The Neuroplastic Surgery Fellowship Experience: Where Tradition Meets Innovation

Kerry-Ann S. Mitchell, MD, PhD,† Tamir Shay, MD,‡§ Judy Huang, MD,† Henry Brem, MD,† Paul Manson, MD,|| and Chad R. Gordon, DO, FACS*†*

"If I have seen further, it is because I stand on the shoulders of giants."—Sir Isaac Newton

"Complex procedures are mostly done to improve the quality of life and to prepare patients for a better future in their many years to come."—Mutaz B. Habal, MD

Neuroplastic surgery was born not out of the need to develop a new specialty per se, but to create a formalized multidisciplinary approach to care for adult patients with craniofacial deformities in the era of increasing surgical sub-specialization. It is not surprising that this field was first developed and described at Johns Hopkins University, or that this would be the site of the first fellowship program. Indeed, the first formal surgical residency was established at Johns Hopkins by Dr. William Halsted in 1890. Dr Halsted is credited with training some of the key educators of surgical sub-specialization, including Harvey Cushing and Walter Dandy in neurosurgery, and Samuel Crowe in otolaryngology. In 1905, Dr Harvey Cushing went on to describe the new field of Neurosurgery.[1] In a similar fashion, Milton Edgerton, considered the father of academic plastic surgery, developed the first formal Plastic Surgery Division at Johns Hopkins, building on the legacy of Dr John Staige Davis.[2] In his historical account of plastic surgery at Johns Hopkins, Dr Edgerton stated "the Hopkins environment has always impressed on each member of its faculty, the obligation to break new ground, and use research to advance his or her field of interest." Indeed, it is a privilege to not only train in their footsteps where it all started, but to be at the forefront of this merger of tradition and innovation that created the field of Neuroplastic Surgery.

So, one might ask, why the impetus for a specialized post graduate training program in Neuroplastic Surgery? Does Craniofacial Surgery training not encompass Neuroplastic Surgery? The answer lies in the fact that traditional craniofacial surgery training model has typically been centered around pediatric patient populations. Indeed, Dr Paul Tessier, the father of craniofacial surgery, worked predominantly with pediatric populations to develop procedures for correcting virtually every major orbitocranial malformation in children. The techniques he pioneered became instrumental in the management of craniofacial trauma, tumors, and even aesthetic surgery. The origins of craniofacial surgery as a primarily pediatric subspecialty are reflected in current training programs and practice. Fellowships are typically based at a pediatric facility, and fellows primarily perform pediatric cases. In fact, in a recent study examining case distribution across craniofacial fellowships in the United States, only 10% of programs highlighted adult craniofacial surgery or facial trauma as a unique strength.[3] Although attempts are made to incorporate adult cranial reconstruction in this training paradigm, as one can imagine, this is logistically limited given that most craniofacial fellowship training programs are based in pediatric hospitals. Furthermore, given the breadth of pediatric cases, it makes sense that these cases are prioritized in a primarily pediatric training program. An additional consideration is the previous lack of a formalized multidisciplinary approach between neurosurgery and plastic surgery to care for adult patients undergoing neurosurgical procedures. Thus, the modern-day craniofacial fellow is predominantly trained to work with pediatric populations, with the principles and techniques extrapolated to adult patients. Interestingly, with advances in prenatal diagnosis and obstetrics care, the incidence of congenital craniofacial anomalies, many of which are relatively rare, is decreasing even further over time. This is reflected in the case types emphasized in current craniofacial fellowship training programs, where the majority are focused more on cleft care, general pediatric plastic surgery, and trauma.[3] To our knowledge, there is no craniofacial fellowship program with a major emphasis towards neuro-based skull and scalp reconstruction in adults.

As one can imagine, the adult craniofacial space is considerably different from that of children, including not only the physiological changes that occur with aging, but also pathologic changes such as radiation-induced and repetitive surgery changes. The presence of the frontal sinuses in the adult skull poses a challenge since it increases the risk for infections when violated during craniotomy. The scalp is also different, with possible scars from previous surgeries that alter the vasculature, and comorbidities such as chemotherapy, uncontrolled diabetes, and/or tobacco smoking, all of which impair wound healing. The dura may also be compromised from scarring from previous resection and/or reconstruction with dural substitutes, previous infections, and so forth. As

From the *Section of Neuroplastic and Reconstructive Surgery, Department of Plastic and Reconstructive Surgery, Johns Hopkins University School of Medicine; †Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, MD; ‡Department of Plastic Surgery & Burns, Rabin Medical Center, Petah Tikva; §Tel Aviv University School of Medicine, Tel Aviv, Israel; and ||Department of Plastic and Reconstructive Surgery, Johns Hopkins School of Medicine, Baltimore, MD.

Received September 14, 2020.
Accepted for publication September 22, 2020.

Address correspondence and reprint requests to Chad R. Gordon, DO, FACS, Section of Neuroplastic and Reconstructive Surgery, Departments of Plastic and Reconstructive Surgery & Neurosurgery, Johns Hopkins School of Medicine, JHOC, 8th Floor, 601 N. Caroline St., Baltimore, MD 21287; E-mail: cgordon@jhmi.edu

The authors report no conflicts of interest.
Supplemental digital contents are available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.jcraniofacialsurgery.com).

ISSN: 1049-2275
DOI: 10.1097/SCS.0000000000007201

such, the neuroplastic surgeon must be versed in trilaminar cranial reconstruction – the scalp, the skull, and the dura.

In parallel with the expansion of Plastic and Reconstructive Surgery and the subspecialty Craniofacial Surgery, there have been numerous advances during recent decades in the field of Neurosurgery. Neurosurgical diagnoses that were once considered formidable are now treatable by a variety of mechanisms. Previously unresectable tumors are now being treated with minimally invasive approaches, stereotactic radiosurgery, and adjunctive chemotherapy. Functional disorders such as epilepsy and Parkinson Diseases are now being managed with implanted neuromodulatory devices. Patients with cerebrospinal fluid disorders are able to live out their lifespan through use of shunt technology, as opposed to 30 years ago when the mortality rate of hydrocephalus was over 50%. With these increasing advances, there is an exploding number of adult patients requiring complex scalp-cranial reconstruction, whether from defects resulting from neurosurgical procedures or trauma.

The establishment of the field of Neuroplastic Surgery has led to numerous advances over the years, as illustrated in Figure 1.[4–19] In addition to honing surgical techniques for cranial soft tissue management and refining implant material customizing for cranioplasty, neuroplastic surgery has also shed new light on utilization of the skull space for placement of neurotechnological devices and the evolution of sonolucent cranial implants with transcranioplasty ultrasound.[15,20] Previously, devices were typically placed on top of the skull in the subgaleal or sub-pericranial space, or at remote sites such as the anterior chest. High profile devices under the scalp not only cause a visible and palpable deformity but may also predispose to pressure induced injury on the overlying scalp, with subsequent device exposure and/or extrusion. In recent years, we have demonstrated that neuromodulatory devices, hydrocephalus shunts, and intracranial pressure monitors can all be safely placed in the skull space – by placing the device within a cranial implant that strategically replaces the bone.[12–14] We have also described the first use of sonolucent cranial implants made of clear-colored polymethyl methacrylate in both cadaver and clinical investigation.[15,20] The Neuroplastic Surgery Fellow not only cultivates a surgical acumen for working with complex neurosurgical patients, but also in developing and utilizing novel technology to improve patient outcomes.

An advantage of plastic surgery residency training is the capability of the plastic surgeon to work in all areas and with all tissues of the human body. Trainees learn about the reconstructive ladder, that is, the principle of utilizing locally available tissues for reconstruction, while reserving distant tissues requiring microvascular anastomoses for more challenging defects. They also learn about using different tissue types for flaps and grafts- skin, fascia,

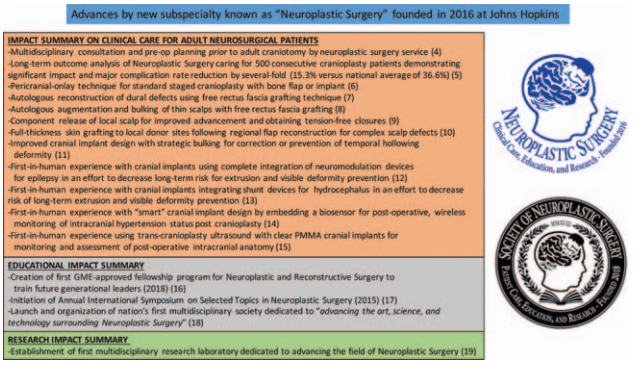

FIGURE 1. A high-level perspective summarizing the major contributions made to date by Neuroplastic Surgery and how the new subspecialty has improved outcomes in adult neurosurgical patients.

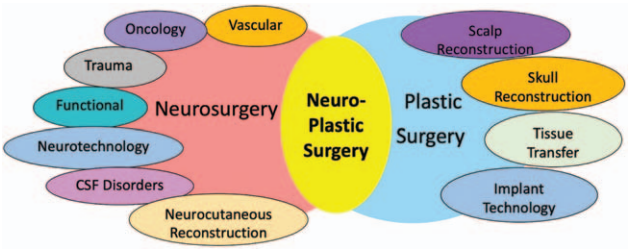

FIGURE 2. Schematic diagram illustrating the multidisciplinary nature of neuroplastic surgery fellowship training, highlighting the external contributions from various specialties.

muscle, blood vessels, cartilage, bone, even intestinal tissue for reconstructing defects. Neuroplastic Surgery fellowship training builds on this unique foundation and provides the opportunity to critically apply this proficiency to caring for adult neurosurgical patients with complex cranial defects, master surgical skills, gain confidence and progressive autonomy, and receive further mentorship before entering independent practice. Figure 2 demonstrates the multidisciplinary facets that are the foundation of neuroplastic surgery training environment.

So, to the potential resident considering a fellowship in Neuroplastic Surgery, how does one decide? First, Neuroplastic Surgery provides an immersive experience at the junction of neurosurgery and plastic surgery, while spanning multiple other fields including biotechnology and engineering.[21] While the majority of cases are performed with a neuroplastic surgeon together with a neurosurgeon, the fellow also operates directly with neurosurgeons, learning the approach to neurosurgical pathologies such as tumor resection, aneurysm clipping, placement of deep brain stimulation leads, hydrocephalus shunt placement, implantation of neuromodulatory devices for seizures, and more. By understanding the neurosurgical approach, the neuroplastic surgeon is better able to foresee areas of possible scalp and skull complications, and work with the neurosurgeon to minimize the risks. This is an integral aspect of neuroplastic surgery fellowship training. Second, in contrast to Craniofacial Surgery, which is an established field with a well-developed foundation for standard of care spanning half a century, Neuroplastic Surgery is a relatively new field with an entire landscape primed for innovation and discovery.

The preliminary clinical research and technological developments in Neuroplastic Surgery represent the tip of the iceberg, with a virtually limitless opportunity to build, expand, and create space to improve quality of life for patients. For example, there continues to be a need for multicenter prospective clinical trials providing level I evidence. Studies to evaluate patient reported outcomes need to be designed, validated, and implemented. Bench to bedside translational studies advancing new cranium-embedded technologies are in the nascent stages, with vast opportunities for expansion. Thus, for the applicant interested in adult scalp-cranial reconstruction, multidisciplinary program building, research and innovation, and novel educational undertakings, neuroplastic surgery fellowship training more than provides the opportunity to build this foundation. As an example, the most recently trained fellow (first author, Dr K. Mitchell) not only performed over 150 cranial reconstruction cases, but also aided in a first-in-human implantation of an intracranial pressure monitor embedded within a cranial implant,[14] a multicenter trial investigating an hydrocephalus shunt device within a cranial implant,[22] as well as design and development of a novel translational animal model of a brain mapping device within a cranial implant (manuscript submitted for publication). This is in addition to presentations at local, national, and international Plastic Surgery and Neurosurgery conferences.

The trajectory of the development of neuroplastic surgery is reminiscent of the relatively new field of urogynecology, otherwise known as Female Pelvic Medicine and Reconstructive Surgery. In the early 1970s, while the other Ob-Gyn subspecialty boards were being formed, there was discussion about forming the subspecialty of urogynecology. However, the general sentiment was that the field was not broad enough to warrant a separate subspecialty.[23] With perseverance from a number of pioneers in the field, urogynecology, subsequently renamed Female Pelvic Medicine and Reconstructive Surgery, is now a specialty recognized by the American Board of Medical Specialties with multiple Accreditation Council for Graduate Medical Education (ACGME)-accredited fellowship training programs.[24] Because of their additional fellowship training and expertise in pelvic conditions, urogynecologists are able to offer the highly specialized care that patients with these conditions require. Interdisciplinary collaboration between gynecologists, urologists, and colorectal surgeons working together has led to numerous advances in both research and clinical practice. Notably, this development took over 40 years to accomplish. (Supplementary Digital Content, Table 1, http://links.lww.com/SCS/C43).

In summary, the field of Neuroplastic Surgery is an actively growing and vibrant new surgical and scientific discipline quite similar to urogynecology, in that it spans a bridge of disciplines and fills a necessary gap.[11,12] There are tremendous opportunities for trainees and junior faculty to make significant contributions to further developing the subspecialty. As the field continues to gain recognition and strength, fellowship-trained neuroplastic surgeons will be uniquely poised to help build university-based centers of excellence, coordinate multidisciplinary care teams, develop relevant clinical and research programs, and ultimately provide important insights into improving outcomes and quality of life for patients with neuroplastic surgery disorders.

ACKNOWLEDGMENT

Dr Mitchell and Dr Shay dedicate this work to all the giants on whose shoulders we stand, and to all the future fellows training in this critical field.

REFERENCES

1. Cushing H. The special field of neurological surgery. Bulletin of the Johns Hopkins Hospital 16:77-87, 1905. *Neurosurgery* 2005;57:1075
2. Santiago GF, Wolff A, Gordon C. Milton Thomas Edgerton: father of academic plastic surgery. *J Craniofac Surg* 2019;30:298–299
3. Patel N, Dittakasem K, Fearon JA. Craniofacial fellowship training: where are we now? *Plast Reconstr Surg* 2015;135:1454–1460
4. Gordon CR, Huang J, Brem H. Neuroplastic surgery. *J Craniofac Surg* 2018;29:4–5
5. Shay T, Belzberg M, Asemota AO, et al. Risk of complications in primary versus revision-type cranioplasty. *J Craniofac Surg* 2020;31:423–427
6. Gordon CR, Fisher M, Liauw J, et al. Multidisciplinary approach for improved outcomes in secondary cranial reconstruction: introducing the pericranial-onlay cranioplasty technique. *Neurosurgery* 2014;10(Suppl 2):179–189
7. Santiago G, Wolff A, Huang J, et al. Dural reconstruction with autologous rectus fascia: a new technique for addressing large-sized defects during cranioplasty. *J Craniofac Surg* 2019;30:326–329
8. Wolff A, Santiago G, Weingart J, et al. Introducing the rectus fascia scalp augmentation technique: a new method for improving scalp durability in cranioplasty reconstruction. *J Craniofac Surg* 2018;29:1733–1736
9. Ibrahim Z, Santiago GF, Huang J, et al. Algorithmic approach to overcome scalp deficiency in the setting of secondary cranial reconstruction. *J Craniofac Surg* 2016;27:229–233
10. Wolff AY, Santiago GF, Belzberg M, et al. Full-thickness skin grafting for local defect coverage following scalp adjacent tissue transfer in the setting of cranioplasty. *J Craniofac Surg* 2019;30:115–119
11. Zhong S, Huang GJ, Susarla SM, et al. Quantitative analysis of dual-purpose, patient-specific craniofacial implants for correction of temporal deformity. *Neurosurgery* 2015;11(Suppl 2):220–229
12. Gordon CR, Santiago GF, Huang J, et al. First in-human experience with complete integration of neuromodulation device within a customized cranial implant. *Oper Neurosurg (Hagerstown)* 2018;15:39–45
13. Gordon CR, Wolff A, Santiago GF, et al. First-in-human experience with integration of a hydrocephalus shunt device within a customized cranial implant. *Oper Neurosurg (Hagerstown)* 2019;17:608–615
14. Mitchell KS, Anderson W, Shay T, et al. First-in-human experience with integration of wireless intracranial pressure monitoring device within a customized cranial implant. *Oper Neurosurg (Hagerstown)* 2020;19:341–350
15. Belzberg M, Shalom NB, Yuhanna E, et al. Sonolucent cranial implants: cadaveric study and clinical findings supporting diagnostic and therapeutic transcranioplasty ultrasound. *J Craniofac Surg* 2019;30:1456–1461
16. Johns Hopkins Medicine. Neuroplastic and Reconstructive Surgery Fellowship. Available at: https://www.hopkinsmedicine.org/plastic_reconstructive_surgery/education/fellowships/neuroplastic_reconstructive_surgery_fellowship.html. Accessed September 10, 2020
17. Wikipedia. Neuroplastic Surgery. Available at: https://en.wikipedia.org/wiki/Neuroplastic_surgery. Accessed September 10, 2020
18. Society of Neuroplastic Surgery. Available at: https://www.snps2018.org/home. Accessed September 10, 2020
19. Neuroplastic Surgery Laboratory. Available at: https://www.snps2018.org/neuroplastic-surgery-lab. Accessed September 10, 2020
20. Belzberg M, Shalom NB, Lu A, et al. Transcranioplasty ultrasound through a sonolucent cranial implant made of polymethyl methacrylate: phantom study comparing ultrasound, computed tomography, and magnetic resonance imaging. *J Craniofac Surg* 2019;30:e626–e629
21. Gordon C. The special field of neuroplastic surgery. *J Craniofac Surg* 2021;32:3–7
22. Mitchell KS, Shay T, Huggins C, et al. Investigation of a valve-agnostic cranial implant for adult hydrocephalus patients requiring ventriculoperitoneal shunting. *J Craniofac Surg* 2020;31:1998–2002
23. Ostergard DR. Reflections on my career as a urogynecologist. *Int Urogynecol J* 2012;23:15–17
24. American Urogynecologic Society. A Timeline of the Development of Urogynecology and Female Pelvic Medicine and Reconstructive Surgery in the US. Available at: https://www.augs.org/about/history/. Accessed September 8, 2020