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Where Will We Be in 2065?

Neurosurgery of the FUTURE

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The Congress of Neurological Surgeons exists to enhance health and improve lives worldwide through the advancement of neurosurgical education and scientific exchange.

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EDITOR'S NOTE

Gerald A. Grant, MD

"Any useful statement about the future should at first seem ridiculous."

Jim Dator

Imagine how your practice will evolve over the next 50 years...

Nanobots repair damaged axons after a traumatic brain injury in this hypothetical future. You are able to diagnose a brain tumor prior to recurrence using a peripheral blood draw, and all tumor surgery is done with a laser guided by tumor paint. Home robots diagnose stroke remotely, and vascular nanorobots are injected intra-arterially to break up a thrombus. A medical cure for hydrocephalus makes the days of the "smart shunt" obsolete. Most neurosurgery is done robotically in the MRI suite and controlled from your office. Restorative neurosurgery is also possible with the use of stem cells for neurodegenerative diseases and stroke. Neurosurgery residents—half of whom are female—work a 40-hour week.

Welcome to year 2065!

Based on the incredible progress over the last 50 years, it is surely difficult to predict the next half century. Before we jump ahead to 2065, Dr. Issam Awad, our CNS historian and past CNS President, takes us back to 1969, the year of the 19th Annual CNS Meeting in Boston. We also hear from CNS President Nate Selden, CNS Secretary Alan Scarrow, and our new CEO, Regina Shupak.

Jump on the time machine, and let's catch a glimpse of the future in this issue of *Congress Quarterly* (cnsq).

CONTENTS

PRESIDENT'S MESSAGE

Nathan R. Selden, MD, PhD
President, Congress of Neurological Surgeons

In Latin, a competition is the act of "going out to seek together." Competitors pursue excellence and, by surpassing each other, continually improve. To the ancient Romans, "competition" meant literally to "testify together." Theirs was a testimony of excellence that depended for success on the strength and effort of both competitors.

There are many reasons for neurological surgeons to work together at a national level: pursuing impactful ongoing education, analyzing new information and technology, advocating for resources, and defending our professional identity. At the same time, we need to renew personal friendships with fellow neurosurgeons and share our wisdom about the constantly evolving challenges of modern medicine.

There are equally compelling reasons, at times, for us to compete: to provide the most cutting-edge and innovative education flexibly available to busy neurosurgeons based on their own schedule and needs, to produce the leading journals of neurosurgical science and technique in the world, and to promote a culture of volunteerism unmatched in any specialty.

To do these things well, we rely on a handful of very different professional organizations. Generally speaking, we can divide these into groups responsible for specialty definition and training versus groups responsible for professional membership and lifelong learning (**Figure 1**).

As for every branch of medicine, our specialty definition and training functions depend on a professional board, a residency accreditation body, and a residency directors' organization. The American Board of Neurological Surgery (ABNS) certifies individual neurological surgeons. The neurological surgery residency review committee (RRC) accredits individual residency training programs. Finally, the Society of Neurological Surgeons (SNS) represents training program directors in the formulation of a national curriculum for the specialty.

Each of these specialty definition and training organizations is small, appropriate to their very focused missions. Each is also held to an exceedingly high standard of conflict of interest avoidance, in recognition of their profound influence on training and lifelong practice. None of these three organizations accepts industry funding, which in theory might compromise their independence and objectivity. For example, although a majority of its members are neurosurgeons, the neurological surgery RRC is constituted by, and answers solely to, the Accreditation Council for Graduate Medical Education (ACGME), a national multi-stakeholder organization for educational quality and safety.

By contrast, professional membership and lifelong learning organizations are large, in order to serve the needs of all practicing neurosurgeons. To provide robust educational and membership services, these

Figure 1: Neurosurgical membership and lifelong learning organizations (the CNS and AANS) accept corporate educational grants and sponsorship, while specialty definition and training organizations (the ABNS, ACGME-RRC, and SNS) are separated from outside financial support by a COI "firewall."

organizations also accept industry and philanthropic funding. For example, surgical device companies have a shared interest with professional organizations in safe and high quality use of their technology. They facilitate those shared interests through educational grant funding. Although a potential for conflict of interest exists, it is mitigated through careful regulations and a mutual focus on transparency.

Unlike many medical and surgical disciplines, neurosurgery has more than one major national membership and lifelong learning organization: the Congress of Neurological Surgeons and the American Association of Neurological Surgeons. While the existence of two major neurosurgical organizations may be a historical coincidence, the reason we continue to support and depend on them both most certainly is not.

First of all, in many important national policy making settings, including the American College of Surgeons, the American Medical Association, and various federal regulatory panels, neurosurgery has dual representation. In other settings, such as the influential Council of Medical Specialty Societies, and our own ABNS, we have a diversity of neurosurgical representation by career stage and perspective, better representing the breadth of neurosurgical practice.

One of the most powerful advantages of two national societies is the tremendous volunteer power of two boards of directors. Together, CNS Executive Committee members and AANS directors contribute thousands and thousands of volunteer hours to our specialty each year. This type of innovative and creative energy, if billed as "consulting" services, would

cost literally millions of dollars. The resulting productivity has expanded our influence on American medicine and surgery far beyond the numerical footprint of the specialty.

The CNS and AANS have also adopted contrasting corporate tax structures. The CNS is a not-for-profit 501c3 corporation, focused predominantly on neurosurgical education. The AANS has adopted a 501c6 tax structure, which allows it more flexibility in pursuing certain forms of advocacy. Most importantly, the CNS funds fully 50 percent of the joint CNS and AANS Washington Committee, our primary advocacy body.

The CNS and AANS also collaborate on important educational infrastructure. In 2011, the CNS joined with the SNS, representing residency program directors, to administer 6 regional courses for incoming neurosurgical residents each year. Now in their 5th year, these "Boot Camp" courses enhance professionalism and safety from the beginning of residency for every new resident in the United States, an unprecedented development for any U.S. specialty. The AANS joined this effort, administering a complementary course for junior residents with the SNS, beginning in 2013. For board-certified neurosurgeons participating in Maintenance of Certification (MOC), the CNS provides the Self-Assessment in Neurological Surgery, an online teaching and testing program, for free, while the AANS provides online CME tracking.

In other areas, the two societies' programs complement each other. The CNS has created a center for practice guidelines formulation, which supports guidelines projects from every subspecialty section. CNS-supported guidelines have already been used in many states, for example, to maintain patient access to lumbar spine surgery. At the same time, the AANS launched NeuroPoint Alliance (NPA) to provide patient outcomes registry data also needed to justify high quality spine and brain care. Without both guidelines and outcomes initiatives, our specialty would be severely handicapped in putting surgeons to work on behalf of patients.

The CNS and AANS also compete in other helpful ways, such as putting on the two largest and most influential annual neurosurgical meetings in the world. Through a tradition of friendly, but avid, competition these meetings provide high quality education and are financially sound. The annual meetings also provide hubs for other crucial activities, such as updating equipment, attending business or committee meetings, performing outreach functions, and recruiting. Although many neurosurgeons attend both meetings, anyone can attend at least one meeting a year with coverage from their partners, allowing them to stay current in a complex and rapidly evolving specialty.

The two most prominent neurological surgery journals in the world are the competing CNS journal, *Neurosurgery*®, and the *Journal of Neurosurgery*, owned by the AANS. Both journals are thriving and deliver excellent science that advances the field and improves neurosurgical care around the world. Both journals contribute significant resources, both intellectual and financial, to neurosurgical education. North American neurosurgery is clearly better and stronger for the stewardship of these two journals by our leading membership societies.

Competition between the two societies also breeds efficiency. The total dues for membership in both organizations is similar to single society dues in other major surgical subspecialties. The CNS is particularly proud of the value offered members for relatively modest dues, with $400 of the $600 CNS annual dues supporting a discounted member subscription to *Neurosurgery*® and the CNS' 50 percent participation in the CNS and AANS Washington Committee, the crucial advocacy arm of our specialty.

Figure 2: Two-thirds of the CNS dues go to cover members' subscriptions to *Neurosurgery* and to fund equal participation in the CNS and AANS Washington Committee, our primary national advocacy body. For SANS-MOC participants, CNS dues are a net savings.

Remarkably, the remaining $200 covers everything else our organization does, including the Self-Assessment in Neurological Surgery (SANS); discounted member meetings, live courses, webinars, and online education; CNS international initiatives; CNS publications, including the *Congress Quarterly* and *Clinical Neurosurgery*; and countless other member benefits. In fact, for an ABNS Maintenance of Certification (MOC) participant (whose CNS-SANS subscription is free), the direct dollar value of the journal, Washington Committee contribution, and SANS: MOC *far* exceeds the price of membership (**Figure 2**).

In many areas, such as advocacy, neurosurgery must speak with one voice and pursue common goals together. For example, the CNS and AANS are currently collaborating with the SNS to create an online learning portal, which will organize digital education according to a national curriculum for core neurosurgery. Here again, neurosurgery is leading other specialties because of the cooperative vision of these three "Summit" organizations, with guidance and input from the ABNS and RRC. The CNS welcomes these opportunities for collaboration.

Like almost all of you, I am a proud member of *both* national neurosurgical organizations. I frequently serve on the faculty of the AANS annual meeting and have participated as a member of AANS committees related to outcomes registries. Neurosurgery succeeds when we all do what we can to help our specialty and the patients we serve.

Both the CNS and the AANS have proud and transformative historical legacies, which deserve our loyalty. This year, the CNS celebrates its particular association with Walter E. Dandy, emblematic of innovation, technological creativity, and of course, a certain rebellious streak. Founded in part by young men who learned neurosurgery serving their country in field hospitals during World War II, we have a tradition of resilience, self-determination, and looking towards the future.

The Congress of Neurological Surgeons' mission is "to enhance health and improve lives worldwide through the advancement of neurosurgical education and scientific exchange." We will continue the relentless pursuit of this mission through tradition *and* innovation, cooperation *and* competition.

Issam Awad, MD, MSc, FACS

Constants Among Change

WHAT THE HISTORY OF THE CONGRESS OF NEUROLOGICAL SURGEONS TELLS US ABOUT THE NEXT 50 YEARS

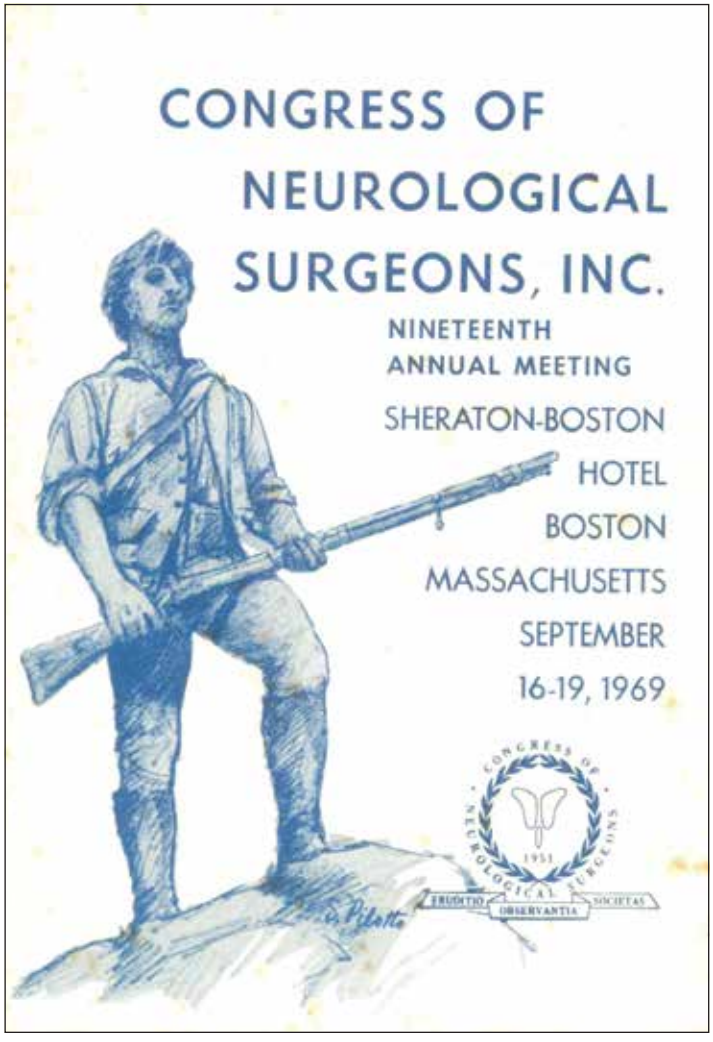

Figure 1: Annual Meeting Logos from 1969 and 2014 meetings in Boston

It has been said that there is no present or future, only history in the making.

The philosopher historian Ibn Khaldun (1332–1406) explained all historical events in the context of human motivation within groups or tribes. Hegel (1770–1831) attempted to find *Reason in History* laying out laws and explanations that shed light on what will unfold in future generations. As neurosurgeons, we are a tribe of sorts, and the history of the Congress of Neurological Surgeons (CNS) provides a rich collection of our contributions and lore for more than six decades. Analysis of early and more recent CNS contributions reveal amazing constants that define a historical personality of sorts, and also affirm a dynamic organization that adapts to changes in science, technology, and societal priorities. Two Annual Meeting logos from the first and most recent CNS meetings in Boston, 45 years apart, reflect the styles of the respective eras, yet show the same human figure leaning forward, embracing a challenge, with courage and prudence, a true personification of the Neurosurgeon we strive to be (**Figure 1**).

A systematic examination of our archives from 1951 through 2015 reveal CNS innovations in a number of areas that are likely to chart our course for the next 50 years. These are outlined as follows, with brief (by no means inclusive) examples.

A Powerhouse of Talent

The CNS founders and early leaders were industrious, talented, diligent, and creative. They came mostly from mid-America rather than the

elite clubs of either coast. They incubated their founding ideas at the Interurban Society in Chicago, but were not initially among the academic leaders of that group. Yet they each ultimately made incredible contributions in their communities as well as in the discipline at large.

A big part of these early leaders' contribution was establishing the organizational structure and processes of the CNS. This founding generation embraced the scientific elite, creating the tradition of the CNS Honored Guest and ambitious star-studded scientific programs. By the mid-1960s, the CNS Executive Committee, the organization's leadership pipeline, began to target academic stars from elite programs as well as the best and brightest young neurosurgeons in private practice.

Beginning in the 1970s, several CNS presidents went on to become presidents of other national and world neurosurgical organizations, and eight achieved the preeminence to be selected as Honored Guest for the Annual Meeting. This brilliant amalgam has ensured incredible creativity and innovation. The ambitious meritocracy and the "young leadership" model will likely continue into the future, with a mix of veterans and novices as well as a balance of insiders and outsiders at the helm of the CNS—a sure recipe for a creative enterprise.[1]

A Packed Scientific Program

From the first CNS Annual Meeting in 1951, the scientific program was meant to be a serious affair. And in each subsequent year we have witnessed a dynamic "raising the bar" with an ever-more impressive showcase of the best, the latest, and the most relevant. No other activity of the CNS has contributed more to its identity and impact. In the earlier years, there were pre-meeting or post-meeting symposia, which further extended the scientific activities. In more recent years, practical courses and evening offerings have added value and options.

Embracing New and Enhanced Technology

The CNS leadership has always leveraged novel technology to help enhance educational offerings and the surgical art. It was the first neurosurgical meeting to televise a live operation to attendees in 1963, and it was the first to compile a World Directory of Neurosurgeons to better reach and connect with practitioners.

In the 1990s, the CNS was the first to implement electronic abstract submissions, and in 2002, the first to offer every meeting attendee an electronic tablet with a preprogrammed meeting calendar and information. Over the last few decades, the Exhibit Hall has grown into a feast that informs and showcases the latest surgical instruments and equipment. In recent years, the CNS embraced the Internet more broadly and deeply, adapting webinar formats and other platforms to enhance educational offerings.

Ambitious Executive Committee Agenda

From its early years, the CNS has refused to limit itself to the business of annual meeting planning. It was the first organization to tackle utilization review, and neurosurgical billing and reimbursement. It launched early taskforces to help influence medicolegal affairs and has played a major role in international outreach, educational policy, and socioeconomic agenda. This breadth of reach has increased in recent years as the CNS has further leveraged its assets on behalf of the profession.

Broad Engagement of Other Organizations

As early as the 1950s, the CNS was a leading force in the assembly of the World Federation of Neurosurgical Societies, and it later strongly supported the Foundation for International Education in Neurological Surgery. In the 1960s it motivated and hosted the first meeting of Presidents of State Neurosurgical Societies (later to evolve into the Council of State Neurosurgical Societies) and joint officers' meetings with the American Association of Neurological Surgeons.

In the 1970s, the CNS played a major role in the founding of the Japanese Congress of Neurological Surgeons, with similar structure and bylaws. It broadened its outreach to neurosurgical societies in Europe, Asia, and Africa in the 1980s and 90s. For the past decade, international activities have been consolidated in a CNS Division with an even more ambitious and far-reaching agenda. For three decades, the CNS has shared the cost and effort of supporting the Washington office, influencing public policy on behalf of our specialty.

Helpful Tools to Members

The CNS logo has proudly embraced numerous projects and documents widely used by our members. CNS publications have found a useful place on neurosurgeons' desks for decades, and more recently on our desktops, smart phones, and tablets. These publications have included the *World Directory, Clinical Neurosurgery, Neurosurgery®, SANS,* and many others. More recent CNS educational offerings have utilized novel media (video streaming, podcasts, etc.) to broaden their reach and enhance their content.

Neurosurgery will continue to change immensely in response to the unfolding revolutions in neuroscience, information, engineering, socio-politics, and economics. In all, the CNS history has been about values and value. These have been imprinted as a double helix in our collective DNA for more than six decades. They will surely maintain a lasting influence on how we tackle the changing world of neurosurgery in the next 50 years and beyond.

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Terry Burns, MD, PhD

Melanie Hayden-Gephart, MD, MAS

THE FUTURE OF NEURO-ONCOLOGY

The neurosurgery training philosophy upholds high expectations for scholarly activity. We require academic programs to contribute to and train our residents in clinical and basic science research, and for good reason. Many malignant neuro-oncological conditions have remained untreatable, or with only marginal improvement in outcomes, over the last several decades. For pediatric brain tumors, improved survival has been achieved only by accepting the price of permanently stunted cognition from radiation and chemotherapy. Fortunately, both for our patients and our own desire to advance the field of neurosurgery, we practice at a time of exponential growth in neuroscience and cancer biology. Paradigm shifts in the management of malignant brain tumors are on the horizon as monumental advances in core basics sciences are channeled to tackle these devastating conditions. We anticipate that the next half-century of scientific discovery will see unprecedented innovation in both the surgical and adjuvant treatment of malignant brain tumors.

Operative methods will continue to build on recent approach advancements (endoscopic assistance), with trends towards decreased invasiveness (sterotactic guided laser thermal ablation) and decreased morbidity (diffusion tensor imaging for white matter tracks). Augmenting nature's biodiversity will enable improved surgical accuracy and precision through fluorescent targeting and guided resection of tumors. Chlorotoxin, derived from scorpion venom,[1] and engineered cystine-knot peptides (knottins), already employed by nature from spider venom to squash plants,[2] will be modified to further improve intraoperative fluorescent-guided resection of intraparenchymal tumors profiled intra-operatively via mass spectroscopy.[3]

Transport vesicles steered by engineered peptides and nanoparticles will accompany tumor-tropic stem cells as vehicles to shuttle therapeutic payloads specifically across the otherwise impenetrable blood-brain barrier. Consequently, many pharmaceuticals previously unsuitable for CNS malignancies due to systemic toxicity or blockage by the blood-brain or blood-tumor barrier may prove quite versatile.

In addition to transport facilitation of drugs, we will be able to activate therapy by light (optogenetics), stereotactic radiosurgery, and/or focused ultrasound. Harnessing nature's biologic innovation will continue to unveil potential for anti-cancer therapy in the same way that studying bacteria in soil may allow for the development of new antibacterials.[4] The immune system's innate ability to regulate cells will be tailored to target infiltrating and malignant tumors—for example, by targeting CD47.[5] Although malignant brain tumors take hold in part by subverting brain microglia into tumor-supportive cells, new strategies to reinvigorate microglial function may help the brain defend against diverse diseases ranging from Alzheimer's disease[6] to glioblastoma.[7]

Genetics has revolutionized the scientific and medical understanding of and approaches to brain tumors. Over the next decades, tumors will be defined not only by their appearance on pathology slides, but also through a routine mutation identification algorithm which will guide operative intervention (outcome-based), medication selection (mutation-specific chemotherapeutics), and radiation (sensitization, timing). This genetic targeting will occur not just at the time of diagnosis but throughout the treatment course through a minimally invasive profiling of the genetic heterogeneity of the malignant brain tumor.

We have already defined the profound heterogeneity of brain tumors at single-cell resolution. Undoubtedly, this innate heterogeneity will contribute to therapeutic failures with molecular therapies—even the "best" single molecular sandbag may not long restrain a heterogeneous flood of tumor-induced alterations. Likely, an upcoming era of molecular polytherapies will be guided by lineage analysis from numerous tumor cells, analyzed on a single-cell basis from each patient. Such tailored molecular cocktails based on a "genome-centric" model will achieve robust effect with minimized side effects by simultaneously targeting (1) upstream initiators of the malignant lineage tree; (2) identified alterations enabling cell-autonomous replication; (3) predicted downstream mutations identified from a vast international database of tumor lineages trees. Indeed, future trials will evaluate the algorithms used to determine the optimal patient-specific cocktails, rather than the individual drugs themselves.

Recent advances in sequencing tumor DNA as circulating tumor markers may make obsolete standard operative procedures such as invasive tumor biopsies. Recently, sequencing fetal-cell-free DNA from a peripheral blood sample of the mother has supplanted amniocentesis to detect Down Syndrome.[8] Similar techniques, applied to tumor-cell-free DNA, have allowed for the tracking of response for treatment of systemic tumors, and brain tumor mutations detectable within cerebral spinal fluid.[9] The application of next-generation sequencing techniques as a research and diagnostic tool will allow for the

tracking of brain tumor mutations as they vary with recurrence and progression of disease, suggesting novel therapies and improving outcomes.

While traditional anti-cancer therapies have focused on anti-proliferative therapies of chemotherapy and radiation, the essentially zero percent cure rate for glioblastoma illustrates the failure of this approach. Slowly dividing quiescent tumor stem cells invariably survive to re-initiate the tumor PMID.[10] Recent advances in stem cell biology have yielded important insights and offer great hope for advancing our management of brain tumors.

First, mechanisms regulating stem cell maintenance and quiescence are increasingly understood. While radiation and chemotherapy will serve a diminishing role in the future, their efficacy will be augmented by concomitant use of agents to tumor stem cell quiescence, thereby rendering them susceptible to ablation. Second, as epitomized by induced pluripotent stem (iPS) cells, stem cell maintenance and function are dictated by epigenetic state. While tumor subgroups are already classified in part by their patterns of gene methylation, future therapies will seek to epigenetically reprogram malignant cells in situ to promote non-malignant behavior and enhance response to therapy.[11] Third, tumors fundamentally result from accumulated genetic damage. Enhanced DNA repair mechanisms and telomere maintenance programs are upregulated in stem cells. Epitomizing this fact, germ cells—the "ultimate" stem cells—successfully pass on a pristine genetic code from generation to generation throughout a species' existence. In the future, mechanisms employed by germ cells to maintain genetic integrity will be harnessed not only to retard the development of additional tumor mutations and heterogeneity, but to forestall the very process of tumorgenesis from endogenous progenitor cells.

Finally, we speculate that a 2065 version of glioma "salvage therapy" will employ highly virulent CNS-tropic self-replicating viruses to simply and unequivocally ablate any and all neuro-ectoderm-derived cells if and whenever they should enter cell cycle. Such an aggressive approach would be a fitting counter to an aggressive disease such as glioblastoma. Although cognitive impacts should result from loss of endogenous neural stem cells and oligodendrocyte progenitor cells, these will be circumvented by either transplant-mediated replacement, in a (i.e., in a manner analogous) manner analogous to bone marrow transplantation, or through regeneration via in situ reprogramming of post-mitotic glia.[12] Critically, such neo-"salvage" approaches will avoid the constellation of premature brain aging, neuro-inflammation, and neurodegenerative-like symptoms induced by the genomic and mitochondrial DNA damage following irradiation and chemotherapy.[13, 14]

The next generations of neurosurgeons will have ever-increasing capacity to safely treat and cure patients with malignant brain tumors. Neurosurgeon-scientists are a critical part of the innovation equation, developing and applying new techniques in collaboration with committed researchers. Our academic commitment in the training of our residents ensures neurosurgeons remain at the center of this conversation for the benefit of our patients and specialty. Modifying nature's design is just one potential method for applying scientific discovery to advance the field of neuro-oncology.

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Praveen Mummaneni, MD Michael Wang, MD

SPINE SURGERY IN 2065

There have been tremendous advances in spinal surgery over the past fifty years. Fifty years ago rigid three-dimensional fixation of the spinal column could not be accomplished, anterior cervical approaches were still being developed, and fracture treatment consisted largely of prolonged bed rest. As recently as the 1990s, residency training in neurosurgery consisted primarily of decompression surgery; instrumentation procedures were limited to trauma and tumor cases, spinal deformity was not on the neurosurgical horizon, and understanding of issues like spinal balance, spinal biomechanics, and bony fusion were rudimentary at best.

Spinal surgery today is far more advanced than it was 25 years ago. We now have the ability to offer surgery to many more patients than we did previously. It was not atypical in the 1990s to tell patients they had a complex spinal problem and there was no surgical solution for it. During residency training in the 1990s we could not imagine offering an operation to a 70-year-old patient debilitated with decompensated kyphoscoliosis or a post-traumatic spinal deformity, for example. Today, medical horizons have expanded enormously with the availability of new and more advanced instrumentation systems.

In the next 50 years, neurosurgeons will need to treat an aging and more active population. It is now not uncommon to see patients working a full-time job well into their 70s and living actively into their 90s. By 2050 the U.S. Census projects that there will be 4.2 million centenarians, and by 2065 the U.S. population forecast is for 500 million people with mean lifespans of nearly 90 years (**Figure 1**). If this population forecast is realized, it will reset the limits of spinal surgery.

Medical treatments for osteoporosis will likely advance to offset the bane of osteoporosis and its related fracture patterns. Diagnosis of spinal pathology will be enhanced with more sophisticated radiology imaging (high tesla MRI and low radiation CT for example). We'll have the ability and the means to view these images on smartphones, smart watches, or monitors anywhere at any time. Typically, the expansion of digital technologies makes their acquisition more affordable over time. For example, during the past decade we have seen the price of LCD televisions drop by over 80 percent. Cost reductions from technological advances will be needed throughout medicine and spinal surgery to make the treatments economical for a larger and aging population.

Furthermore, patient recovery from surgery will become quicker with the implementation of new generations of minimally invasive access pathways and instrumentation designed to limit blood loss and tissue disruption while obtaining decompression and, when needed, spinal fixation and correction of deformity. New biologics will likely enhance spinal fusion in the setting of osteoporosis.

Some have proposed that treatments at the molecular and cellular levels may offset the need for some surgery in the future. While we cannot accurately predict the full impact of such treatments now, encouraging entrepreneurial innovation is important if we hope to see how far current boundaries can be pushed in the next half-century. Non-fusion alternatives for treating degeneration of the intervertebral disc and facet joints would be a welcome addition to our armamentarium and will still likely require the services of spinal surgeons or injection specialists to place biologic therapies in their appropriate anatomic location. However, such treatments, if available, will not eliminate the need for spinal surgery to treat trauma, deformity, tumor, and degenerative disease. The future of spinal surgery is bright, as the next generation of spinal neurosurgeons will undoubtedly translate new technological developments for the improvement of patient care (**Figure 2**).

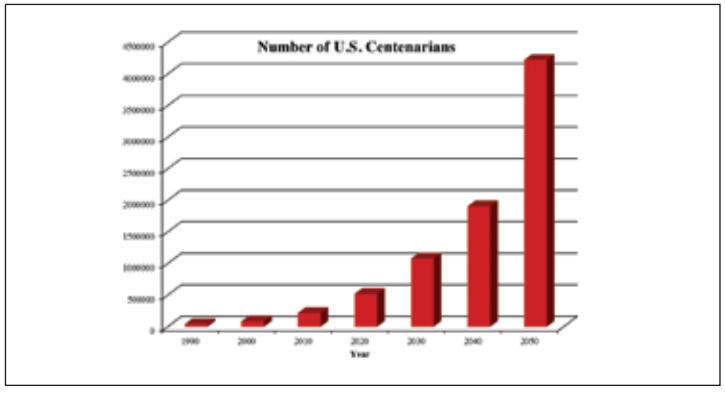

Figure 1: U.S. Census projection of the number of centenarians.

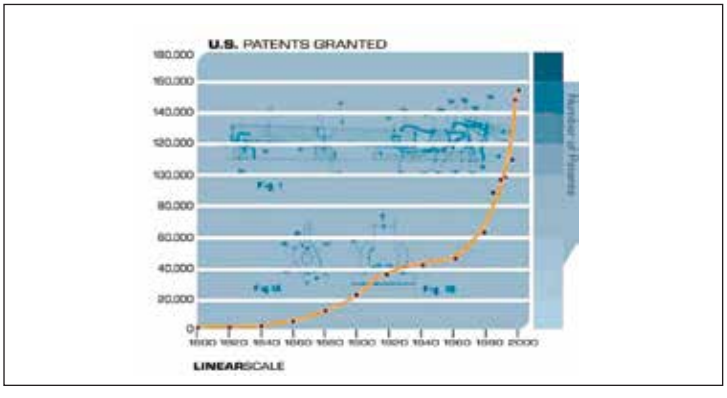

Figure 2: Technological advancement as exemplified by the number of U.S. Patents granted.


Rami J. Aoun, MD, MPH


Bernard R. Bendok, MD, MSCI


Michael B. Bendok


Youssef J. Hamade, MD, MSCI


Kristin Swanson, PhD


Samer G. Zammar, MD

FROM SCIENCE FICTION TO A PLATINUM ERA: VASCULAR NEUROSURGERY IN 2065

Figure 1: The *Fantastic Voyage* (Brit Posters Odeon, 1966)

In Harry Kleiner's 1966 sci-fi movie *Fantastic Voyage*, a band of heroes attempts to save a dying patient's life by navigating a miniaturized submarine through a patient's bloodstream (**Figure 1**). The team on board saves the day by removing a clot located in the patient's brain using an advanced laser weapon. Such a scenario, even in today's world, seems completely implausible. But what once only existed within the realms of science fiction is fast becoming reality as advancements and innovations accelerate on an exponential scale. From artificial intelligence to tablets, laser guns, and vertical airplane takeoffs, what was envisioned in movies and media is now becoming reality per IBM's Watson, Apple's iPad, LaWS (the Navy's new laser weapon system), and the Lockheed Martin Military F-35 Joint Strike Fighter (**Figure 2**).

While challenging to envision, the state of vascular neurosurgery in the year 2065 will likely be shaped by three seemingly disparate forces that have historically fueled innovation. The first is need. Stroke remains the leading cause of disability in North America and a dominant cause of mortality. The onerous impact on society will almost certainly stimulate significant public and private research funding initiatives over the next five decades with resulting incremental enhancements in diagnosis and management. Second is the accelerating rate of innovations unfolding in various fields of health care and the biomedical sciences, including genomics, proteomics, molecular imaging, and bioengineering, to name a few. Third are the current and expected innovations in seemingly unrelated fields including the military, nanotechnology, and space exploration, with an eventual trickle-down effect into medical applications, thus illustrating the "adjacent possible," the concept that one novelty can pave the way for new possibilities through naturally formed networks of meaningful associations that are thematically adjacent.[1]

By 2065, biomarker research from five decades interpreted through elegant mathematical modeling and supercomputing will allow for very precise early disease detection and more refined understanding of disease evolution. The "natural history" for diseases like arteriovenous malformation and aneurysms will be individualized and used to provide patients with very precise recommendations based on a true, patient-specific "crystal ball"—which is fundamentally lacking for neurovascular diseases today. These detection and predictive capabilities will

Figure 2: An aerial photograph of the F-35 in action (Lockheed Martin)

Figure 3: A rendering of a hospital drone delivering medical supplies (The Futures Agency, 2014)

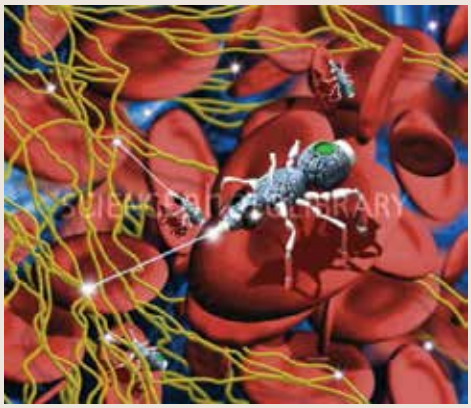

Figure 4: A rendering of a vascular nanorobots breaking up a thrombus with lasers (Victor Habbick Visions/ Science Photo Library)

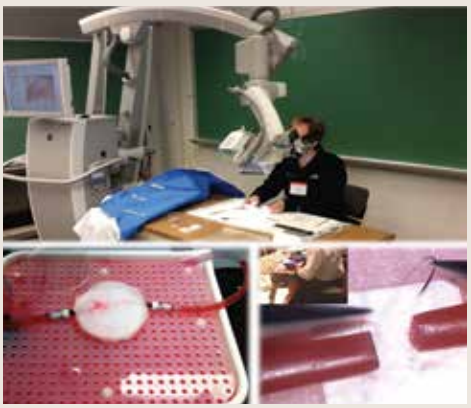

Figure 5: Vascular bypass simulation at 2014 CNS Annual Meeting

enable early therapies before morbid neurovascular diseases and stroke strike.

When these diseases do strike, however, it is likely that an individual's own "home robot" will make the diagnosis and initiate emergency medical services. Moreover, ambulance sirens will not be heard wailing from afar. Instead, mobile diagnostic and therapeutic tools will be flown in by drones equipped with robots that are prepared to stabilize and treat the patient (**Figure 3**). One can envision a team of human physicians working from home or a hospital in a virtual environment in coordination with the drones to make the diagnosis and guide therapy.

It is even plausible that nano-submarines could be injected into the femoral artery, making their way to acutely occluded vessels to deliver therapy or reestablish flow. A craniectomy and/or ventriculostomy could be performed in a mobile operating room operated by robotics to relieve pressure. A spontaneous intracerebral hematoma could be evacuated with image-guided aspiration. In five decades more complex treatments would likely remain centralized, but they will have become much more refined.

By the year 2065, dramatic advances will have likely occurred in the microsurgical, endovascular, and radiosurgical approaches to neurovascular diseases, to a point perhaps of rendering them obsolete in their current form. On the microsurgical front, significant strides will have been made through a combination of sophisticated intraoperative navigation, making tailored cranial and micro-endoscopic approaches safer, allowing greater maneuverability and visualization through minimally invasive procedures. Furthermore, pharmacological advances in cerebral protection and more precise intraoperative monitoring will allow for safer operative processes. Robotics will undoubtedly be a big part of the neurovascular surgical environment.

On the endovascular front, MRI-guided interventions will likely have supplanted fluoroscopic-guided procedures. Moreover, nanotechnology will allow a revolution in devices that can be navigated to the brain without the use of catheters and wires (**Figure 4**). It is also likely that biological therapies will be commonly delivered endovascularly. It is conceivable, for example, that embolic agents for aneurysms and AVMs will be targeted at the biology of the disease itself.

Radiosurgery will likely continue to become more precise. This could be achieved by combining radiosurgery with biological sensitizers that are delivered endovascularly. Furthermore, parent artery reconstruction for atherosclerosis and aneurysms will have become more biologically sophisticated with less need for antiplatelets. And finally, postoperative care will be enhanced by sophisticated neuromonitoring modalities, which incorporate both robotics and advanced brain physiological monitoring. The field of rehabilitation will also be radically different, with brain computer interfaces and robotics restoring function where it has been lost.

Over the next 50 years simulation (**Figure 5**) will evolve to the point of making a simulated operation indistinguishable from a real one. Such an operation would likely be holographic and enabled by computing technology that makes today's technologies appear primitive. This will result in a dramatic enhancement of surgical skills at a younger age. Patient-specific simulation will facilitate more precise device selection, reduce infection and radiation doses, and accelerate research on best surgical and interventional approaches.

From science fiction to reality, human creativity and ingenuity seem to have no boundaries. The next 50 years in vascular neurosurgery will be exciting beyond imagination. Given the exponential explosion of progress in biomedical and non-biomedical sciences and the spirit of ingenuity that marks our current time in human history, it is beyond plausible that we are entering the dawn of a platinum era in vascular neurosurgery that will manifest brilliantly in 2065.

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Jam Ghajar, MD, PhD, FACS

NEUROTRAUMA AND CRITICAL CARE OF THE FUTURE

Looking forward to what neurotrauma care could potentially deliver in 2065 brings to mind what is new in 2015 and what could be imagined in the future, given sufficient time and funding. The following topics explore neurotrauma care from concussion to coma and from prevention to rehabilitation. They by no means cover all the very exciting developments that are currently on the horizon, but rather focus on areas I believe will significantly impact morbidity and mortality.

The recent public interest in concussion and its long-term sequelae have fueled tremendous federal and commercial funding for clinical research that promises solutions not only for traumatic brain injury (TBI) but also for cognitive neuroscience in general.

Concussion selectively disrupts attention, which is the main cognitive impairment following a concussion. What is attention, and how do we pay attention? These are questions that will be answered once we understand the biology of concussion—hopefully much sooner than 2065.

Prevention and Trauma Systems

Cars: Motor vehicle deaths have dropped dramatically since the wide implementation of airbags and seatbelts; however, survivors still have significant TBI. Side airbags and decreasing rotational motion of cars on impact are now appearing in cars.

For 2065 expect driverless cars and an increase in mass transit leading to minimal transportation-related TBI.

Helmets: Helmets prevent scalp and skull fractures but do not prevent concussions, which are caused by rotational forces exaggerated by the flexibility of the neck.

For 2065 expect much smaller profile helmets (to prevent scalp and skull injuries) with integrated neck-sensor-restraint devices to reduce angular acceleration/deceleration.

Trauma systems: Early resuscitation of blood pressure and oxygenation in severe TBI patients is key to improving survival and long-term outcome. Pre-hospital services and regional trauma system organization have contributed significantly to improved outcomes from severe TBI.

For 2065 expect globalization of pre-hospital and integrated trauma systems in a cost-efficient model that is financed by innovative taxation.

> WHAT IS ATTENTION, AND HOW DO WE PAY ATTENTION? THESE ARE QUESTIONS THAT WILL BE ANSWERED ONCE WE UNDERSTAND THE BIOLOGY OF CONCUSSION—HOPEFULLY MUCH SOONER THAN 2065. <

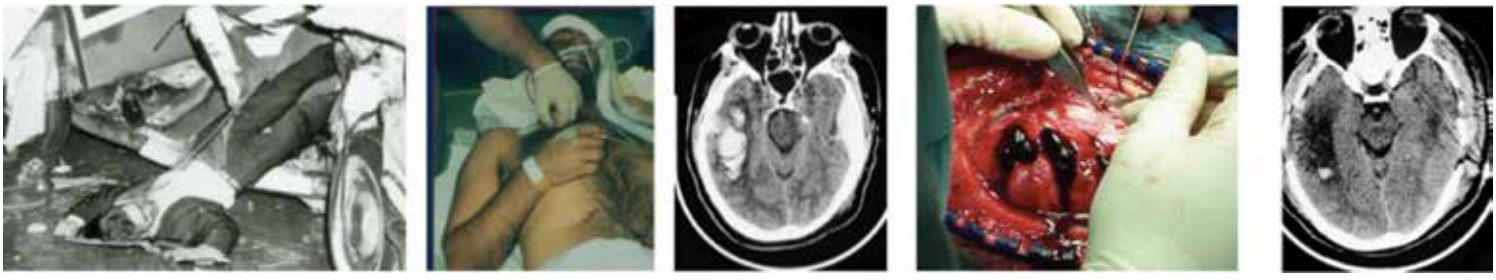

Figure 1: 2015

Brain Resuscitation

In the past, resuscitation of the brain and torso were contrary; "dry the brain" was the mantra, achieved by vigorous hyperventilation, mannitol, and restriction of fluids. Now we know that the brain and body need full resuscitation to reduce ischemia reperfusion syndrome.

For 2065 expect brain-specific resuscitation fluids/pharmaceuticals that ensure oxygenated perfusion, reduce the inflammatory process, and recharge mitochondria.

Biomarkers of Injury

Currently, CT imaging is our only biomarker of acute injury, with MRI used rarely. Research on white matter integrity using MRI diffusion tensor imaging is promising, but involves comparing groups of subjects rather than individual analysis. Unfortunately, the variance in normal anatomy makes determination of "minor" injury problematic without a normative database.

Blood biomarkers derived from glial and neuronal elements are very promising, analogous to cardiac ischemia markers, and can potentially represent the degree, timing, and functional impact of TBI.

For 2065 expect extensive knowledge about "normal" imaging specific to age, gender, and socio-educational status. MRI will be the standard of imaging with auto-standardized comparison to detect abnormalities in anatomy, metabolism, as well as functional networks.

Blood biomarkers will detect minor trauma and give focal-antigen information that combine with other functional markers to determine management and prognosis.

Functional Metrics

GCS is our current metric for functional assessment. It is an excellent and easy-to-use metric for determining arousal status (awake, lethargy, stupor, and coma), but it fails in determining higher cognitive function (it was not designed to do so). Assessing higher cognitive function in concussion is usually focused on attention and those functions dependent on it—working memory, orientation, processing etc. Current cognitive tests have learning effects, are effort-dependent, and are unreliable when used multiple times. In addition, these tests mix the selective attention function with cognitive processing—one has to select 2 and 3 (selective attention) to process the addition of 2+3.

To solely assess selective attention one needs a test that can measure spatial and temporal prediction—the selection of information in dynamic space and time that needs to be processed. Neuromotor analytics can assess this predictive brain state that is operant in selective attention with variance as the key metric. Measurement of eye tracking a predictable moving target or gait analytics on a treadmill are examples of neuromotor analytics that can be used, have little to no learning or effort effects, and are highly reliable.

For 2065 expect head mounted, goggle-based, eye-tracking analytics that can be done in 10 seconds to assess attention, and body-sensor technology to assess other neuromotor variance. Baseline values of neuromotor analytics for individuals will be available for immediate comparison and to evaluate patients for return to work/athletics/school.

ICP and Beyond

The leading cause of death in severe TBI is from intracranial hypertension and systemic hypotension. Controlling early rises in ICP

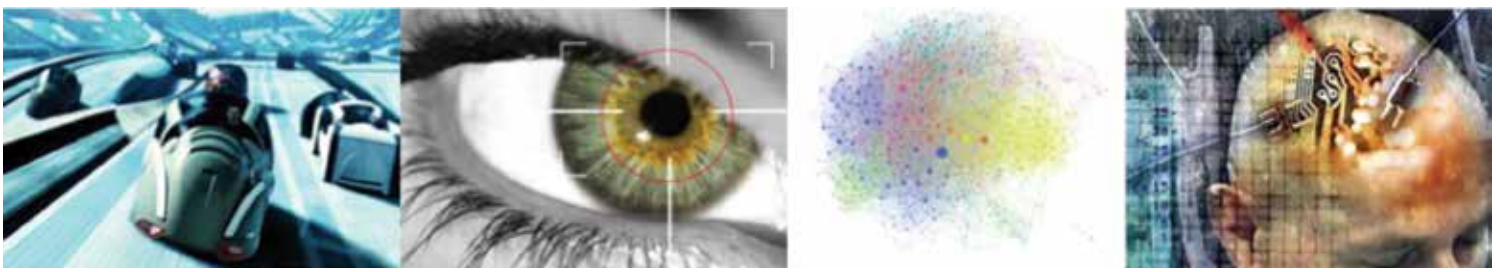

Figure 2: 2065

> FOR 2065 EXPECT ACTIVE, EARLY REHABILITATION OF COGNITIVE AND MOTOR SYNCHRONIZATION IN CONCUSSION AND COMA RECOVERED SUBJECTS USING NEUROMOTOR ANALYTICS WITH AUDITORY, VISUAL, AND TACTILE ONLINE FEEDBACK TECHNIQUES. <

with ventriculostomy and osmotic diuretics while maintaining cerebral perfusion pressure works for 85 percent of patients, but the 15 percent that exhibit severe, uncontrollable ICP are difficult to manage. Lumbar CSF drainage in concert with ventricular CSF drainage has proven very effective in mixed pathology studies (TBI and stroke), dramatically reducing high ICP and maintaining the reduction. Early prophylactic lumbar CSF drainage has not been studied. The reluctance to use lumbar CSF drainage comes from an expectation of cerebral herniation, which is infrequent in published studies and may represent frontal lobe edema pressure on the third nerve rather than herniation.

Blood flow, metabolism, and function are normally linked but can be disrupted in TBI. Direct measurement of these three parameters would be useful in directing therapy. One candidate locus for measurement of these multiple parameters is the ventriculostomy catheter sitting in gray and white matter as well as in the ventricular system, but the ventricular catheter is currently largely used to measure ICP and drain CSF (oxygen, temperature, and parenchymal ICP are available currently). EEG measurement off a ventricular catheter in gray and white matter would be extremely useful to assess seizures, depth of sedation/anesthesia (propofol), and wakening/extubation indications.

For 2065 expect prophylactic lumbar and ventricular CSF drainage and monitoring/management TBI algorithms that use multiparametric ventricular catheter technology containing sensors for cerebral blood flow, oxygen and glucose consumption, and EEG.

Rehabilitation

Early management of concussion involves rest and removal from activities that could produce another injury. This “natural course of recovery” approach is also seen in cognitive rehabilitation for severe TBI survivors. This approach comes from a lack of understanding of the true cognitive deficits in concussion and coma survivors. Motor disorders or sensory disorders are targeted for specific rehabilitation based on measureable deficits, yet cognition has escaped precise measurement and rehabilitation.

The brain has delays in sensorimotor processing yet manages to interact in real time. A major problem for cognition is to anticipate incoming sensory input to process/interact just in time. This predictive brain state is the pre-processing state usually labeled as “selective attention.” The predictive brain state is sub-served by cerebellar, basal ganglia (both involved in timing), and parietal (spatial) areas, which synchronize the individual with the outside world. Both cognition and motor synchronization share these subcortical timers.

Impairments in prediction create an “out of sync” individual, who cannot maintain the normal cadence of interactions—conversations, work, school, sports, driving, etc. The utility of identifying this brain function is that it can be measured and rehabilitated.

For 2065 expect active, early rehabilitation of cognitive and motor synchronization in concussion and coma recovered subjects using neuromotor analytics with auditory, visual, and tactile online feedback techniques. Also direct neuromodulation techniques with transcranial and cranial nerve stimulation will be used to treat TBI-associated depression, anxiety, and attention disorders. <

Samuel R. Browd, MD, PhD, FACS, FAANS, FAAP

PEDIATRIC NEUROSURGERY IN 50 YEARS

What does pediatric neurosurgery look like in 50 years? What advances have been made? Have we cured cancer, eliminated hydrocephalus, eradicated intraoperative infections? As I work to build my academic career around innovation and device development in neurosurgery, it is fun to speculate where our field will move during the next half century as our surgical successors treat our grand- and great-grandchildren.

We are fortunate to be practicing neurosurgery during one of the most exciting times in biomedical technology—ever. New ideas and concepts unthinkable ten years ago are now becoming reality, and innovators are looking for ways to move technological advancements into medical practice. The triple aim of improving the patient experience of care (including quality and satisfaction), improving the health of populations, and reducing the per capita cost of health care will be met through innovation. Precise (or personalized) medicine, big data, standardized clinical and surgical work, and cost-containment will reshape how we practice and provide huge incentives for innovation.

Four key verticals will drive much of the biomedical innovation in the next 50 years: the Internet, computing power, genomics, and additive manufacturing. The evolution of the "Internet of things" will reshape how we practice medicine as the patient-physician relationship becomes closer with monitored implants, virtual and home-based diagnostics, and telemedicine (the house call is coming back). As an example, shunts will become electromechanical devices having auto-diagnostic capabilities, sensing and adjusting to ICP (or flow) and reporting failures prior to the development of symptoms.

Moore's Law has seen computing power increase exponentially since the 1970s, allowing for computing power that doubles every 18 months. Computer processing on this scale allows for advanced diagnostics, applications of big data, and next-generation image processing and display (think real-time virtual reality or remote, robotically driven OR suites).

Recent advances in genomic sciences have been equally amazing, and set up a future where precise, or individualized, medicine is the standard of care. In 2007 it cost upwards of $1 million to map an individual's genome. Now it is a few thousand dollars, and the race to the $100 genome is well underway. Companies now offer limited gene sequencing for $99; *23andMe* is an example of the exploding field of personalized, predictive genomic diagnostics.

Finally, additive manufacturing, including 3D printing, has rapidly evolved in the last few years and is on the verge of a huge paradigm shift in the multi-billion dollar surgical implant industry, a shift that will redefine the current models of hospital purchasing and demand flow.

Fast forward 50 years—Dr. Marty McFly is in his first year of being a pediatric neurosurgery attending. His training is comprised of both real and virtual patients with at least 50 percent of his operative experience done on simulated patients combined with virtual reality and realistic

haptic feedback. He has performed hundreds of pediatric operations—chiari malformations, in utero myelomenigocele closures, posterior fossa tumor resections—and masterfully handled a plethora of complications in virtual reality born from real-world experiences archived and cataloged to a national neurosurgical teaching data repository.

Today Dr. McFly is operating on a four-year-old with a medulloblastoma in the posterior fossa. Preoperatively, many details are already known. Imaging has been performed with advanced MRI. He already knows many specifics of the tumor—the anatomy is defined; he knows exactly where any infiltrating cells reside outside of the main tumor border since he gave an advanced contrast agent that binds specific tumor cell surface markers, and biomarkers such as advanced chemical spectroscopy help refine the likely tumor subtype.

Functional imaging provides a clear assessment of cognition, including specific processing deficits compared to matched controls, and provides a predictive assessment of postoperative function based on planned resection borders. Dr. McFly has uploaded the imaging, has practiced the surgery virtually, and has set the limits of his surgical resection. During surgery the intraoperative navigation will warn him if he is straying outside of his pre-defined plan, operative corridor, or is in danger of harming vital structures.

The day of surgery arrives. The patient is brought into the room, the "time-out" is performed, and the patient's identity and surgery are confirmed using RFID and facial recognition technologies. The patient is anesthetized. We know the exact level of sedation, and monitor cortical, cranial nerve, and spinal cord function with wireless electrodes. A monitoring system is simple and placed by the anesthesiologist, who also monitors the automated diagnostic feedback. Dr. McFly dons his virtual reality goggles and goes to scrub. Scrubbing no longer requires soap and water; UV irradiation sterilizes his skin, and the patient is "prepped" in a similar fashion.

The patient is positioned with a pin-less Mayfield system, and the navigation automatically registers to the patient without additional input. Dr. McFly uses his VR goggles to view the operative field in real-time, using an assortment of cameras directed towards the operative field. He can magnify his field of view at will with voice, gesture, or ocular tracking. Likewise he can view images, his operative plan, or surgical atlases overlaid and warped to the patient's anatomy on demand. His senior partner, on vacation in Hawaii, plans to join him virtually to offer guidance during the case.

Surgery starts with a bloodless opening using a harmonic scalpel; the drill has been supplanted with a device that effortlessly opens the cranium without compromising the dura. Similarly the dura is opened with a simple device that cuts and oversews the edge simultaneously. The operative microscope of 2015 has been replaced by a simple articulated camera that is pointed to the operative field. The camera's robotic arm moves to follow the surgeon's line of sight and utilizes operative navigation to enter the surgical corridor, offering superior magnification and illumination. Dr. McFly operates comfortably with two hands, never needing to readjust the microscope. Similarly the instrumentation he uses is multifaceted. Suction calibers change automatically without the scrub tech intervening, and clogs are automatically detected and cleared. Tumor resection occurs with a device that aspirates and coagulates simultaneously; it is tracked via navigation and samples the aspirate to determine if tumor is present. The patient was injected with "tumor paint" at incision, and the edges of the lesion fluoresce during the surgical resection to guide margins. In real time during the operation, the navigation autocorrects for brain shift, providing sub-millimeter accuracy throughout the case.

A small, intraoperative MRI is brought over the field prior to closure to confirm complete resection. The closure occurs quickly once all bleeding is controlled. Any fine vessels are coagulated with a fine laser beam, and the VR goggles are able to refine the specific location of bleeding based on thermography or other features such as spectral discrimination. The dura is closed with an autosuture device, and any defects are filled with 3D printed or cut synthetic biologics. The template is created during the procedure based on intraoperative topographic measurements of the defect taken with a laser scanner and sent to the sterile printer. The bone flap is replaced and spot welded in strategic locations with instant curing bone cement; the skin is reapproximated and closed with an autosuture device.

The tumor is precisely categorized, and the specific genetic defects are compared to all age-matched patients with the same tumor type worldwide. Big data is used to recommend best treatment recommendations. Prior to initiating treatment, live tumor is tested in vitro against hundreds of chemotherapy options using microfluidic devices, and the most robust combination of medications are given to the patient for precise, individualized treatment after resection. The patient makes a full recovery, and yearly follow up is done via telemedicine, utilizing local imaging facilities, remote diagnostics, and examination surrogates (semi-autonomous robots or smart instruments—ophthalmoscopes, stethoscopes, etc.).

Technology in 2065 has improved the likelihood of a safe and successful surgery. The patient and their family are happy, and we've improved health and reduced overall cost of care. After a productive day in the OR, it's time to head to the 6D cinema, relax, and watch *Back to the Future VII*. (Yes, there still will be movie theaters. Maybe. And sequels? Definitely.)

Disclosures: Dr. Browd is co-founder and chief medical officer of Aqueduct Neurosciences Inc., Aqueduct Critical Care Inc., Navisonics Inc., and Vicis Inc. Dr. Browd is vice president of business development at ThermaNeurosciences Inc.

Chuck Mikell, MD

Guy McKhann II, MD

Sameer A. Sheth, MD, PhD

TOWARDS NEXT-GENERATION DETECTION AND MODULATION OF PATHOLOGICAL NETWORK ACTIVITY

FUNCTIONAL NEUROSURGERY IN 2065

Of the neurosurgical subspecialties, functional neurosurgery is the one that has the greatest potential to become emblematic of scientific progress of the age. Just as the moon landing signified advances in aeronautics in the 1960s, a paralyzed child able to control a wheelchair with a cortical implant may signify the progress of the last decade.[1] In addition to spinal cord injury, restorative neurosurgical therapies are being investigated for a number of devastating diseases, including traumatic brain injury,[2] autism,[3] and Alzheimer's disease.[4] Although our goals are lofty, our current interventional tools are relatively crude. Our electrical stimulation techniques, which have not substantially changed in 30 years, target brain regions but not cell types, and typically lack feedback control. Non-invasive stimulation methods using magnetic or electric fields have limited specificity, especially for deep structures. Functional genetic modulation is still in its infancy. In recognition of this technological gap, development efforts are underway on truly novel interventional strategies, including nanowire electrodes[5] and optical interrogation of brain networks.[6] While these technologies hold promise, *we suggest that the next generation of treatments for functional disorders should require modulation of global brain networks with high spatiotemporal resolution and broad coverage* (**Figure 1**).

Here, we make the case that the arc of neuroscientific progress has been in the direction of increased spatial and temporal precision, and we explore how this work has illuminated our understanding of how brain circuits support behaviors. We discuss how constraints on resolution and coverage have led to the currently available models of the etiology of brain disorders. We then suggest that current terminology (such as "bipolar disorder" or "seizure disorder") can hinder progress by imposing artificial diagnostic categories on highly idiosyncratic functional abnormalities that vary tremendously between individual patients. Finally, we speculate on the tools that will be needed to interrogate and modulate brain networks with the required precision and coverage, an approach that will truly individualize diagnosis and treatment.

As neurosurgeons, we are uniquely positioned to contribute to this technological development by virtue of our access to the brain and our preparedness to capitalize on neuroscience developments to create novel treatments.

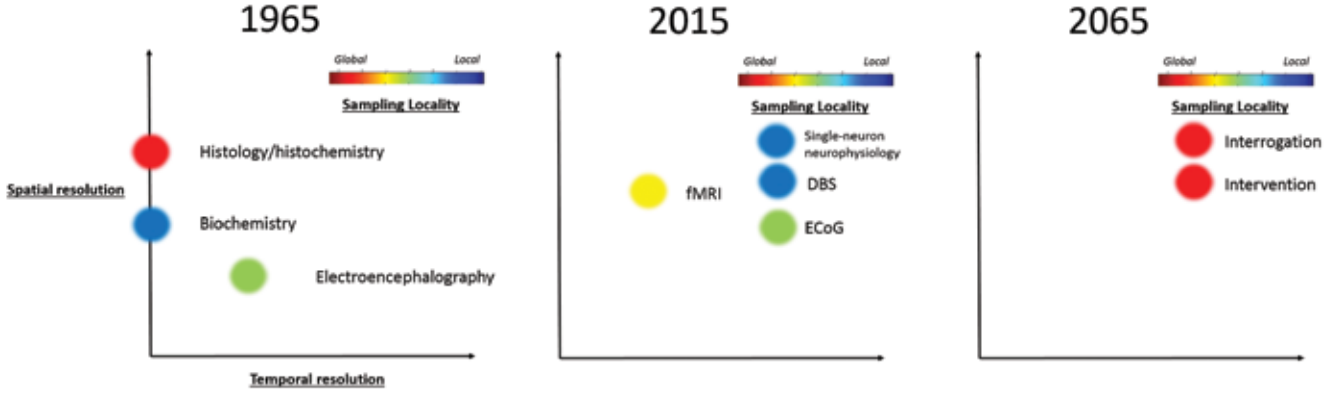

Figure 1: Advances in neuroscience are constrained by spatial and temporal resolution and by locality of sampling. In 1965, postmortem histological and histochemical techniques were available, which had high spatial precision along with global sampling, but essentially no temporal resolution (left panel). Electroencephalography (EEG) allowed for some spatial and temporal resolution, with fairly wide sampling. In 2015, current techniques represent tradeoffs, exemplified by that between fMRI (high spatial resolution, low temporal resolution, global sampling) and single cell recordings (high spatial and temporal resolution, extremely local sampling) (center panel). DBS is essentially a local technique. In 2065, the putative technology may allow for interrogation of brain networks with high spatial and temporal precision, along with global sampling (right panel). Moreover, intervention will hopefully share these characteristics.

Neurosurgeons have a strong track record of translating basic science findings into the clinic, the ICU, and the operating room. Although this review is necessarily speculative, we believe some general themes can be extracted from progress made in previous decades and that these themes can be used to conjecture about where the field is headed.

Advances over the last 50 years have been driven by progress within neurosurgery as well as the broader realms of medicine, psychology, and neuroscience. The etiology of Parkinson's disease is an illustrative example. In the 1950s, it was observed that the blood pressure agent reserpine caused exacerbation of Parkinsonian symptoms by depletion of dopamine;[7] around the same time, histochemical techniques subsequently confirmed that the striatum contained most of the dopamine in the mammalian brain. A crude model of the "extrapyramidal" dopamine system was proposed, in which excess dopamine in the striatum led to hyperkinetic disorders, and decreased dopamine led to Parkinson's disease.[8] The common theme of these observations was their very low spatial and temporal resolution.

A key prediction of this model was soon realized: Walther Birkmayer administered intravenous levodopa to Parkinson's patients, leading to marked improvement of symptoms, and the first rationally designed neurobiological therapy was born.[9] Despite this major advance, the explanatory power of this model was limited, and it lacked the ability to make sophisticated predictions about how dysfunction in dopamine circuits leads to movement dysfunction.

In recent years, neuroimaging and primate single-neuron neurophysiology have enabled more sophisticated interrogation of the dopamine system. These techniques offer major advantages over previous biochemical and histological techniques. Neuroimaging has very high spatial resolution and generally global sampling; however, it has limited simultaneous temporal resolution. Similarly, single cell recordings have high temporal and high spatial resolution but very limited coverage. Nonetheless, these techniques allowed for the development of a more sophisticated model of dopaminergic transmission. In this view, dopamine transmission is segregated into "direct" and "indirect" pathways through the striatum, which promote and inhibit movement, respectively.[10]

Deep brain stimulation of the subthalamic nucleus grew out of a conscious attempt to inhibit the indirect pathway.[11, 12] However, despite its efficacy, DBS is ultimately limited in its effects; it has moderately high spatial precision (brain regions but not cell types) but only the grossest temporal resolution (i.e., the ability to be turned on or off). Although it represents a major advance in the treatment of Parkinson patients, these limitations may be why DBS has thus far had mixed results in the treatment of behavioral disorders.[13]

Behavioral disorders (including neuropsychiatric and developmental disorders) account for a considerable portion of human suffering. Because of their prevalence, they likely represent a major component of the future of functional neurosurgery. For several reasons, however, they have been very difficult to understand in neurobiological terms. First, the need for diagnostic terminology has led to inappropriate "silos" between disorders that mean little to individual patients. For instance, obsessive-compulsive disorder and depression are comorbid in approximately a third of patients.[14] While considerable research has gone into each disease, the fact that so many patients meet criteria for both diseases suggests that the distinction is more fluid than the terminology supposes.

Alternative frameworks have been proposed, most prominently the Research Domain Criteria (RDoC), which proposes diagnosing psychiatric disease on a "matrix" of symptom dimensions, agnostic to current Diagnostic and Statistical Manual-V (DSM-V) terminology.[15] It is hoped that these symptom dimensions will map more easily onto functions known to be supported by individual circuits (e.g., reward valence by the dopamine system). However, even these symptom domains are limited by terminology that may or may not be appropriate, and reflect an understanding of circuits limited by current techniques. For example, the symptom domain called "attention" is likely subserved by numerous circuits that have selectivity for various categories of stimuli, including faces, emotions, environmental cues, language, and so on. As techniques advance for studying the nervous system, these categories may require refocusing.

In the neuroscience of the future, it seems likely that *global* or *brain-wide* networks will be interrogated with techniques that marry *high spatial and temporal resolution*. They would allow for single-subject analysis of how pathological thoughts or behaviors arise from corticothalamic networks (e.g., how a schizophrenia patient comes to believe that the television is sending

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him messages). One current, primitive view is that in patients with schizophrenia, inappropriate dopamine release leads to aberrant salience of sensory input, leading to complex delusion formation.[16] The hoped-for technology would be able to identify the exact brain circuits that attribute salience in the individual patient (high spatial precision) and know when they are working well and when they are misbehaving (high temporal precision). They would not be limited to local sampling of, for instance, the ventral hippocampus, but would have global sampling ability and the ability to identify pathologic circuits from primary sensory cortex through association areas and back to motor output.

In this putative framework, the neurosurgeon of the future would be able to identify and modulate these circuits. His or her techniques would not be limited to local delivery of electrical current or genetic material; rather, the firing rates of large groups of neurons would be able to be modulated with high temporal and spatial accuracy. Healthy percepts would be allowed through, and pathologic ones silenced or repaired. One could imagine a stay in an inpatient unit akin to an epilepsy monitoring unit (EMU), where both behavior and neural activity could be monitored. To extend the epilepsy metaphor, the patient could then undergo definitive treatment when his or her individual pathology is understood, much as an epilepsy patient whose seizures localize to the hippocampus undergoes resection of the temporal lobe. It is obviously hoped that this approach would share the high success rate of epilepsy surgery in this setting.

For that matter, it seems likely that epilepsy will be treated with methods that also exploit high-fidelity techniques. It may be the case that the activity captured by conventional EMU techniques is largely post-synaptic and does not reflect underlying spiking dynamics.[17] Thus, new techniques should be able to identify areas of high neuronal activity with high precision and treat them with methods that might even be noninvasive. As another example, prostheses will likely be much more effective and "human" if they can harness combined information streams from sensory, integrative, and executive networks, not just motor.

While it is difficult to conceive what direction novel therapeutics may take, the future seems to have already arrived with the advent of focused ultrasound[18] and optogenetics in primates.[19] What these seemingly disparate techniques have in common is the ability to modulate neuronal spiking with high spatiotemporal resolution. What they lack is the ability to do so across brain-wide networks, rather than just in certain nodes within the network. Accomplishing the proposed goal requires either the targeted delivery of energy, whether mechanical (ultrasound) or electromagnetic (electrical, magnetic, optical), or else targeted biological transformation (using exogenous genetic material or the body's own tissues). Which of these methods prevail, or whether entirely new approaches emerge, remains to be seen.

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Andre Machado, MD

William S. Rosenberg, MD

PAIN NEUROSURGERY IN 2065

"What we need is more people who specialize in the impossible."

—Theodore Roethke

There is an accident. The patient is brought to the emergency room, injuries are documented, and a severe right-ankle fracture is diagnosed. Along with orthopedic stabilization and rehabilitation, the interdisciplinary pain service is consulted, as it is the standard of care for all significant pain. Genotyping reveals a strong predilection for the development of complex regional pain syndrome; a subclinical diagnosis confirmed by detailed pain phenotyping and functional MRI neuromatrix examination. An urgent microneurostimulation unit (with onboard pulse generator) is deployed percutaneously to the sciatic nerve, and spinal glial genomic modification is performed at the appropriate radicular entry zones. The patient also receives targeted, computer-assisted behavioral training during the healing process to minimize the likelihood of pain chronification. Within the next 50 years, the toolbox of pain care modalities is going to rapidly expand, while the lines of conventional professional responsibility blur into a well-orchestrated clinical choreography centered on the patient. The neurosurgeon can and must be central to this evolution.

The enabling step in advancing pain care will come through improvements in diagnosis and outcome prediction. Fifty years ago, it was thought that pain was caused by the electrical stimulation of specific axons associated with the experience of pain in the brain. Our understanding has progressed quite far from this overly simplistic notion, with the identification of peripheral mechanisms and central circuitry that modulate both the perception of pain as well as its emotional valence.

As more data accrues, a higher level of broad neural processing is becoming apparent, a neuromatrix in which multicentric fluctuations, patterns, and feedback loops account for not only pain and suffering, but perhaps the transition from acute to chronic pain as well. Improved pattern recognition—and hence diagnosis—in this field will lead to more accurate segmentation of patients into specific, homogeneous subgroups, which in turn will result in more personalized treatment on the individual level and higher quality data on the population level.

Augmenting our understanding of the neural meta-architecture of pain will be the ongoing progress in investigations on the opposite end of the spectrum at the subcellular, genomic level. Novel devices, drugs, and interventions will aim at controlling not only how much peripheral pain information is transmitted to the cerebral cortex, but also how cognitive and affective areas may interpret repetitive painful stimuli and avoid mechanisms that lead to chronification. Armed with the ability to more accurately diagnose patients and categorize them into reproducible clinical populations, the neurosurgeon of 2065 will be able to precisely identify the most effective treatment strategy. Patients at risk will receive interventions earlier in the disease process, and patients who do develop chronic pain will be treated with smarter technologies that address not only the signaling of pain but the entire pain experience.

Better segmentation of disease processes for outcome studies will facilitate the rapid technical development we are currently experiencing, ranging from battery technology to computer processor size and speed.

> THE ENABLING STEP IN ADVANCING PAIN CARE WILL COME THROUGH IMPROVEMENTS IN DIAGNOSIS AND OUTCOME PREDICTION. <

> NEUROABLATIVE PROCEDURES, WHICH PREDATE THE INTRODUCTION OF OPIOID ANALGESIA, ARE BEING TRANSFORMED THROUGH THE APPLICATION OF MODERN TECHNICAL ADVANCES INTO CLINICAL POSSIBILITIES WITH MINIMAL, IF ANY, DISRUPTION AND THE POTENTIAL FOR DRAMATIC IMPROVEMENTS IN PATIENT OUTCOMES. <

Ever greater miniaturization, improvements in the means of deploying implants, and a better understanding of electrophysiology will combine to allow more effective, less invasive, and earlier use of neurostimulation throughout the nervous system. Similar improvements in the technology of targeted drug delivery, using not only pharmacological compounds but also gene modifying agents, will both broaden the indications for this intervention and move it earlier in the clinical treatment paradigm.

"What has been will be again, what has been done will be done again; there is nothing new under the sun" (Ecclesiastes 1:9) is an aphorism that is certainly true in the area of neurosurgery specializing in surgical modification of the nervous system's response to pain. Neuroablative procedures, which predate the introduction of opioid analgesia, are being transformed through the application of modern technical advances into clinical possibilities with minimal, if any, disruption and the potential for dramatic improvements in patient outcomes. Nowhere is this more evident than in the treatment of cancer-related pain, an endeavor that requires active participation on the part of the neurosurgeon to be effective. As these procedures become less invasive and incorporate more real-time patient feedback and advanced knowledge of neurophysiological monitoring, their efficacy will mandate close integration into any sophisticated approach to cancer-related pain. Moreover, implementation for non-malignant pain syndromes will become more widespread as the expected outcomes and complications of the modern form of neuroablative procedures are understood.

As we move into a more patient-centered, post-discipline era of medicine, pain care will be delivered by a well-coordinated group of specialists, each bringing wide-ranging expertise, into a merged strategy for treatment. This represents both enormous opportunity and significant risk; Hippocrates was prescient in stating that "timidity betrays want of powers and audacity want of skill." With a solid foundation in neuroanatomy and neurophysiology, a well-honed skill in differential diagnosis, and comprehensive knowledge of the spectrum of possible interventions and their relative merits, the neurosurgeon will move toward a leadership position on the interdisciplinary pain team. Future patients are depending upon our ability to provide a perspective properly balanced between active intervention and the desire to "do no harm," coupled with a crucial empathy for the plight of the one who is suffering.

This bright future notwithstanding, there is a cautionary tale to be heard, a dystopian alternative to consider. Neurosurgery, along with health care delivery in general, is at a crossroads, a juncture that is nowhere more apparent than in the field of pain neurosurgery. Currently, there is little support for the education and nurturing of neurosurgeons interested in pain care. Moreover, there are systemic challenges to reimbursement for technical innovations and lack of coordination of governmental regulatory bodies, with consequent difficulty in bringing novel treatments to the patient in refractory pain. With a deficit in properly trained leaders, a dearth of information on clinical outcomes, and an inability to offer state-of-the-art treatments, the promise of better and more effective treatment for patients in pain can quickly evaporate. To avoid this, organized neurosurgery and its constituents must follow the advice of Ralph Waldo Emerson to "… not go where the path may lead, go instead where there is no path and leave a trail." In 2065, may we have blazed that trail, for the betterment of all those who suffer. <

Sharona Ben-Haim, MD

Julie Pilitsis, MD, PhD

WOMEN IN NEUROSURGERY: PAST, PRESENT, AND FUTURE

During the 1960s, a time of overt gender inequality in the United States, women earned just 59 cents to the male dollar, and pregnancy was a potentially fireable offense. While the feminist movement was beginning to gain traction, women were still systematically excluded from many Ivy League institutions and, in most states, could not serve on juries. In 1965 females represented only 9 percent of U.S. medical school enrollment, and only 7 percent of medical school graduates.[1] Not surprisingly, only two women were board certified in neurosurgery between 1960 and 1969.

While immense strides have been made by women during the past 50 years e.g., laws are now in place to prevent gross gender discrimination, inequality in the workplace still exists. Women now represent nearly half of the U.S. workforce, but still make only 78 cents to the male dollar.[2] They represent 46 percent of all U.S. medical residents, yet only comprise 15.8 percent of all neurosurgical residents and 6 percent of all board-certified neurosurgeons.[3] Recent analysis demonstrates that female residents graduating from 1990 to 1999 were significantly less likely to become board certified than their male colleagues.[4] Along with orthopedics and thoracic surgery, neurosurgery currently trails behind all other specialties, including general surgery, in attracting, retaining, and promoting accomplished women.

This disparity continues at all levels of academic medicine with respect to faculty appointments, promotions, and tenure. There is a striking lack of women in positions of leadership, and women remain underrepresented in professional societies and on editorial boards.[5] There is currently only one female chair of a neurosurgical department, and approximately ten female professors of neurosurgery. Not one of our three major national organizations has had a female neurosurgeon serve as president.

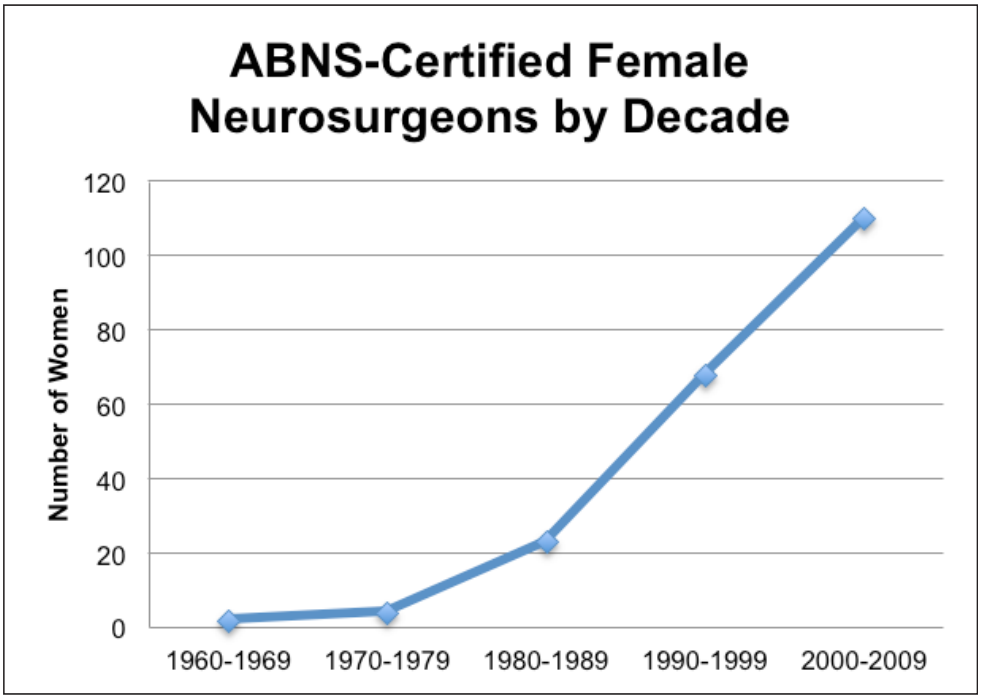

Figure 1: Board-certified female neurosurgeons by decade

Though we have a significant way to go, neurosurgery has seen an exponential growth in the numbers of board-certified female neurosurgeons over the past 50 years (**Figure 1**). We will continue to see the advancement of women in our field, and in society in general, concurrent with changes in the post-industrial workforce during the information age. The future economy will be dependent on knowledge, innovation, and ideas grounded in technological platforms. Social intelligence, communication, team building, and management skills will become increasingly vital to success—traits in which women have traditionally excelled.[6] A new paradigm of thought will emerge, one in which diverse thinking is mandatory for success.

By 2065, with increasingly more successful women in the general workforce, there will be an attendant change in family dynamics

and a resultant transformation of the global workplace culture. We will see a transition to an outcome-oriented rather than a face-time-driven model of success. High-functioning workplaces will emphasize an environment that promotes optimal employee performance. Leaders will require a tailored understanding of how best to motivate and reward their employees, and the social intelligence to understand gender differences in motivation strategies. For example, while men often strive to achieve success through rank and position, women may view success based on the development of meaningful achievements.[7] The leaders of the future will understand how to create workplace value systems that transcend the current "one-size-fits-all" model to effectively stimulate the entire workforce.

Similarly, by 2065 we predict that the neurosurgical training paradigm will shift to a goal-oriented, outcomes-based model, resulting in a more effective and resourceful preparation for neurosurgical practice. Teaching strategies will be tailored to individual learning styles and take place in environments conducive to learning. These strategies will account for potential gender differences in learning as well as differences in the way men and women tend to perceive their performances—with men traditionally overestimating and women underestimating how well they do.[8]

The most successful training programs in 2065 will be the ones that focus on fostering the consistent development of competent, compassionate, and innovative neurosurgeons. Residents trained in these flexible, forward-thinking workplaces will go on to foster similar environments in their careers, thus propagating the cultivation and maintenance of a diverse workforce.

Outside the workplace in 2065, society will look quite different. With the increased workplace flexibility that equality demands, caregiving for children and the elderly will be far more gender neutral. As the societal value placed on care of the family increases over the next 50 years, the 20-hours-per-week discrepancy between the current number of hours academic men and women dedicate to work in the home[9] will be greatly diminished. With the increased number of women in the workforce and a decrease in gender disparity in caregiving and household responsibilities, American society will begin to value the caregiving of family to an equal extent as career success, further propagating gender equality in the home and, subsequently, the workplace.

By 2065, 50 percent of neurosurgical residents will be female, and neurosurgical departments will be well on their way to achieving equality in gender distribution. With an increased number of female mentors and residency programs focused on targeted learning, we will attract the best and brightest individuals, regardless of gender.

The result will be a more balanced and effective workforce, working together to ensure the successful future of our field. With these advances, the next 50 years will see a burst of growth and ideas, allowing for more precisely targeted, safer, and efficient surgical practices. Combined with a greater understanding of the functional circuitry of the human brain, we will set the stage for the rise of a new era of neurosurgical interventions.

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Deborah I. Benzil, MD, FaCS, FaanS

DREAMING THE (IM)POSSIBLE DREAM: EHR'S FUTURE

What do Google, Apple, Nike, and Polar (along with hundreds of tech and gadget start-ups) have in common? All of these astute companies have recognized the potential in "digital medicine" and are looking to create a system or a niche product (think Fitbit) that has or may significantly impact the health of Americans. Despite this rash of forward-thinking companies, the Electronic Medical Record (EMR, also known as EHR—Electronic Health Record) that serves our current health care system is a mess and only getting worse. Therefore, trying to envision how the EMR/EHR of 2065 will look and function for both physicians and patients is quite challenging. Will this electronic system become the creative foundation for innovation, efficiency, improved population health, true outcomes, and value analysis? Or will it continue to be mired in an ever-tighter vortex of regulation and inanity? Let us examine both of these possibilities based on a little history, the current health care policy, and dreaming the (im) possible dream.

Current EHR systems function as they do for several reasons:

1. The software was developed primarily for the business and finance of health care, and as such, less attention was given to physician-friendly applications.
2. When software companies started developing EHR systems, there were no standards or universal foundations precluding common language and interoperability.
3. Software development has been driven exclusively by open-market competition without regard to quality control.
4. The Accountable Care Act has led to a barrage of regulations such as PQRS and Meaningful Use, which has further impacted EHR software and physician use of EHR systems.

> IN SILICON VALLEY AND BEYOND, PEOPLE ARE IMAGINING THE ABILITY FOR INDIVIDUALS TO HAVE A FULLY PORTABLE AND COMPREHENSIVE EHR THAT THEY CAN MAKE AVAILABLE TO ALL PRACTITIONERS INVOLVED IN THEIR CARE. <

EHR technology development and usability has too often excluded physician input. As a result, the adaptation of these business systems for clinical care has resulted in suboptimal systems with severe limitations. These same issues apply equally to the Centers for Medicare and Medicaid Services programs (established with enticing incentives and converting ultimately to punitive penalties).

As outlined in the 2013 summer issue of the CNS *Congress Quarterly* magazine,[1] the most basic wish list for contemporary EHR would include:

1. Privacy: Going beyond confidentiality (HIPAA), data is made available to relevant parties but is protected from abuse by insurers, employers, and others.
2. Universal interoperability: Labs, reports, and imaging are fully interchangeable across locations, practices, and settings.
3. Portability: System is accessible across computer platforms and devices.
4. Queriability: Data can be utilized to support approved clinical research projects.
5. Speed: System can be accessed quickly, easily, and securely.
6. Flexibility: Many agents can contribute different but predictable pieces to a rich, multidimensional canvas.
7. Decision/Management Support: System is embedded with logic and educational materials.
8. Universal Final Chart: System provides safe and comprehensive transmission of information.

Add to this now outdated list the facile incorporation of individual health devices into a patient's EHR system. In Silicon Valley and beyond, people are imagining the ability for individuals to have a fully portable and

comprehensive EHR that they can make available to all practitioners involved in their care. There are also visions of incorporating fitness and diet data into the healthy living components of health care delivery, as well as a simple means of transmitting health moments such as glucose and BP testing, EKGs, and more.

All of these ideas in some way emphasize a few basic concepts. First, they assume a critical need to bring all health care data, whether subjective, objective, physician driven, or patient engendered, under a single umbrella (accepting the information is likely to come from a variety of sources).

This brings us back to 2065 and the EHR. There are two scenarios that seem equally possible.

IMPOSSIBLE: The physician sits forever in front of the computer, trying to manage the enormous volume of data for each patient and the endless government, institutional, and practice-related mandates, still using "fly by the seat of the pants" decision making while the patient feels increasingly disconnected from their physicians, health care, and ultimately their own health.

POSSIBLE: The patient has a fully integrated, absolutely portable, instantly accessible health log that is compatible with all systems used by any of their healthcare providers and institutions. This health record is automatically updated with every pharmacy change, every physician encounter, and every hospitalization. This remarkable record eliminates all mistakes in knowing current medications, family history, etc. The system is seamless and includes HEALTH information (diet, exercise, habits) fully wired with NUDGES (you haven't done any back exercises in five days, you need to see the ophthalmologist in follow up, etc.) with readily accessible health education materials. The system also serves as a powerful research tool for physicians to better understand true value, quality, and outcomes.

I know which system I am hoping for when I reach the age of 105!

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Alan M. Scarrow, MD, JD

NEUROSURGERY: THE NEXT 50 YEARS

If the editor of a neurosurgery journal ever asks you to write an article about predictions for the next 50 years of our specialty, the best answer is "no." It's a fool's errand—particularly in the medical world, where knowledge is accumulated and recorded by experiment and observation. Predictions are for psychics and astrologists. Any thinking person knows that as the world becomes more uncertain and changes more rapidly, predicting the future becomes exceedingly difficult. Even when we are aware of and understand the innovations around us, it is hard to know how they will circulate and trigger changes in unforeseen ways.

Author Steven Johnson notes in *How We Got to Now* that Gutenberg invented movable type printing in the early 1400s, which prompted new readers to recognize they were farsighted, which begat eyeglasses, which led to the microscope, which allowed Robert Hooke to describe cells 200 years later, which paved the way for a revolution in biology and medicine—hardly a set of foreseeable events.

But the human brain is a nonstop prediction machine. It is always trying to figure out what's coming next and craves certainty. So while predicting the future may be the stuff of crystal balls and Ouija boards, perhaps a reasonable task for us non-magic folk is to first try and understand the barriers that keep the future from arriving sooner. What lack of knowledge, technology gaps, economic forces, or regulatory shackles keep us where we are? Those are the types of questions that illuminate the future more than reckless predictions.

A public health professional would likely say that the best-case scenario for our battle against neurologic disease in 2065 would be to simply prevent it from happening in the first place. This would require filling at least two large knowledge gaps. First, we would have to understand the underlying cause for common neurologic conditions like arthritis, tumors, aneurysms, traumatic, and cognitive disorders. Second, we would need to understand the behavioral choices that either cause or contribute to those maladies—and more importantly, we would need to have the ability to influence patient behavior and avoid the inherent risk of those choices. Both knowledge gaps seem immense, but the first may be easier than the second.

> IF WE PRESUME THAT IN 2065 WE WILL UNDERSTAND THE CAUSE OF MOST NEUROLOGIC DISEASE BUT NOT BE ABLE TO PREVENT THEM FROM HAPPENING, WHAT WILL BE THE ROLE OF NEUROSURGERY IN TREATING THOSE MALADIES? <

Two years ago at the CNS Annual Meeting in Chicago, Google's Director of Engineering Ray Kurzweil detailed his oft-noted observation that human knowledge grows exponentially over time, as evidenced by the number of patents, volume of information, and computing capacity. He asserts that human knowledge is now beyond the inflection point of the exponential curve, which will allow us to make extremely rapid improvements in the prevention of disease and significant advancement in life extension.

Whether or not Kurzweil is right about life extension and the prevention of disease, it is clear that our knowledge is growing quite rapidly. Every two days we create as much information as we did from the dawn of civilization up to 2003. Perhaps this is because we have more scientists. The number of working scientists grew from 4.3 million to 6.3 million between 1999 and 2009. And that doesn't include scientists in the entire country of India. Does this mean we will understand the cause of most neurologic disease 50 years from now? The trajectory of knowledge indicates the odds are with us.

But even if we knew what caused neurologic disease, what would we do about it? The struggle of most developed countries to control chronic disease indicates there is great difficulty answering that question. For example, consuming too many calories leads to

obesity, obesity often leads to Type II diabetes, and Type II diabetes leads to all kinds of illness. This is not a secret, and yet it has been nearly impossible to control people's eating habits regardless of culture, race, or ethnicity. It's not that surprising. After all, no matter the language, instructing patients to say "no" to ice cream and expecting it to stick when they are in the privacy of their own home or the anonymity of a restaurant is a fantasy. Clearly we don't always make choices in our best interest, and coming up with ways to influence behavior in politically and economically satisfying terms is daunting.

However, according to *Nudge* authors Richard Thaler and Cass Sunstein, those choices may improve when we gain experience, have good information, and receive prompt feedback. For example, while it is easy for us to choose our favorite ice cream flavor for dessert, it's not so easy choosing between ice cream and fruit (or no dessert at all) when the long-term effects of the choice are slow and the feedback is poor. If there was reliable, immediate feedback about the long-term consequences of choosing ice cream over fruit, we might have a chance. Will we be able to influence our patients in ways that lead to better choices and simultaneously keep their fundamental rights of liberty and privacy? I suspect maybe a little, but it seems very likely we will be dealing with the consequences of poor behavioral choices for a long time to come.

If we presume that in 2065 we will understand the cause of most neurologic disease but not be able to prevent them from happening, what will be the role of neurosurgery in treating those maladies? In part, the answer may lie in our specialty's name. Who would want to have surgery of any sort unless they absolutely had to? Obtaining all the benefits of surgery without having to go through any of the risks of surgery would seem to be a worthy goal. What would we have to overcome from a technological perspective in order to perform "non-invasive surgery"? Imaging would be a prerequisite. In some futuristic "Bones" McCoy way, we must be able to visualize that which we propose to treat, whether degenerative, tumor, traumatic, vascular, or otherwise. Once able to see it, we would need therapies that were small enough to transgress the skin or other natural orifice and attack the disease process. Nanomachines or molecular machines are nouveau instruments that get thrown around as examples of those therapies. Huge investments and advancement in nanotechnology in the past 10 years combined with Kurzweil's exponential growth theory push me to believe that 50 years from now those kinds of technologies would be available. Moreover, as we are able to generate more personalized data about each patient, our ability to tailor individualized therapies seems even more likely. To put an even finer point on it, with these presumably portable diagnostic and miniscule personalized therapies, would there be a need for clinics and hospitals? And to create even more discomfort, would there be a need for people with highly trained eye-hand coordination like, say, surgeons?

This leads to the last big barrier that keeps the future at arm's length. There are economic and regulatory (i.e., ethical and political) realities that may seem tiresome in such a high-minded discussion about the future, but these are the limits we choose to put on ourselves. Sometimes they reflect our priorities, such as spending more for education or defense and less on healthcare. Sometimes they reflect our fears that we will be unable to control the consequences of new ideas, such as genetic enhancement therapies. But whether it's 2015 or 2065, I hope we are just as thoughtful about those issues and that we approach them with honesty, integrity, and all the freedom and clarity of thought they deserve. There should always be important questions like: Will some therapies only be available to those who can afford them? Who will be able to diagnose and provide therapies, and with what education or qualifications? Who will decide when therapies are indicated or futile? And when do individual choices produce too great a burden for the rest of our community?

No matter how much our brains may want to know the future, the inherent limitation of our experience is that we can only imagine it to be some version of the present. In a Western mindset of indefinite optimism, we may want to believe that there are inevitabilities such as the reduction of disease and the ease of suffering that will make our lives and those of our descendants better. But far more common than inevitabilities are the complete surprises—those events we never saw coming because the things we know we don't know are overwhelmed by all the things we don't know we don't know. I think that tiny yet powerful suspicion in each of us—that we have come so far but have so much further to go—is what drives us to get better, to push the boundaries within the small world of what we know and into the vastness of all that is unknown. For in the end, as the great former U.S. President Abraham Lincoln is often quoted as saying, "The best way to predict the future is to create it."

INSIDE THE CNS

CEO's Message

The future depends on what you do today

Regina Shupak

I am honored to serve as the CEO for the Congress of Neurological Surgeons. For the past 16 years, I have had the privilege to work in support of neurosurgery. I continue to be inspired by the specialty, CNS members, corporate partners, Executive Committee, and staff. The Congress of Neurological Surgeons' rich history and pioneering progress in education provide a foundation for my deep commitment to the future of the CNS.

The CNS Scientific Program Committee is developing an innovative program for our 2015 Annual Meeting in New Orleans, September 26-30, which we expect to exceed the success of last fall's meeting—one that featured captivating live surgical presentations, new late-breaking abstract sessions, symposia highlighting breakthrough technologies, controversial topics, and many hot-button issues facing the specialty.

The CNS continues to leverage its novel online learning system and deep catalog of material, bringing critical topics to neurosurgeons with the click of a mouse. The online education site includes a completely revamped version of SANS—the CNS' premiere online product and a staple of written board preparation and MOC.

We are proud that the CNS achieves its unparalleled success with one of the leanest staff organizations and strongest volunteer armies of any surgical specialty society.

But we're not slowing down now.

Neurosurgery is facing an unprecedented number of challenges and pressures today and in the years ahead. The CNS will passionately pursue solutions on your behalf—now and into the future. We are committed to aligning our resources to develop effective solutions to support your needs. The CNS mission is to advance health and improve lives worldwide, and we can only achieve that mission by providing you with the **education, resources, and support you need to improve your practice and patient care.**

As Gandhi once said, "The future depends on what you do today." Your needs and the needs of the specialty are of the highest priority and will continue to be 50 years from now. The CNS is invested in meeting your future needs, and committed to staying the course. Please reach out to the CNS office any time to share your perspective. You are the reason we are here.

CelebrateService
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April 12-18, 2015

To honor National Volunteer Week, April 12-18, the CNS would like to take this opportunity to thank our many volunteers for their time, energy, and commitment to our mission and neurosurgical education.

Thank you for your inspiring dedication and hard work. It is a pleasure and a privilege to work with you.

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IMAGES IN NEUROSURGERY

Anomalous Branches of the Cervical Internal Carotid Artery

Figure 1: A left common carotid bifurcation. In the panel on the left, the superior thyroid artery can be seen rising from the distal common carotid. The occipital artery (marked by an asterisk) is traversed superiorly by hypoglossal nerve, and black suture surrounds the ascending pharyngeal artery. The panel on the right shows the carotid vessels lifted up to show posterior aspect.

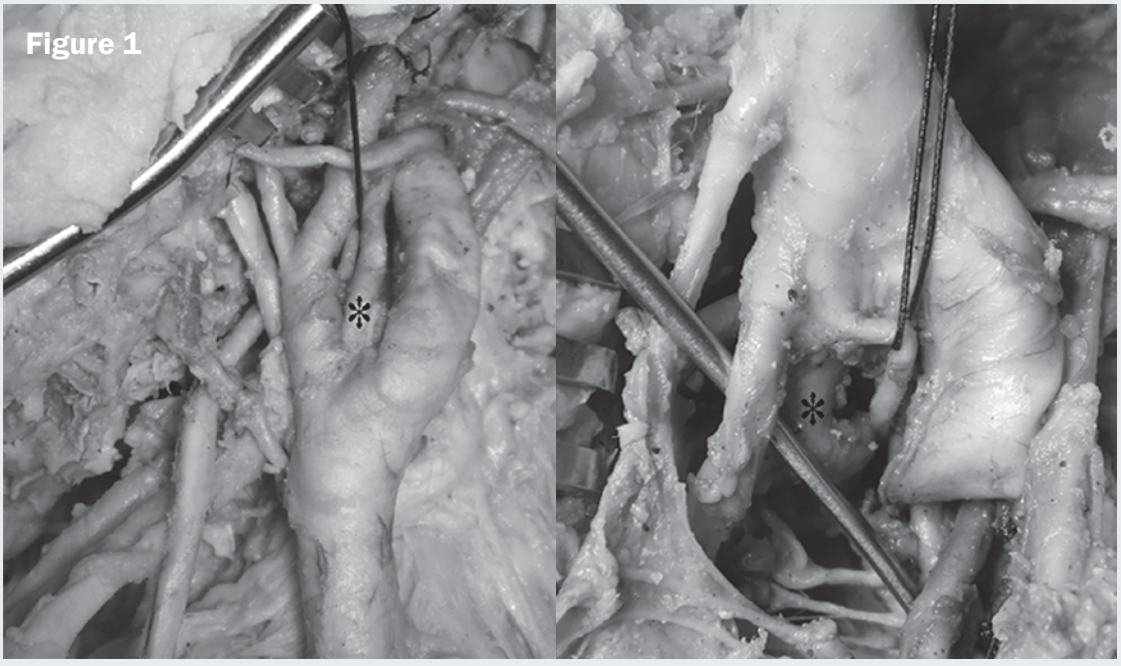
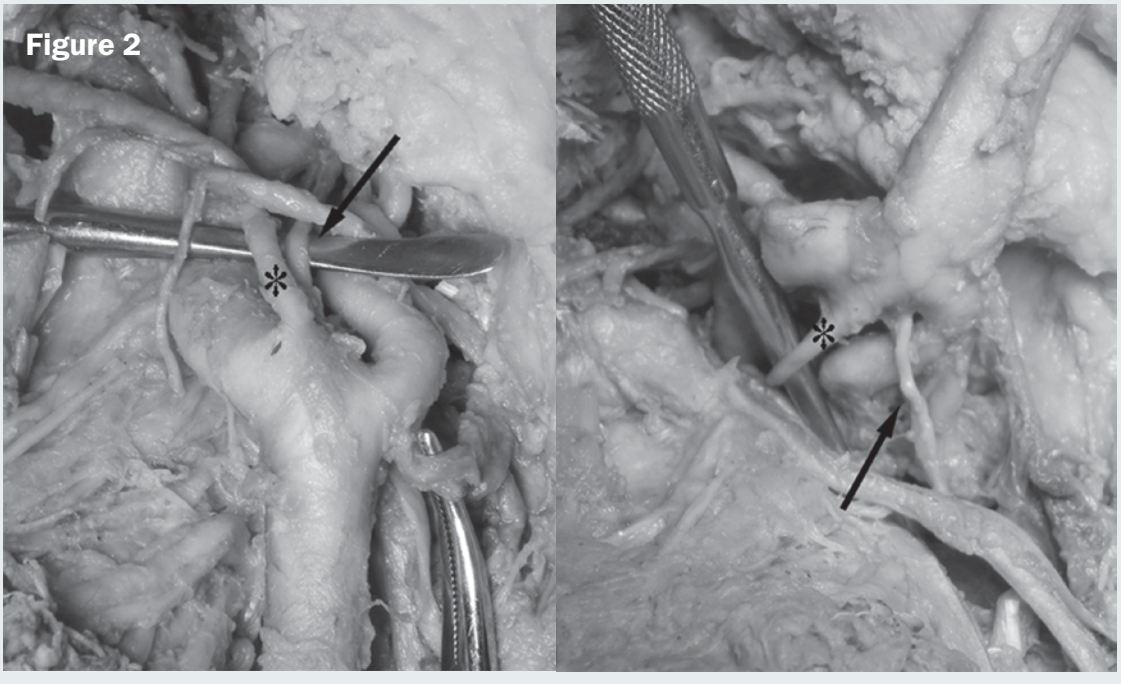


Figure 2: A right common carotid artery shows the occipital artery (marked by asterisks) and the ascending pharyngeal artery (arrows). Both are rising from the internal carotid artery.



Submitted by: **Suresh Ramnath, MBBS, FRCSC**
University of Michigan
Department of Neurosurgery

MasterMind

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- **CONTROVERSY SESSION:** ICH Management: Minimally Invasive to Decompression Craniectomy Surgical Intervention

Tuesday September 29, 2015 2:30–4:00 pm

- **HOT TOPIC:** "Liquid Biopsy": Advancements in Next-Generation Personalized Care for Brain Cancer
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