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A Roadmap for Aspiring Surgeon-Scientists in Today's Healthcare Environment

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Abstract

Objective: Surgeon-scientists are an essential component of the field of academic surgery, contributing to the fundamental understanding of disease and the discovery of innovative therapies. Despite this recognized value, the current landscape of academic medicine presents significant barriers to establishing and maintaining a successful career as a surgeon performing basic/translational research. Our objective is to define these barriers to academic success for surgeons, and to provide a consensus strategy for optimizing the chances of success.

Summary Background Data: There is a significant decline in the proportion of academic surgeons who are pursuing basic science/translational research, which represents a potential threat to the very identify of the translational surgeon-scientist.

Methods: Based on published literature and expert opinion, the Basic Science Committee of the Society of University of Surgeons prepared this roadmap to encourage and guide the next generation of surgeon-scientists as they embark on their academic careers.

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Results: This roadmap highlights key elements to consider in choosing an initial job and the importance of identifying a team of committed mentors. Expectations and guidelines for the first several years in practice are offered.

Conclusions: With guidance and mentorship, aspiring surgeonscientists can overcome the challenges inherent in choosing this career path and sustain the important legacy of those before them.

Keywords

academic surgery; basic science; surgeon-scientist

Although technical excellence and clinical judgment are undeniably imperative for all surgeons, a commitment to the study of fundamental disease biology is essential for advancing the field of surgery. Surgeons are uniquely positioned to make important contributions to understanding the biology of surgical diseases because of their proximity to the diagnosis and management of those

conditions, their direct access to tissue samples, and their unique perspectives on surgical diseases and their treatment. Landmark achievements of past surgeon-scientists include Alfred Blalock incorporating laboratory investigations of circulatory shock to the treatment of congenital cyanotic heart disease, Thomas Starzl performing pioneering work in organ transplantation, and Judah Folkman discovering the biology and importance of angiogenesis in cancer. Nine surgeons have been awarded a Nobel Prize for their scientific accomplishments.[1] Surgeon-scientists also contribute a great deal in less apparent ways, and are important contributors to the overall mission of academic medical centers.

Although surgeons contribute to knowledge through a variety of scientific disciplines, the challenges that confront surgeons pursuing basic science are unique. Therefore, in this manuscript we define “surgeon-scientist” as a surgeon engaged in bench research, usually translational in nature, and in fields as wide-ranging as genetics and genomics, cell and developmental biology, proteomics, biomedical engineering, systems biology, and more recently, machine learning and computer-patient interfaces. As the surgeon’s fields of interest have expanded and grown more complex, the surgeon-scientist has evolved from a bench researcher toiling away in isolation, to his/her incorporation into a group of investigators working together in multidisciplinary teams. Given the expanding nature of basic research conducted by surgeon investigators, the barriers posed by the current healthcare and academic research environments that negatively impact the success of surgeon-scientists will likely have wide-ranging implications on many aspects of academic surgery.[2–4]

Barriers to the success of surgeon-scientists have received growing attention. A recent report identified a 27% decline from 2007 to 2014 in the proportion of National Institutes of Health (NIH) funding going to Departments of Surgery relative to total NIH funding.[5] This significant decline has occurred along with a growing sense among the majority of academic surgeons that they cannot be successful basic scientists in today’s environment.[5] This perception is coupled with data from earlier studies showing that surgeons submit fewer

grant applications and receive fewer research grants than their colleagues in nonsurgical fields,[6–8] which further contributes to a cycle of progressive loss of basic/translational surgeon investigators. The challenges confronting surgeon-scientists include increased competition for decreased available grant funding, rising demand for clinical productivity, increasing complexity of the regulatory environment, and associated administrative burden, changing expectations regarding work-life balance, and perceived reduction in departmental and institutional support.[5,9–11] Faced with the threat of the extinction of surgeon-scientists, experts have called to preserve the pipeline by investing in training and protecting the time of surgical investigators.[12] Leaders in academic surgery must confront the changing environment facing young faculty today and identify strategies that will ensure the continued encouragement, support, and development of future generations of surgeon-scientists.

Here, we present a roadmap for trainees and young faculty to navigate the increasingly challenging path of becoming a surgeon scientist. Acknowledging that there are many potential paths to success, the roadmap outlined below is not intended to proscriptively define a single pathway, but rather to highlight key elements employed by successful surgical investigators early in their careers. These key elements were identified based on a review of published literature and the expert opinion of members of the Basic Science Committee of the Society of University Surgeons. Although “success” as a surgeon basic scientist can be defined in many ways, here we define success as obtaining competitive extramural funding and publishing basic/translational research in high-impact journals, both important requirements for a sustainable research enterprise. Although this article focuses on the necessary environmental elements that are important in fostering the success of the surgeon-scientist, we will first consider the various training mechanisms and candidate-specific qualities that may be of particular importance to a surgeon-scientist, and we will also consider the early predictors of success.

IMPORTANCE OF THE CANDIDATE AND THEIR TRAINING IN SUCCESS OF A SURGEON-SCIENTIST

Being a surgeon-scientist takes creativity, a deep understanding of the literature, and perhaps most importantly, the ability to generate new ideas to solve clinical problems. Yet a mere understanding of these elements is insufficient to achieve success as a surgeon-scientist; rather, effective scientific training is required. Nobody would expect the talented athlete to win any games simply by *understanding* that hitting and catching are important; it is assumed that effective training in the art of baseball is required. So too, the aspiring surgeon-scientist needs to be trained not only in the art of surgery, but also in the art and method of science. It is our view that adequate scientific training is one of the most important elements of success as a future surgical investigator.

Various training models are available for aspiring surgeon scientists, and each has important advantages and disadvantages. Perhaps the most common mechanism is the period of dedicated nonclinical time that surgical residents are afforded during their 5year clinic training programs, a bloc that typically lasts 2 years. In the appropriate research environment, with a committed and skilled mentor capable of selecting a resident-friendly

basic science project, a 2-year research training period can provide the fundamental skills necessary for success as a surgeon-scientist, provided the graduating resident secures the appropriate first job, as discussed below. In many institutions, the resident researcher has the opportunity to enroll in graduate school and to complete a masters or doctoral degree, which will likely provide additional educational benefits, yet comes at a cost of added time to graduation and a need to secure additional financial resources. There is certainly no absolute requirement for the surgical resident to obtain either of these degrees. An alternative approach is to obtain research training during medical school, in the form of an MD-PhD dual degree. The advantages here include formal training embedded within medical school, perhaps opening up subsequent career opportunities at the same institution. The major pitfall of the MD-PhD dual degree for surgical residents is the relatively long gap between completion of research training and the start of the first research job, which could be remedied through completing a postdoctoral fellowship during residency or fellowship.

Although there is not a single approach that is likely to portend success as a surgical investigator, what is important is the need for a dynamic, cutting-edge and highly effective laboratory experience capable of providing fundamental skills around a focused research topic. Moreover, the future success of the resident as an independent surgical investigator may be predicted by the success achieved during this laboratory time, suggesting that the laboratory experience is key not just to the resident who is acquiring research skills, but also to the department chairs hiring such candidates as a means to evaluate how well those skills were acquired and leveraged toward high-impact manuscripts and research grants by the trainee. The gap in time between when the research training is completed and the first academic job begins can be a significant factor in determining the success of the surgeon-scientist. This gap can be shortened by several mechanisms. One approach is to move the formative research experience during residency closer to the time of the first academic position. Alternatively, the research experience can occur at the usual time, between 3rd and 4th year of residency, but the resident could be afforded the opportunity to maintain active engagement in ongoing research during their final residency years, perhaps by having a fulltime technician in the laboratory with whom they work closely. Another approach is to embed the new junior surgeon-scientist in a senior scientist’s laboratory, and thus using the first few years on faculty essentially as a post-doctoral fellowship, as described below.

WHAT TO LOOK FOR IN AN ACADEMIC SURGICAL JOB

Supportive Environment

Having completed a period of research training, the freshly minted surgeon-scientist will need to look for that first job. Although each situation is unique, certain elements are necessary for a surgeon scientist to be successful. Among these, environment and mentorship are of greatest importance. A surgeon-scientist’s first job should ideally be in an institution that is strongly supportive of research and in a department that is committed to, and has a track record of, supporting and nurturing surgical investigators. With ever-growing barriers and challenges, a department that has successfully developed young surgeon-scientists likely has the necessary infrastructure to promote success. The absence of recent departmental success, as judged by lack of extramurally funded surgeons, suggests that the

necessary infrastructure is not available and that significant challenges in developing a surgical research program focused on the basic sciences may be present.

Included in consideration of environment are the available resources and personnel: (1) shared facilities and equipment that allow achievement of research goals; (2) grants management staff, with pre- and post a ward personnel; (3) core laboratories that provide routine services (eg, sequencing, advanced microscopy, biostatistics, etc); and (4) proximity to potential collaborators, because expert collaborators add valuable insight and expertise and broaden one's scientific perspective.[13] Each area of investigation requires a different set of resources, equipment, and facilities, and the availability of the specific resources relevant to the proposed research program should be considered.

Many examples of supportive environments exist.[14,15] In some cases, it may be that colleagues in the investigator's Department genuinely appreciate basic research and demonstrate this in the allocation of resources or the development of compensation models. Support may also be manifested by a department that encourages the investigator's efforts to build a clinical practice with a specific focus in their area of scientific expertise. These elements enhance the surgeon-scientist's work environment and increase the likelihood of achieving success.

One aspect of the environment that deserves special emphasis is the degree to which the environment fosters "team science," as evidenced by multiple collaborators from various disciplines contributing to a given project. One of the most effective ways for the junior surgical investingator to compete in today's highly competitive research environment, in which grants are being funded at historically low levels, is to engage a network of experts on a project, each of whom is expected to deliver different areas of scientific expertise. Institutions vary as to the extent that team science occurs, and this is a function of institutional culture and the degree to which collaboration is encouraged. These criteria can be difficult to assess and indeed provide an insider's advantage when considering one's first academic position. Careful attention should be paid during the faculty interview process regarding inter faculty harmony and the degree to which investigators at the same institution work together and coauthor manuscripts.

Protected Time

A department committed to an investigator's success will recognize the need for "protected time" that is dedicated to establishing and maintaining one's research effort. This allows uninterrupted focus on performing or supervising research and writing grants. No single formula exists for balancing clinical responsibilities with laboratory research time, both of which are important to a young surgeon's career. Although the need and specific percentage of protected time may vary for each individual, time and effort must be allocated for focused research activities that include, in addition to bench-top research, supervising and mentoring trainees and laboratory staff, attending scientific conferences, and writing papers and grants.[16] Although many medical specialties favor a pure "protected time" model in which continuous weeks or months are devoted to the laboratory, surgeons are unlikely to find such an arrangement attractive or even feasible. The proportion of effort required for research

varies depending on the individual, support from colleagues and the institution, and the nature of the research, but must be sufficient to achieve success.

Departments and institutions that prioritize research often offer compensation models that reward academic productivity. Such models might guarantee a salary for the protected time, lower relative value unit expectations, or provide compensation for grants awarded, manuscripts published, and national presentations. The early-stage surgeon should remember that, as surgeons, there is a great need to be available to patients and referring doctors. Although this adds to the challenge and complexity of balancing science and clinical surgery, it also adds to the reward. The concept of protected time may not easily apply to surgeons when these additional factors are considered. Some surgical disciplines (trauma, emergency surgery, critical care, transplant) are often team-based and may more readily fit a practice that protects and nurtures academic productivity. Herein lies one of the major challenges that a successful surgeon-scientist must face, namely the requirement to be engaged in laboratory research activities while also being available to his/her patients. Being part of a group of trustworthy and reliable partners is one way to address this significant challenge, although admittedly for some junior faculty it is this very challenge that drives surgeons away from participating in basic science research in the first place.

Committed Mentors

One of the essential ingredients for launching a career as a surgeon-scientist is the selection of appropriate mentors. A mentor is a partner as well as an adviser, teacher, role model, friend, and advocate.[17] Surgeons often perform their initial research experience early during residency in an area that may or may not relate to their eventual field of study. Major advances in science occur during the 4 to 6 years of clinical training between completing a resident research experience and obtaining the first faculty position, and thus creating a potential knowledge gap that may hinder the development of an independent research program. Mentors are essential in helping guide early surgeon-scientists to address this gap, and to establish realistic and achievable scientific and career goals. The mentor will also promote the mentee in academic circles, both within the institution and nationally, and aid in the process of navigating and confronting the inevitable challenges. A good mentor is experienced, respected in her/his field, accessible, motivated for encouraging excellence, able to provide opportunities for collaboration and networking, and eager to educate, supervise, and advise mentees.[14,15,18,19] The mentor often has a track record of productivity in independently funded research and a history of mentoring other young surgeon-scientists. In addition, peer mentors who are early stage investigators can also be invaluable.

With the rapid advancements and evolving demands of medicine and science, it is improbable to find a single individual who can serve the diverse roles of the ideal mentor. For this reason, developing a mentoring network can be valuable.[20,21] Multiple mentors from different departments, disciplines, and institutions can provide varying skill sets that allow an opportunity to capitalize on each of their strengths, including providing advice in the often-disparate worlds of academic surgery and basic science. Some Departments of Surgery facilitate the development of a mentoring relationship between young faculty and more senior members. This arrangement suggests a departmental commitment to mentoring,

but should not substitute for a robust mentoring network. Furthermore, any mentorship team should be continually examined and restructured over time as needs and goals change. The availability of strong mentors and the capability to build a broad mentor network are key factors when assessing early job options and can have a major impact on achieving research success.[5] It is equally important, however, to be a good mentee. Like any relationship, the mentor and mentee will be most successful if both are committed to the success of the relationship. A mentor can only be effective if the mentee is proactive about meeting, open to listening, receptive to constructive criticism, responsive to advice, and fully committed and focused on their scientific endeavors. The budding surgeon-scientist is encouraged to seek out mentors and supporters in diverse fields at their own or other institutions for maximal benefit.

Strong Social Support

A major impediment to success identified in recent surveys of surgeon-scientists is the difficulty of achieving work-life balance.[5,22] The significance of having a robust social support system should therefore not be discounted. A surgical career has enormous rewards but can also be quite challenging, with long hours and occasional frustrations, both clinical and scientific.[23] “Work-life balance” is the term often used, but “work-life integration” may be more appropriate. The term “balance” suggests that certain components may be compromised in favor of others. By contrast, one’s personal and family life should be considered integral to one’s career. The domains of work, self, family, and community are intertwined and all contribute to an individual’s satisfaction and self-worth. A support system outside of the hospital is therefore essential, including family, friends, and a social network. Finding examples of successful integration by other faculty role models in the department is highly reassuring. The culture of leadership in an institution, inspired by the department chair and the dean, will be critical to determining whether the environment is an appropriate “fit” for developing surgeon-scientists. Furthermore, one needs to establish appropriate expectations for themselves and their family regarding how they anticipate integrating a surgeon-scientist career with their personal life. Setting realistic expectations upfront will help to minimize frustration later.

Appropriate Compensation and Start-Up Support—Research-focused careers are gratifying and meaningful, but can also be less financially rewarding than a purely clinically focused position, at least in the short term. By necessity, however, the commitment to an academic surgical-scientist career path is made at the outset of a surgeon’s career, precisely when financial pressures from medical school debt and raising a family are greatest.

Compensation is a factor that needs to be considered when assessing jobs and negotiating offers. One should consider whether the department genuinely values the contributions of surgeon-scientists with competitive compensation. The NIH Loan Repayment Program offers an opportunity to alleviate the financial pressure of student loans by providing up to $35,000 annually toward educational debt for clinicians with research-focused careers (https://www.lrp.nih.gov). Faculty being recruited into academic environments will typically have a compensation plan. These plans are valuable in that they bring an element of transparency to the otherwise often opaque realm of compensation. Many compensation

models are, however, heavily based on RVU production, and this may be a hindrance to a department's efforts to build a successful research enterprise. Early discussion on how academic compensation will be structured is essential, both before and after substantial grant funding is obtained.

A "start-up" research package is essential for initiating research that generates preliminary data to support applications for competitive, extramural grants. It is important to consider the amount and number of years of start-up funding being offered, the stipulations for funding renewal, and the associated essential, nonmonetary resources provided, such as access to shared equipment, cores, grant managers, and technicians. Common starting packages include a fixed amount of money for reagents, salaries for technicians, graduate students, and/or post-doctoral fellows, and a limited amount of funds for capital equipment. For this reason, it may also be advantageous for the junior surgeon-scientist to partner with an established investigator, to share reagents, equipment, and personnel. Commonly, startup packages provide support for 3 to 5 years with the option to continue or extend support if benchmarks for success are met. It should be uncommon for institutions to limit support for faculty who demonstrate an appropriate positive trajectory, because the start-up costs for recruiting new faculty member far exceed the financial support for maintaining existing faculty. If benchmarks are established, it is important to ensure they are reasonable and achievable. For most, independent funding is no longer earned within a 3- to 5-year time frame from initial faculty appointment as in the past. The average age for the awardee of a first R01 grant is approximately 45 years old for physicians.[24] Expectations by department and institutional leaders regarding funding independence must take this fact about the current funding environment into consideration when establishing timelines and support durations.

In addition to financial support, physical laboratory space must be carefully considered. The bench space needs to be adequate and preferably in proximity to mentors and/or collaborators to maximize the research environment and create synergies for success. One approach is to colocate young faculty with their primary mentor, with the potential to transition them to their own laboratory space as their research program develops. It is also important that the laboratory not be far from the hospital, as trips back and forth to the Emergency Department, outpatient clinics, inpatient units, and operating room are inevitable.

Careful Evaluation of the Offer—After the job search, it is possible that the perfect offer will not materialize. Academic surgery is a competitive field with a finite number of opportunities. The details of each offer must be compared against each other and against a list of priorities, including the factors discussed above (Fig. 1). One should consider what resources are important for success and, among those, which are indispensable. If necessary resources are missing, negotiation is an important tool to make one's wishes known. For young physicians, business negotiations are generally foreign and uncomfortable, but the recruitment process is the optimal time to identify and request needed resources and support. Ultimately, the goal is to find a job that meets one's needs and have these detailed in writing. Getting help from friends, family, or colleagues with experience in successful negotiation is worthwhile. In addition, asking a trusted advisor to review and advise on the contract being

offered can be helpful. Thinking and learning about negotiation as early as possible during residency training can be very beneficial. Some physicians seek contract review from an attorney. Although this is less common in academics, it is an option that can be considered. Remember that this is the optimal opportunity to get what you need to be successful, which is not only the applicant's goal, but also that of the recruiting department.

THE FIRST FEW YEARS: A SUGGESTED TIMELINE

The first few years of a surgeon-scientist's practice are important determinants of long-term success. The competing interests of building a research program and establishing a clinical practice are difficult to balance. During these initial years, referring clinicians expect to see an eager surgeon who is affable, available, and able as a surgical colleague. Establishing oneself as a researcher from the beginning runs the risk of losing opportunities to be deemed a competent surgeon and becoming regarded only as a scientist. However, this is also an important period for building a laboratory, assembling the right team, identifying collaborators and mentors, generating high-quality preliminary data, and submitting grants. Both aspects of being a surgeon and scientist require attention and development, and an awareness that both need to be fostered and cultivated for ultimate success. Pursuing both clinical surgery and basic research is uniquely challenging and seeking advice from mentors and role models is invaluable.

Year 1: Getting Started

One of the most important fundamental goals during the first year, and one which often starts well before the faculty position is obtained, is to identify the broad scientific questions that will serve as the laboratory's focus and the experimental approaches that will be used to answer them. Considering the effort that is required to achieve a successful research enterprise, one needs to be passionate about the scientific questions being asked and fully committed to their study. A time-tested approach is to marry one's clinical focus with one's research endeavor whenever possible. This approach helps to ensure that your clinical effort will not make you less competitive for funding than pure basic scientists, but rather creates important synergies that strengthen your work. This approach has many advantages, including optimizing one's time, as the academic focus is in one area so that staying current with the literature and attending conferences serves both clinical and scientific goals. Furthermore, by mastering both scientific and clinical aspects of a disease, the surgeon-scientist has the opportunity to become an expert who understands the relevant issues from both perspectives, which adds great value, including in the eyes of grant reviewers. A clinical research symbiotic niche can fuel a robust clinical practice that is beneficial to both aspects of one's career.

Another important goal in the first year is to begin to obtain the skills needed to achieve success and eventual independence by immersing oneself in all aspects of the research program. This includes attending workshops in specific areas (eg, grant writing, statistics, stem cell biology), voraciously reading the relevant literature, and attending conferences both within and outside of surgery. These conferences serve as opportune venues to learn the current state of the field, to identify peers and potential collaborators, and to hear diverse

perspectives on the scientific questions being posed and the approaches used to answer them.

During the first year the investigator should begin to obtain preliminary data aimed at supporting initial grant applications. Startup funds should be used to generate these data, and this often requires hiring a research technician and/or postdoctoral fellow. These early hires are critically important and it is appropriate to seek advice from colleagues and have them help in the interviewing process. The importance of interviewing and hiring the right people should not be underestimated. A poor initial hire can have a significant effect on productivity. This year is also the time to pursue fundamental practices that will enable long-term success: identifying and utilizing a time management system and learning about and submitting protocols for institutional biosafety and animal care and use review. This is also the time to begin assembling a team of mentors, collaborators, and colleagues that will increase the likelihood of achieving research success. The starting surgeon-scientist is also encouraged to seek institutional support and resources for coursework in developing research and grant-writing skills.

Years 2 to 3: Obtaining Extramural Research Funding

Years 2 and 3 are opportune times to begin writing grants. The rigor demanded by grant writing is extremely valuable in helping an investigator to lay out a coherent, logical, and well-supported research plan. Given the challenges of obtaining extramural funding, one must develop discipline in submitting grants routinely. Initial grants can be submitted to private foundations and specialty or regional surgical societies. Departmental and institutional funds should also be pursued. As more robust preliminary data are obtained, federal funding sources should be considered. The young investigator should be frequently searching for grants, and the grant manager and mentors can also help identify opportunities.

Although there is no guaranteed path to achieving research independence, the mentored career development awards offered by the NIH are a well-established approach toward that goal. The “Kaward” mechanism (https://researchtraining.nih.gov/programs/career-development) is a competitive grant intended to support early-career physician-scientists who have demonstrated an aptitude in basic science or translational research. The goal of the award is to achieve a transition to independence over a 5-year period, with the “K-to-R” transition representing a common, although not required, route for success.

One should note that the K-award mechanism may not meet the needs of all early-stage surgeon-scientists. Some surgical Departments may not support applications for this funding mechanism, feeling that the salary support provided by a K-award is not sufficient to justify protecting 75% of a surgeon’s time, as mandated by most of these awards. There are exceptions to this, including the 50% effort requirement of National Institute of Neurological Disorders and Stroke K-awards to neurosurgeons and National Institute of Arthritis and Musculoskeletal and Skin Diseases K-awards to orthopedic surgeons, both of which should serve as models for other institutes of the NIH to cultivate surgeon-scientists. Many K08 awardees are successful in advancing to more significant levels of federal funding. A study of K08-funded pediatric surgeons found that 39% converted to an R01 and 24% to other NIH funding by the time the K-award grant was completed.[11] In addition to

providing salary support and laboratory funding, the K award also helps to facilitate relationships with NIH program officers, who can be extremely helpful resources for long-term success in obtaining grant funding. In considering when to submit a K award application, it is important to remember that a typical cycle to obtain a K-award includes a resubmission, and therefore the usual length of time from first submission to obtaining funds following a resubmission is approximately 20 months. Therefore, start-up funds, foundation grants, and institutional awards should be used with this timeline in mind.

Finally, the K award is not the sole mechanism to obtain research independence. In one study, 56% of pediatric surgeon scientists successfully obtained R01 funding without a prior K award.[11] In addition to the funding sources described above, industry-sponsored research should be considered. Funding from industry is anticipated to increase due to changes in the health care system, with success rates for all grants funded by NIH dramatically dropping from 32% in the 1990s to <20% currently (https://report.nih.gov/nihdatabook/). Companies often seek to partner with academic medical centers and these relationships can be very productive for both parties.[25] All industry sponsorships need to be fully reviewed by the institution to guarantee compliance with conflict of interest policies and to ensure that the negotiated agreement appropriately rewards the institution and the individual surgeon-scientist.[26]

These early years are also an important time to become actively involved in relevant national societies, both surgical and scientific. Membership in specialty societies is important as it represents an opportunity to become involved in the field, to get to know the leadership, and to have a forum for presenting research. Mentors and department chairs can provide value by getting young surgeon-scientists onto committees that increase their engagement and visibility within the larger community.

Year 4 and Beyond

At this stage the start-up package has been, or is nearly, depleted. It is important to address beforehand if the department will continue to provide support if preliminary promise is demonstrated, ideally based on clear, previously defined benchmarks. During this period, the young investigator should continue to apply for career development awards and grants to obtain funding and advance closer to independence. Kodadek et al[20] queried surgical chairmen about the qualities of successful K awardees, with responses noting passion for research, persistence, availability of physical space, protected time, partner support, and senior mentorship. These are the same components required for any surgeon-scientist to succeed, and need to be considered not only when seeking a job but continually throughout the early years.

Persistence, resilience, and the ability to learn from failures are individual factors that shine during this early career period. The keys to successful grant writing hinge on knowing the format and audience, identifying weaknesses and how to address them, having clear and explicit goals, and utilizing mentor assistance to guide and revise applications.[17] Some departments and institutions offer mechanisms for internal grant review which can provide useful feedback before submitting the final application. It is especially important to address reviewer comments on grant applications that are not funded. These comments often hold

the keys to improving subsequent applications. Ignoring comments from any reviewer, or responding defensively, will dramatically reduce the likelihood of funding on a revised application. Participating in grant review committees and study sections are excellent opportunities to study the pitfalls and challenges of major grant submissions. Reviewing manuscript submissions to journals also has great value in continuing development of critical thinking skills and keeps a surgeon-scientist abreast of advances in his/her research area. It also provides an invaluable service to editors and the investigator's scientific community (Table 1).

The Promotion Process

In their early years on faculty, surgeon-scientists should become familiar with their institution's promotion process. In some respects, an institution's reputation is based on the rigor of promotion from assistant to associate to full professor. Predictably, institutions with a strong history of extramural research funding have more challenging requirements for number and quality of publications, number and value of external grants, with critical measures of reputation and impact. All institutions, however, share the need for the promotion process to be transparent, equitable, unbiased, and fair, and to seek significant recommendations from outside referees. Collecting a network of people familiar with your work is essential for promotion, and this requires publication in high visibility journals with consistent high impact and significance. In anticipation of eventual promotion, one should maintain an up-to date curriculum vitae in real-time. Reviewing and complying with the University's requirements for CV formatting from the beginning will avoid unnecessary delays when preparing a promotion package. By knowing the requirements for promotion, deficiencies can be addressed early and milestones for achievement can be established.

CONCLUSIONS

Anecdotal evidence suggests that there are multiple potential paths to success as a surgeon scientist. We have herein presented a roadmap to guide young surgeons in their pursuit of developing an independent research career. The importance of quality mentorship, institutional support, and individual passion and commitment cannot be overstated. The surgeon-scientist of the 21st century faces significant hurdles, but these challenges can be overcome, for the sake of our patients and the advancement of academic surgery.

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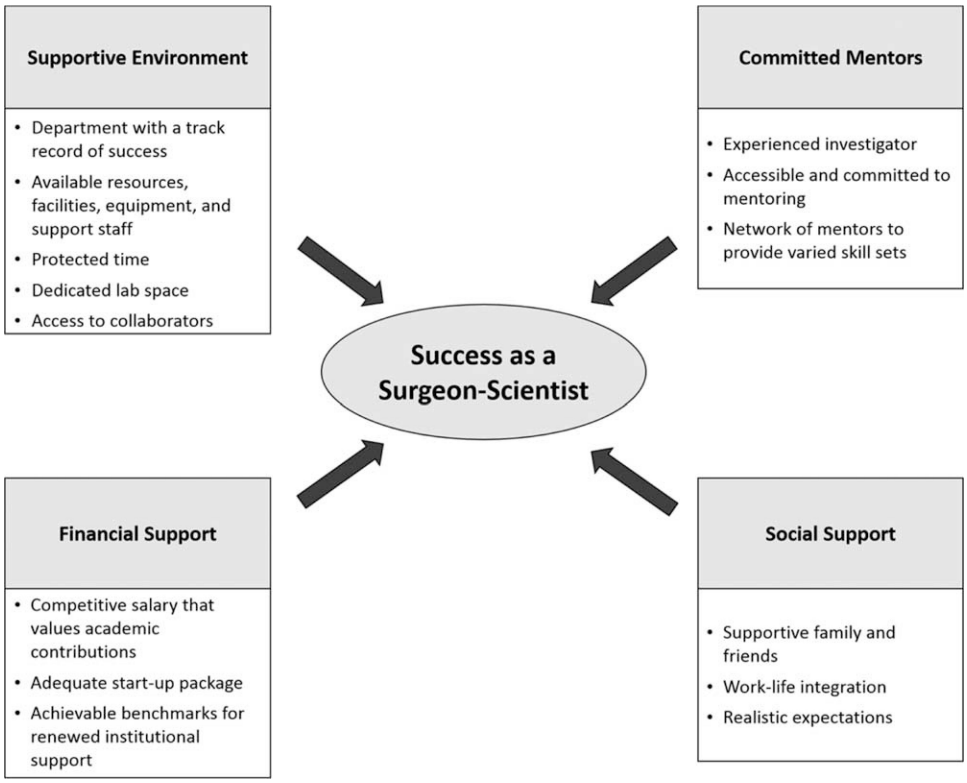

FIGURE 1.
Essential components for achieving success as a surgeon-scientist.

Table 1.

Timeline for the Initial Years of a Surgeon-Scientist's Career

Early Years	Goals and Milestones
	Identify the scientific questions to be tackled
Year 1	Obtain skills necessary to achieve scientific goals Master the relevant literature and knowledge gap Begin to obtain preliminary data Hire a research technician and/or trainee or fellow Submit applications for institutional approvals Identify a team of mentors Attend research skills and grant writing workshops Start submitting grant applications Become active in national societies
Years 2–3	Identify collaborators Begin to publish initial manuscripts Maintain an up-to-date curriculum vitae Continue applying for research grants Participate in manuscript and grant reviews
Year 4 and beyond	Become familiar with requirements for academic promotion Be persistent and resilient!