Roadmap for Successful Research Training in Neurosurgery

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A benchmark of success for the neurosurgeon-scientist includes obtaining individual research funding from the National Institutes of Health. Successful roadmaps to this goal highlight individual commitment and resiliency, innovative research goals, intentional mentoring, protected research time, and financial support. Neurosurgery residents must carefully plan their training career to surmount obstacles such as long clinical training period, gaps in research productivity during clinical training, and limited protected time for research to ensure successful transition to independent research careers. To maximize potential for success as a neurosurgeon-scientist, individuals should have strong research experience on entering residency, choose residency programs that enthusiastically commit to research success among its residents, choose research mentors who will guide them expertly toward a research career, and become well-prepared to apply for research funding during residency. Moreover, individuals who wish to become leaders as neurosurgeon-researchers should seek environments that provide exposure to the widest range of experiences, perspectives, and thinking about medical and research problems.

KEY WORDS: Diversity, Neurosurgery, Physician-scientist, Research training, Residency

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Neurosurgeon-scientists have a unique capacity to inform and translate bench-to-bedside-to-bench research, expediting therapeutic breakthroughs for patients and expanding our understanding of neurophysiology and disease. Individual residency programs, the National Institutes of Health (NIH), and organized neurosurgery have made considerable investments to support the success of future neurosurgeon-scientists. A variety of pathways toward dual clinical-research careers exist, but all depend on individual commitment and resiliency, structured, intentional mentoring, protected research time, and financial support. Here, we detail approaches to be considered by individuals during the medical school, residency, and at the start of junior faculty positions that will help facilitate a successful transition to an independent research career.

ABBREVIATIONS: AVAS, Association of VA Surgeons; **LRP,** Loan Repayment Program; **NIH,** National Institutes of Health; **NINDS,** National Institute of Neurological Disorders and Stroke; **NRCDP,** Neurosurgery Research and Education Foundation; **NREF,** Neurosurgery Research and Education Foundation; **NSTP,** Neurosurgery Scientist Training Program; **PGY,** post graduate year; **USD,** United States Dollars; **VA,** veterans affairs.

BACKGROUND

The purpose of research education programs in Neurosurgery was to educate, prepare, and encourage a diverse group of trainees to become independent physician-scientists. This, in turn, will allow them to investigate the mechanisms of, and develop treatments for, neurological disease. This is achieved through research immersion, under the tailored guidance of engaged mentors, to ensure trainees develop a significant research topic and gain the necessary knowledge, motivation, and preparation to successfully compete for individual research funding that will support continuation of a dual research and clinical career. Early in 2000, concern arose that the number of physician-scientists dwindled despite increases in the total number of practicing physicians.[1] Moreover, surgeon-scientists were 2.5 times less likely than other physician-scientists to apply for NIH funding.[2,3]

Neurosurgeon-scientists are particularly susceptible to attrition from research careers given the length of training, associated debt, demand for clinical productivity, and lack of adequate protected time to develop research skills and experience. Starting in 2009, concerted efforts were undertaken to address the decline in funded neurosurgeon-directed research. Programs such as the National Institute of Neurological Disorders and Stroke (NINDS) Research Education Program (R25) for residents and fellows and the Neurosurgery Research Career Development Award (Neurosurgery Research and Education Foundation [NRCDP] K12) were established to support neurosurgery trainees on a research-oriented academic path. Participants from both programs have a high likelihood of success in obtaining independent NIH research funding.[4] As a result, the number of independent NIH grants and funding to neurosurgeons and to neurosurgery departments has more than doubled.[4,5] Here, we discuss lessons learned from these programs and considerations for individuals who wish to transition to successful careers as clinician-scientists.

EARLY ENGAGEMENT IN RESEARCH

For medically trained individuals who wish to pursue a dual research and clinical career, it is advantageous to have experience in research before residency. Skills required for research are largely different from those gained in clinical training. Moreover, even the most successful research careers are marked by frequent instances of "failure" (failed experiments, technical difficulties, rejected manuscripts, unfunded grant applications, etc.) and thus require individuals to be both deeply committed and highly resilient. Consequently, a strong early experience can be instructive about the depth of one's interest, as well as providing beneficial skills and knowledge. Many medical students complete advanced graduate research degrees or devote 1 or more dedicated research years during or immediately after medical school. Importantly, medical students interested in pursuing a research career should obtain a broad foundation of investigational skills; early research need not be directed toward a neurosurgical focus. Regardless of research subject, strong training in investigational methods, experimental design, rigorous data analysis, and unbiased data interpretation is the cornerstone of making a meaningful contribution to scientific knowledge. Research skills obtained in many areas of study (molecular biology, genomics, bioinformatics, imaging, electrophysiology, computational neuroscience, clinical outcomes, and clinical trials, etc.) can all be applied to many fields of neurosurgery. Engaging in formal, intensive research training during medical school allows for early exposure to the research environment, informs individuals about their interest in pursuing a research career, and may also help a student formulate where a specific research interest may or may not lie (clinical vs basic, technological approaches, etc.).

CHOOSING A RESIDENCY PROGRAM

When considering residency programs, students interested in academic careers should consider residency structure, and importantly, the extent to which long-term research accomplishment is encouraged during residency (Figure 1). If students have a strong desire for a dual career as neurosurgeon-scientist, they should look for residency programs that enthusiastically support research training by providing significant time dedicated to research, strong mentorship (at both the individual mentor and departmental level), financial support for research, and a strong history of government-funded faculty research. Residency applicants should consider the publication and grant productivity of former and current residents and faculty, institutional resources, potential mentors, and the percentage of recent graduates currently in academic practice. One important metric of a department's commitment to research training is the number of graduating residents who subsequently occupy academic positions and have funded research programs. Applicants should become acquainted with the clinical/research goals and orientation of the department, the neurosurgery research training curriculum, the enthusiasm of the program to train neurosurgeon-scientists, and the breadth of research opportunities available. Importantly, applicants should understand whether a significant portion of the departmental NIH funding is to neurosurgeon-scientists or predominantly to nonclinician scientists within the department. Whereas a primary research mentor for an individual may be a PhD scientist, mentorship and guidance from neurosurgeons who successfully balance an active clinical practice with an aligned, NIH-funded research program is invaluable for navigating one's own pathway to success.

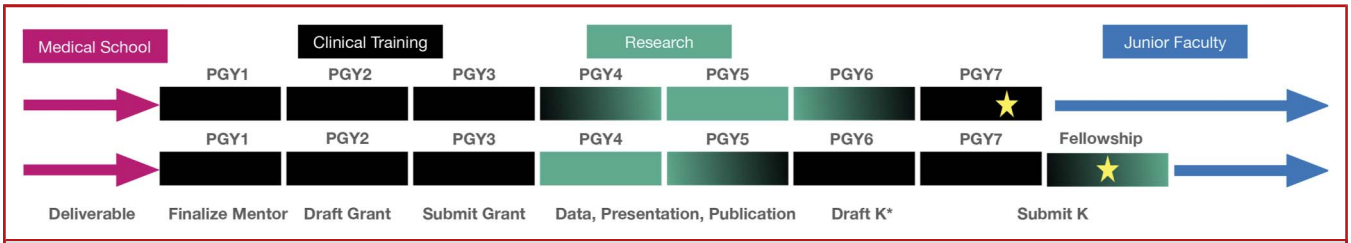

FIGURE 1. *Timeline of example residency structure for protected research training. Neurosurgeon-scientist trainees should have clear expectations of the ideal timeline for mentor identification, data acquisition, and grant submission. A mentored grant (*eg, a K award) should be ready for submission 6 months before the end of the final training year (star). PGY, post graduate year.*

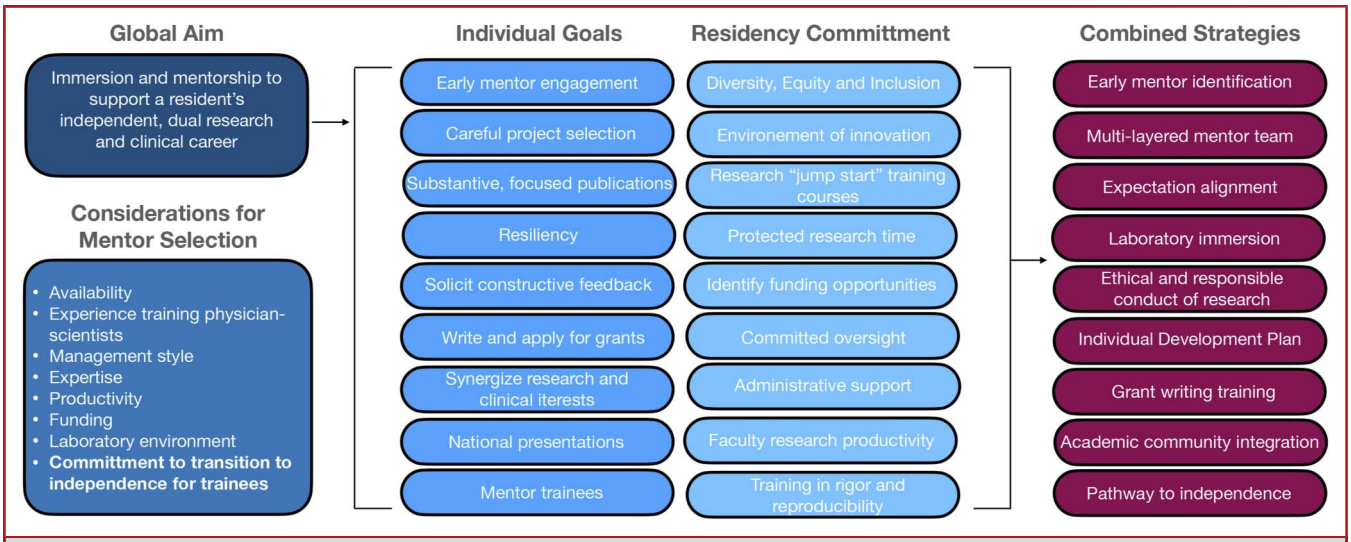

FIGURE 2. *Contributors to neurosurgeon-scientist trainee success. Combined mentor, trainee, and departmental support encourage and retain strong, diverse neurosurgeon-scientists in their transition to independent research and clinical practice.*

Candidates should also strongly consider the diversity of the residency program. Exposure to the broadest thinking and array of perspectives is most conducive to making novel research discoveries and will be available to those who surround themselves with individuals who contain the largest diversity of backgrounds, perspectives, expertise, and experiences. Moreover, training with a diverse set of individuals can provide exposure to clinical and research opportunities that may otherwise stay hidden.

NEUROSURGERY RESIDENCY RESEARCH ROADMAP

General Residency Program Characteristics

To equip residents for success as both physicians and scientists, training pathways in neurosurgery and other medical specialties must provide the necessary balance of clinical and research training.[6] Future success as clinician-scientists will depend on mastery of both clinical neurosurgery and cutting-edge scientific techniques, the generation of preliminary data, publication, and submission of grant applications for funding. Protected, in-depth research exposure during residency is required for an individual to acquire new technical skills, show academic productivity, engage profoundly with mentors, and develop an innovative and achievable individual research project that they will use to launch a funded research program.

Whereas established researchers, similar to clinicians, often have quite narrow specialties, early research training must be sufficiently broad to allow individuals an understanding the many different scientific approaches and technical opportunities that can be brought to bear for understanding neurobiology and treating disease. Moreover, successful development as a neurosurgeon-researcher requires that the residency training program encourages trainees to develop original ideas, immerse themselves in direct investigative study that addresses those ideas, receive strong training in the scientific method (eg, experimental design, statistical methodology, and proper data analysis) and the ethical and responsible conduct of research, and gain proficiency in oral and written scientific presentation. And perhaps most importantly, the success of residents in research depends heavily on strong mentorship that is appropriate for their needs (Figure 2).

Project Development for Launching a Successful Research Career

When considering project scope, it is important to develop a project that will both produce results within the research time allotted and help launch an independent research career. The ability to obtain research funding during training depends on proposing a study that can provide new, important knowledge and can serve as the foundation for additional, highly significant studies. Similarly, when applying for training grants, residents should consider which aspect(s) of research expertise they need to develop. Applicants to mentored awards should have a publication record, even if sparse, achieved before or during residency. Publications are a necessary demonstration of the applicant's commitment to research and ability to pursue a research project to completion. First author publications demonstrate the ability of the applicant to be the leader of the project and are, therefore, favored in grant review. Conversely, too many publications of low impact or unrelated to the primary research focus may draw into question the applicant's focus, relative contribution to the work,

and the depth of an applicant's thinking or commitment to advancing the state of knowledge for a given research problem. Consequently, the limited value of publishing indiscriminate reviews and case reports should be carefully considered in light of the requisite time commitment. Whereas both can strengthen a resident's reputation within their profession, they are generally of little or no value for obtaining research grant funding and can be so time-consuming as to detract from the resident's research effort. From the perspective of obtaining research funding during or subsequent to training, having a few high-quality publications, one or more of which is a first author publication, is far more valuable than having many publications of little intrinsic value.

THE ROLE OF MENTORSHIP

General Principles

Central to a resident's success in research is a deliberate and active mentoring network. This involves coordinated mentorship at all levels, including a clinical mentor, research mentor, Principal Investigator of the research team where the research will take place, residency program director, and department chair. Expectations for an individual research mentor should, at a minimum, include the following 3 criteria: (1) demonstrated success at education, training, and mentoring of research scientists; (2) a substantial recent and/or current history of research funding; and (3) relevance of a potential research project to the understanding and/or treatment of neurological disorders or diseases. When identifying a research mentor and topic, the resident should consider the following related to the mentor: availability, experience training physician-scientists, management style (which will range from close oversight to expectation of independence), training, background, overall productivity, and laboratory environment. The size of a research team, access to the mentor, and overall research atmosphere will vary with each mentor. Importantly, there is no "right" environment for training; successful research training will almost invariably depend on mentors and mentees having expectations that align. It is too often the case that individuals choose a mentor based on a research topic or the mentor's fame, with little consideration given to compatibility of personal and research expectations. The fitness between 2 individuals should be a critical factor, and perhaps the priority, in mentee choice of mentor and mentor acceptance of a mentee into the research environment. Moreover, both mentor and mentee should carefully assess the time available for the mentor to spend individually with the mentee to ensure sufficient guidance.

When constructing a mentorship team, it is important to consider the complementary skills of the mentors and their availability. It is beneficial for the individual mentors to have or develop a strong working relationship with one another (even if not as collaborators) and meet periodically as a group with the trainee. These logistics should be considered and worked out when forming a mentorship team to ensure success.

Meetings With Research Mentor(s)

Successful research training requires frequent consultations between mentor and mentee. Like clinical training, research training requires regular, scheduled discussions of data, problems, challenges, and ideas between a trainee and mentor. Early in the process of developing plans, mentors and mentees must communicate goals and expectations clearly to foster a productive working relationship. In line with expectations of nationally renowned mentors and NIH review, we propose that primary mentors and mentees have, at a minimum, regular weekly calendar appointments, which are used except when unavoidable, such as for travel, vacation, or sickness. Moreover, because science is best performed as a collaboration with frequent exchange of thoughts and ideas, mentees and mentors should make every effort to discuss data and ideas informally as a matter of course, not simply when some urgent need arises. The frequency of meeting with secondary mentors will vary with the role of each mentor and should be determined with the goal of maximum and most expeditious possible success of the trainee. Early on, when a research project is being developed and technical skills considered and being learned, it is best to meet frequently even with secondary mentors. With progress in both knowledge and skill development, it is likely that the frequency of meetings with secondary mentors can be reduced.

Mentees should prepare an agenda in advance of each meeting to promote efficiency of time and maximize meeting usefulness. Research progress should be discussed weekly, and career progression should be discussed at least quarterly. To facilitate both tracking progress and discussion, trainees should prepare written records (eg, in slide form) of their experiments, results, interpretations, and future plans. These records should be well-organized, shared, and cumulative to easily monitor progress and help "course-correct" as needed. Keeping brief "minutes" of meetings that are shared by the mentee with the mentor after each meeting to track discussions and codify action items can be an additional useful tool in confirming a common shared understanding of discussions. The creation of written documents not only memorializes ideas and discussions but also, similar to grant writing, promotes profound evaluation of research data, approaches, and plans; this is well worth the time investment.

Journal Clubs

Residents should strive to participate in regularly scheduled journal clubs, which generally focus on discussion of papers relevant to the participating group's research. Although it is typical for one research team member to present, all should read the article carefully and be prepared in advance to contribute to the discussion. Although biological or technical content usually drive the discussion, these journal clubs have little value unless they include an in-depth examination of experimental design, appropriateness of data analysis, a knowledgeable discussion of statistical approach used (as opposed to simple acceptance of the statistical analysis), and a critical evaluation of data interpretation.

With an emphasis on methodology, trainees can become experts in a breadth of research areas and technologies as well as develop skills in critically reading and interpreting papers. This emphasis will also promote a culture of intellectual exchange among all participants about experimental design and analysis for a wide variety of different types of studies. Moreover, although difficult for many biomedical scientists, routine, in depth discussion of statistical approaches will not only bring to light methodological weaknesses in the research but will also facilitate an increase in understanding of statistical methodology for all participants.

Individual Development Plan

Residents and mentors should have open and honest discussions about the resident's goals and aspirations as a scientist. Some programs and individuals used an Individual Development Plan, which is a planning tool customized for each trainee's developmental stage and goals, to guide discussions between mentor and mentee about the resident's research and training plans. However, it is accomplished; a regular, transparent discussion between mentor and mentee of goals and interests will help guide the development of the research project, the emphasis on technological expertise, and the consideration of appropriate milestones and timeline of achievement.

External Presentations

Trainees should present their research as often as possible at research team meetings, department retreats, and at local and national scientific meetings. Moreover, regardless of forum, presentations should always be as organized and polished as possible. In this way, each presentation will lead to improvement in thought and communication. Importantly, trainees should seek from colleagues, in advance of a formal presentation, critical, constructive feedback. Trainees should welcome, and indeed insist on, highly critical feedback. Such feedback, which should never be given or viewed as personal criticism, promotes the best possible science and improvement in communication.

Practice Mentoring

Strong mentorship is a critical component to developing a strong research culture. Just as all trainees need and desire dedicated mentorship for themselves, trainees should embrace their own role as mentors to others. Consequently, opportunities for mentorship and discussions about mentorship should be integrated into the research career development plan.

Training in Rigor and Reproducibility

We seek to find truths relevant to human disease; flawed experimentation delays and even obstructs scientific progress. Publication of faulty data, analysis, or interpretation wastes the time and money of other investigators who rely on published findings when advancing their own research. More importantly, however, flawed data directly harm patients, many of whom face death or disability in the absence of effective treatments. Viewing the academic demand for productivity in the light of patient clinical need ensures a committed culture of rigor in experimentation and interpretation. Trainees and mentors should use research team meetings to discuss and reinforce critical research practices (eg, scientific method, controls, blinding, consideration of sex and other biological variables, authentication of key resources, and statistical methods), as well as discussing data and literature. A critical tenet of a neurosurgery research culture should be that the sole purpose of conducting research is to benefit the patient, not simply as an intellectual endeavor for the scientist or for any benefit for the institution or faculty researcher.

Grant and Manuscript Writing

Residents should enroll in formal grant writing and scientific writing courses and submit applications for independent fellowships/funding. Grant writing is obviously necessary for obtaining research and training funding. Equally important, however, the act of repeatedly writing a coherent set of hypotheses and experimental plans to address those hypotheses sharpens the trainee's ideas, improves communication of these ideas, and speeds the process of scientific discovery. Even with respect to grant writing, whereas the obvious, immediate benefit to the scientist is the need to obtain research funding, the more global importance is the impact of significant discovery on patient lives and wellbeing that results from rigorous scientific thinking and experimentation.

When a grant application is not funded, it is important that mentor and mentee carefully consider reviewer critiques (when provided). No resident (nor any investigator) should have the expectation that all grant submissions will result in funding. The key to long-term success lies in persistence and an ability of the applicant to use critiques as guidance to improve research approach, communication, or both. If revision and resubmission is an option, investigators who desire a research career should never "give up" after a single, nonfunded application; the ability to respond well to critiques (and constructive criticism), both psychologically and in writing, is an indispensable skill for success as a research scientist.

Funding for Research Training

Neurosurgery residents should seek grant writing mentorship that can provide knowledgeable guidance on all the relevant components of a training grant application: research plan, career development plan, mentorship plan, and institutional support. This is typically the responsibility of a primary mentor, but residents and fellows should seek advice from other faculty who have had success with K awardees as well. Training grant applications are also significantly strengthened when they include personal statements in both the applicant's and all mentor biosketches that provide detailed information specifically relevant to the application. Moreover, for success in obtaining an NIH training award, the resident must have a mentor who demonstrates, through a detailed mentorship plan, a structured commitment to help the resident pursue a successful research career.

TABLE. Example Funding Opportunities for Neurosurgery Resident Trainees

Institute	Funding mechanism	Training level	Amount (USD)[a]	Maximum duration (y)	Comments
Society of Neurological Surgeons	NSTP	Resident	2500, (Y1) 50 000 (Y2)	2	Y1: Travel funding only Y2: competitive extension
NREF	Research Fellowship Grant	Resident	50 000	1	
AVAS	AVAS Resident Research Scholarship	Resident	25 000	1	Faculty mentor with minimum 5/8 VA appointment
NIH	F32	Resident	Stipend for salary, travel	3	100% research time required
NIH	R25	Resident	PGY salary plus travel funds	3	Home institution hosts the R25; 80% research time required
NIH	T32	Resident	Stipend for salary, travel	3	Home institution hosts the T32; 100% research time required
NIH	LRP	Resident	Variable	Variable	Loan repayment
American Association of Neurological Surgeons	Van Wagenen	Junior Faculty	120 000	1	
NIH	KL2	Junior Faculty	120 000	2	Home institution hosts the UL1. Clinical translational research. 50% research time required
NIH	K08/K23	Junior Faculty	~220 000 per year	5	50% research time required
NIH	K12	Junior Faculty	~205 000 per year	2	50% research time required
NREF	Young Clinician Investigator	Junior Faculty	50 000	1	

AVAS, Association of VA Surgeons; LRP, Loan Repayment Program; NIH, National Institutes of Health; NREF, Neurosurgery Research and Education Foundation; NSTP, Neurosurgery Scientist Training Program; PGY, post graduate year; USD, United States Dollars; VA, Veterans Affairs.

[a]Approximate direct costs.

Trainees are encouraged to consult with their mentors and NIH staff regarding the correct research opportunity, funding allocation, and percent research time required. Neurosurgery subspecialty groups, state governmental organizations, disease-focused national organizations, and foundation awards should also be considered.

Research experiences of limited duration and depth are insufficient to positively affect a resident's research career and are unlikely to garner financial support. An ideal research block should be modeled after the highly successful R25 program, consisting of a minimum of 12 months with 80% protected time for research. Ideally, if a resident shows a strong dedication to research, as evidenced by impressive data collection; strong progress toward research publications; and significant intellectual contribution to an original project, departments will develop a plan for continuation of a resident's research, under the resident's ownership and general oversight. Some departments, for example, have committed additional research support while the resident returns to the clinical service to fund a research technician or situation-specific needs to help the resident maintain engagement and continue collection of valuable preliminary data for a K or R01-level award.

Several funding mechanisms are available to support a minimum of a year of full-time (eg, 80% or more) research during residency and/or fellowship (eg, Neurosurgery Research and Education Foundation, NIH R25 and F32, disease foundation grants, and the newly launched Society of Neurological Surgeons Neurosurgery Scientist Training Program; Table). After the initial full-time year of funding, the R25 and Neurosurgery Scientist Training Program, for example, will provide additional research support for individuals who reduce their research effort to 50%.

SUCCESSFUL TRANSITION TO INDEPENDENT NEUROSURGEON-SCIENTIST

As junior faculty, neurosurgeons require continued mentorship on how to balance research careers with clinical demands. Negotiation with the chair of the first faculty position must include discussion of access to shared core resources, laboratory/clinical research space, personnel, initial financial support, and protected

research time. To achieve success as a clinician-researcher, individuals in their first 3–5 years of faculty position should devote at least 50% of full-time professional effort to research (a minimum of 50% is required for NINDS and National Cancer Institute K awards). Ideally, once the faculty position has been secured, the junior faculty member will quickly identify research mentors and refine their research plan, so they will be ready for grant submission within the first faculty year. Indeed, the NRCDP K12 is deliberately set up to promote the development of a research project, career development plan, and mentoring plan as well as requires the generation of a full-size, well-written K application, within 3–4 months of the start of the faculty position.

The NRCDP K12 has, as a key component, an annual meeting for all current and past scholars, new applicants, and other junior faculty applying for their first major grants. Participants meet with their peers, successful clinician-scientists at all levels and chairs; recent meetings have been attended by approximately 70 individuals, including 10 or more neurosurgery chairs at each meeting. All Chief Residents and first-year faculty dedicated to a successful, funded research career are strongly encouraged to become involved in this meeting because it provides a venue for strong mentorship, career advice, and several days of uninterrupted access to peers, senior neurosurgeon researchers, and department chairs who enthusiastically promote research within the neurosurgery community.

CONCLUSION

To have the highest likelihood of success, students and residents interested in a career as neurosurgeon-scientist should be well-prepared, thoughtful, and intentional about their choices of residency programs, mentors, training, and research direction. Both neurosurgery leadership and the NINDS have developed programs to ensure success for those truly dedicated to careers as clinician-scientists.

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