparative studies. The Office of the Secretary of the US Department of Health and Human Services (OS-DHHS; 400 million dollars) has focused efforts on the development of data infrastructure to support CER. The Institute of Medicine (IOM) defines CER as “the generation and synthesis of evidence that compares the benefits and harms of alternative methods to prevent, diagnose, treat, and monitor a clinical condition or to improve the delivery of care. The purpose of CER is to assist consumers, clinicians, purchasers, and policy makers to make informed decisions that improve health care at both the individual and population levels.” The IOM has identified conditions such as low back pain and cervical spondylosis as being among the top 100 priority conditions that would benefit from CER.

State of Neurosurgical Evidence
Most published clinical studies in neurosurgery are retrospective. Prospective studies including randomized trials are expensive and difficult to execute. Even when RCTs are performed, they do not necessarily provide definitive evidence that guides clinical practice. Organized neurosurgery, through the AANS/CNS Guidelines Committee, has emphasized the need for evidence-based practice by endorsing evidence-based guidelines on a variety of topics. Despite this initiative, many of the guidelines have demonstrated that there is little evidence to guide practice on major practical matters such as whether an unruptured aneurysm should be clipped or coiled, or whether a lumbar spinal deformity with nerve compression should be decompressed alone or decompressed with instrumented fusion. Many ask whether acoustic neuroma should be treated with surgery vs. stereotactic radiosurgery. Often, finding the answer requires careful long-term follow-up. Large administrative claims databases in their current form are unable to answer these questions because they lack the necessary patient identifiers to provide risk-adjusted outcome assessment and they lack sufficient follow-up outcome data to make meaningful conclusions.

Are More RCTs the Answer?
The RCT remains the gold standard for evaluating the clinical benefit of any particular intervention primarily because it reduces bias from known or unknown confounders. RCTs, for example, have established the clear benefit of carotid endarterectomy over medical treatment for hemodynamically significant carotid stenosis. Traditional RCTs might be unlikely to provide answers for many current questions that involve neurosurgeons because the comparative treatment options are not always testing a medical hypothesis. Rather, they are comparing two valid treatment options whose outcome depends more upon patient-specific factors and technical factors that can be highly variable. Randomized studies generally require homogeneous clinical populations that are often a very select group, and therefore results from these carefully defined populations might limit generalizability. Patient crossover has also been shown to limit the power of the RCT, as shown in the SPORT trials where up to 40% of patients did not comply with their randomized assignment. In the SPORT trials, the treatment groups as treated were not comparable at baseline. Most clinicians feel that SPORT did not provide data to guide clinical practice. Perhaps we should ask if CER is the answer for evaluating neurosurgical problems where patient heterogeneity is the norm.

Modern Prospective Registries and Comparative Effectiveness
CER in contrast to the traditional RCT aims to assess the actual effectiveness of a medical test or intervention. That is, by design, it includes all or most patients with a particular condition to be studied, and it therefore might improve generalizability. The heterogeneity among patient populations might limit the power of CER studies to detect meaningful differences, although CER studies that show non-inferiority might be equally valuable as those that show superiority—again, because the results represent actual practice and therefore actual effectiveness.

Advanced Technology and Changing Practice Patterns
What might CER look like for a neurosurgical problem and how might it work? Let’s consider ruptured intracranial aneurysms (Figure 1). The International subarachnoid aneurysm trial (ISAT) randomized 2,143 patients at 42 sites in an effort to compare microsurgical clipping to endovascular coiling for the treatment of ruptured intracranial aneurysms. Endovascular coiling was more likely to result in independent survival at one year compared to microsurgical clipping, although the risk of late re-bleeding was higher in the endovascular cohort. As endovascular techniques continue to advance, the re-bleeding risk might reduce. As practice patterns change, the population of patients treated with microsurgical clipping might change and as a result the complication rate may also change. Further RCTs comparing clipping and coiling are
Clinical Heterogeneity and Patient-Reported Outcomes

Let’s now consider a spinal disorder. In any condition where there is significant heterogeneity, it is critical to define a population in which there is clinical equipoise between two or more interventions before conducting a comparative study. Cervical spondylotic myelopathy was designated by the IOM as among the top research priorities for CER. For over 50 years, debate has raged over the approach (Figure 2). There are several options, ventral decompression and fusion, dorsal decompression with fusion, and dorsal decompression without fusion (laminectomy alone or laminoplasty). The heterogeneity of the clinical population has complicated the interpretation of study results in the past including the recent prospective AO Foundation studies. Recent efforts have defined an appropriate and significant population where equipoise between ventral and dorsal approaches appear to exist. This equipoise population now serves as the basis for a comparative effectiveness trial being considered by NIAMS to compare ventral fusion to dorsal fusion. Since patient-reported quality of life outcomes, re-operation rates and complications including C5 palsy and pseudarthrosis will all play a role in defining overall success in these patient populations, a careful study with dedicated study coordinators will be required to ensure the completeness and integrity of the data. A simple claims-based registry would be unlikely to provide answers.

Implications of Comparative Effectiveness Research

One of the major differences in CER compared with other clinical research is that many efforts in this realm will need to involve many stakeholders and will not necessarily be purely investigator-initiated. This means that the agenda of those who design CER studies might be different from physician-scientists. CER could be designed to limit access to expensive health care. CER might be designed to promote changes in healthcare policy.

Although the US government does not plan to make payment decisions based on CER alone, no one can deny the enormous economic pressures to reduce health care costs. If CER demonstrated that two medical interventions were similar in terms of safety and effectiveness but that one treatment was ten times the cost of another, it would be difficult to justify paying for the more expensive treatment as a general rule.

Neurosurgeons cannot afford to sit on the sidelines waiting for CER to define what should be done for back pain, for cervical spondylotic myelopathy, or for cerebrovascular disease. As researchers, we must lead the process for evaluating, treating, and monitoring the conditions that we treat. As neurosurgeons, we must organize ourselves in order to make certain that policy makers and purchasers of health care become familiar with our unique perspectives on which procedure is best for which patients and why.

References:
SECTION NEWS

UPDATE FROM THE AANS/CNS PAIN SECTION EXECUTIVE COUNCIL ON EDUCATION

The AANS/CNS Pain Section Executive Council has been working to enhance continuing medical education as well as education for neurosurgeons in training. We recognize that there is a relatively small group of neurosurgeons with a subspecialty interest in pain, but understand that managing refractory chronic pain is part of the daily duties of most neurosurgeons. In this spirit, we have organized educational activities to cover all the spectra of interests in chronic pain. These curricula have been organized in different formats to specifically optimize a) a resident’s first exposure to the pathophysiology of chronic pain, patient selection and procedure techniques; b) continued medical education and special lectures with topics that are of interest to all neurosurgeons and c) sessions aimed at those with a subspecialty interest in pain.

Biannual Symposia
Every other year our committee organizes a full day symposium on pain that is targeted to appeal to all neurosurgeons and not only those with subspecialty interest. Each of these symposia is organized around a core topic that is selected to be of general neurosurgical interest. For example, our past symposium was on complication avoidance in neurosurgery. These full day events are organized so that the topic is comprehensively reviewed, from disease mechanisms to multidisciplinary evaluation and treatment options. We hope you will be able to attend our next symposium in 2012. We would appreciate suggestions from our colleagues on topics for our next symposia. If you would like to make a suggestion, please contact the current section chairperson, Alon Mogilner, or any member of the executive council.

Residents Education - Didactic Courses
To increase interest in pain management among neurosurgeons in training, breakfast seminars have been organized for the past two years, free to residents and fellows, that teach fundamentals of pain procedures. We hope that as the popularity of these seminars increases, we can transform them into cadaver courses to offer more hands-on experience. Recently, we have partnered with the North American Neuromodulation Society (NANS) to sponsor a one-day comprehensive neurosurgical pain management course for residents and fellows, which was held during the NANS meeting this December. This course included a review of indications for neuromodulatory procedures for pain and theoretical background and procedural training in cadavers, including placement of spinal cord stimulation leads and peripheral nerve stimulation. We received excellent feedback for this activity and plan on organizing more hands-on opportunities in the future.

Oakley Scholarship
The AANS/CNS Pain Section has organized a fund for a fellowship in the memory of Dr. John Oakley. The annual John Oakley Fellowship in Surgical Pain Management will soon be fully-funded. The fellowship will sponsor a senior level neurosurgical resident to travel to an academic institution of choice, other than their home residency training institution, for a period of specialized training in pain neurosurgery. The goal will be to gain in-depth exposure to the surgical management of chronic pain. We anticipate that this will be a good training opportunity for our residents and will ultimately lead to the continued rejuvenation of pain neurosurgery.

Surveys on Pain Training and Pain as a Part of Neurosurgical Practice
The AANS/CNS Pain Section Executive Council is currently conducting an e-mail survey to all society members. We ask you to participate in this anonymous survey, which is critical to provide us with guidance to prepare our future courses and symposia. The survey, which was e-mailed to all members, can be completed in five minutes and is composed of multiple choice questions regarding your training in neurosurgical procedures for pain, current practices, limitations that may prevent you from offering this service to patients in your practice/institution and suggestions for future topics. An optional free-text window will be found at the bottom for any comments or suggestions. We understand that this is one more thing to complete but this is critical for us to better serve Neurosurgery. Your time to participate is greatly appreciated.

Andre Machado, MD, PhD  Alon Y. Mogilner, MD
Repeal the Patient Protection and Affordable Care Act (PPACA)
America’s neurosurgeons strongly support improving our nation’s healthcare system; however, the AANS and the CNS firmly believe that PPACA goes far beyond that which is necessary to fix what is broken with the current healthcare system. Rather than enacting a carefully targeted set of reforms that would improve access to affordable health insurance and redress a number of deplorable insurance practices, the PPACA vastly expands the federal government’s role in healthcare and fails to address significant problems with the current system. The AANS and the CNS urge Congress to repeal PPACA and replace it with common sense reforms. If, however, Congress is unable to repeal the law, the AANS and the CNS urge lawmakers to make changes as outlined below.

Abolish the Independent Payment Advisory Board (IPAB)
Established by PPACA, the IPAB is a 15-member advisory board whose members are appointed by the President and which essentially has no meaningful Congressional oversight protections. The principal responsibility of this board is to cut Medicare spending. Proposed spending cuts automatically go into effect if Congress does not replace the recommendations with cuts of equal magnitude. Congress only has a very short time in which to pass its own proposal – making it a virtual certainty that the board’s recommendations would be adopted. The AANS and the CNS strongly urge repeal of the IPAB because leaving Medicare payment decisions in the hands of an unelected, unaccountable governmental body with minimal congressional oversight will negatively affect timely access to quality neurosurgical care for our nation’s senior citizens and the disabled.

Champion an Improved Medicare Physician Reimbursement System
Year after year, because of Medicare’s flawed sustainable growth rate (SGR) formula, physicians face significant cuts in Medicare reimbursement. And time and time again, Congress intervenes with a short-term “fix” to prevent these steep cuts. Congress needs avoid band-aid solutions for fixing the physician payment system and once and for all replace the Medicare SGR formula with a stable mechanism for reimbursing physicians. A critical component of a new payment system must also allow patients and physicians to privately contract without penalty to either patient or physician. The AANS and the CNS are committed to working with Congress to pass a long-term solution to avert the ongoing payment cuts and identify innovative approaches for reforming the Medicare payment system.

Restructure & Streamline Quality Improvement Programs
While Congress has taken the first steps towards implementing quality improvement programs, the current Physician Quality Reporting System (PQRS – formerly PQRI) needs to be drastically reworked to better incorporate a system for clinical data collection and reporting. A “one-size-fits-all” approach will not result in better patient outcomes. The AANS and the CNS support a pay-for-participation system under which data regarding physician quality are collected in a non-punitive environment and analyzed using accurate risk-adjustment mechanisms; public reporting of data only occurs at the aggregate level and not at the individual level; and physicians receive performance feedback continually and in a timely manner. Congress should rescind the PQRS penalties, reconsider the value-based payment modifier, and streamline the federal quality improvement programs created by PPACA.

Alleviate The Medical Liability Crisis
The AANS and the CNS support legislation to provide common sense, proven, comprehensive medical liability reform. Federal legislation modeled after the laws in California or Texas, which includes reasonable limits on non-economic damages, represents the “gold standard.” The Congressional Budget Office has shown that comprehensive medical liability reform would provide $54 billion in savings to the federal government. Other solutions should be adopted including: (1) Applying the Federal Tort Claims Act to services mandated by the Emergency Medical Treatment and Labor Act; (2) liability protections for physicians who volunteer their services; (3) liability protections for physicians who follow practice guidelines set by their specialties; and (4) clarifying that PPACA did not create any new causes of action.

Continue Progress with Medical Innovations
America has a long tradition of excellence and innovation in patient care and neurosurgeons have been on the cutting edge of these advancements. However, American medical innovation is at serious risk. Policymakers have the opportunity to facilitate innovation or speed its destruction. The Food and Drug Administration (FDA) and the Institute of Medicine are currently examining the FDA’s expedited device approval path, referred to as 510(k), and the FDA has released 70 proposed recommendations, some of which are potentially troublesome. Additionally, the FDA may be considering an overly restrictive “off-label” device policy. Finally, Medicare payment and coverage policy can stifle innovation if it is overly limiting. Approaches such as accountable care organizations, bundling, and not paying for procedures in which new technology is used may seem cost effective in the short run, but if they prohibit the development of safer and better procedures that get patients back to health, work, and activity faster, they may be much more costly in the long run. The AANS and the CNS urge Congress to be vigilant over any measures that would inappropriately increase the regulatory burden for medical device innovation, hurt America’s competitive advantage in healthcare advancements, and delay or deny appropriate care for patients.

Preserve Quality Resident Training & Education
Concerns about resident fatigue must be balanced with the need to adequately train neurosurgical residents and ensure timely access to quality patient care. The AANS and the CNS believe that further reductions in resident work hours will have a negative impact on resident training and education by creating a new generation of surgeons with reduced surgical experience and expertise due to less exposure to complex surgical cases and direct patient care. In addition, adherence to strict work hours can actually lead to increased medical errors due to more frequent patient handoffs, fragmentation and loss of continuity of care. Finally, additional restrictions in resident work hours will significantly increase healthcare costs. The Accreditation Council for Graduate Medical Education (ACGME) is effectively addressing these issues. The AANS and CNS believe that legislation or other regulatory intervention in resident work hours is therefore unnecessary. Furthermore, to ensure the quality of our nation’s medical residents, Congress should maintain Medicare’s current financial support of graduate medical education.

Provide Funding to Preserve and Enhance Access to Trauma & Emergency Care
There are significant gaps in our trauma and emergency healthcare delivery systems, and trauma is the leading killer of Americans under the age of 44. The AANS and the CNS strongly urge Congress to provide the full $24 million for trauma and emergency care regionalization programs, which will support grants to states to improve critically needed state-wide trauma care systems and pilot projects to develop models for regionalizing emergency care. As recommended by the IOM in its groundbreaking 2006 report, “the objective of regionalization is to improve patient outcomes by directing patients to facilities with optimal capabilities for any given type of illness or injury.”

Fund Pediatric Loan Repayment Programs
To address critical shortages of pediatric subspecialty physicians, the Department of Health and Human Services is authorized to establish a loan repayment program for pediatric specialists, including pediatric neurosurgeons, who agree to provide full-time pediatric specialty services for at least two years in areas of the country where there are demonstrated shortages of pediatric specialists. Under this program, the federal government may make payments on the principal and interest of undergraduate, graduate or graduate medical education loans of up to $35,000 a year for each year of service for a maximum of three years. The AANS and the CNS urge Congress to fully fund this program at its authorized amount of $30 million per year for FYs 2010 through 2014.

For More Information Contact:
Adrienne A. Roberts, Senior Manager for Legislative Affairs
AANS/CNS Washington Office
725 15th Street, N.W., Suite 500
Washington, DC 20005
Office: 202-446-2029
Email: aroberts@neurosurgery.org

The American Association of Neurological Surgeons was founded in 1931 and is dedicated to advancing the specialty of neurological surgery in order to promote the highest quality of patient care. The Congress of Neurological Surgeons was founded in 1951 and exists to enhance health and improve lives worldwide through the advancement of education and scientific exchange. The AANS and CNS are the two largest scientific and educational associations for neurosurgical professionals in the world and represent over 4,000 practicing neurosurgeons in the United States. Neurosurgery is the surgical specialty concerned with the prevention, diagnosis, treatment and rehabilitation of disorders that affect the spinal column, spinal cord, brain, and peripheral nerves.
For more than 25 years, Self-Assessment in Neurological Surgery (SANS) has been utilized as a neurosurgical training and examination preparatory tool, as well as a continuing medical education (CME) resource. SANS has been integrated into the maintenance of certification (MOC) process overseen by the American Board of Neurological Surgery (ABNS).

Over the years, SANS has evolved to meet the changing educational needs of neurosurgeons. Neurotrauma specific CME is now required for neurosurgeons in certain states. Obtaining sufficient CME specific to neurotrauma can, however, be a challenge even after attending annual regional and national neurosurgical meetings.

To meet these challenges, SANS now offers a specific neurotrauma module for lifelong learning. The scope of this module includes head injury, spinal injury, critical care and neuroanesthesia. The module is comprised of 100 questions; successful completion awards the subscriber with 10 CME annually. Each of the questions follows typical SANS format, which adheres to NBME requirements but also contains a critique and learning links that facilitate broadening of the user’s knowledge base. Single user and institutional licenses for SANS Neurotrauma are available to meet the diverse educational needs of neurosurgeons.

Completion of the SANS Neurotrauma module represents the work of numerous volunteers. It is impossible in such a forum to acknowledge all the individuals who played a role in this product; however, backgrounds of the question writers included neurosurgery, anesthesia, and critical care physicians. Also, the AANS/CNS Neurotrauma and Critical Care Section played a critical role in the development of this educational product.

We encourage you to subscribe to SANS Neurotrauma today and welcome your comments on this new SANS offering. In addition, recommendations for current or future SANS products are always appreciated.
A 73-year old female who had a VPS placed for NPH one year ago, underwent a single shunt revision (2-months prior at an outside hospital) and now presents with recurrent fevers and return of her NPH symptoms. The path of the distal shunt on AP films was along the course of the transverse and descending colon. This was confirmed with CT scan and patient underwent a bowel repair and subsequent VPS after all cultures cleared in a staged manner.

Submitted by: 
Chengyuan Wu, MD
Thomas Jefferson University Hospital
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