A Study of Inventiveness among Society of Interventional Radiology Members and the Impact of Their Social Networks

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ABSTRACT

Purpose: To investigate the nature of inventiveness among members of the Society of Interventional Radiology (SIR) and learn what influenced the inventors and assisted their creativity.

Materials and Methods: The membership directory of the SIR was cross-referenced with filings at the United States Patent and Trademark Organization (USPTO) and the Patent Cooperation Treaty (PCT). The inventors were queried with an online survey to illuminate their institutions of training and practice as well as enabling or inhibiting factors to their inventiveness. Responses were analyzed through the construction of social network maps and thematic and graphical analysis.

Results: It was found that 457 members of the SIR held 2,492 patents or patent filings. After 1986, there was a marked and sustained increase in patent filings. The online survey was completed by 73 inventors holding 470 patents and patent filings. The social network maps show the key role of large academic interventional radiology departments and individual inventors in the formation of interconnectivity among inventors and the creation of the intellectual property (IP). Key inhibitors of the inventive process include lack of mentorship, of industry contacts, and of legal advice. Key enablers include mentorship, motivation, and industry contacts.

Conclusions: Creativity and inventiveness in SIR members stem from institutions that are hubs of innovation and networks of key innovators; inventors are facilitated by personal motivation, mentorship, and strong industry contacts.

ABBREVIATIONS

IP = intellectual property, PCT = Patent Cooperation Treaty, USPTO = United States Patent and Trademark Office

A challenge that all academic institutions face is to accelerate innovation, translation, and commercialization. There is a belief that this innovation can be taught, initiated programmatically, or "turned on"—that these are nascent skills in every individual and that all universities are capable of being successful in this space. Rogers and van de Ven were pioneers in developing an understanding of innovation diffusion and the spread of change (1). Rogers (1) postulated that individuals could be placed on a normal bell curve, with the "innovators" representing the first 2.5% of individuals. He suggested innovators possess characteristics of risk tolerance, a fascination with novelty, venturesomeness, and willingness to step outside of their metaphorical village to learn. Rogers also noted that innovators are typically members of networks that expand beyond geographic boundaries and that they invest heavily in these connections (1).

The dynamics of these connections between innovators became a focus of sociologic analysis > 6 decades ago. Morena is credited as the first theorist to develop sociologic concepts from social network analysis in the 1950s; he drew sociograms depicting individuals as the social hubs of radiating patterns of lines, the lines depicting relationships from one individual to another—the first social network mapping (2). Social network analysis methods were subsequently applied to a variety of queries in community structure, labor market studies, science citation studies, and informational sciences (3,4).

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The past 2 decades have also seen a dramatic increase in use of these methods in innovation research (5), including research focusing on innovation in biotechnology (6). Patents are a common unit of analysis in such studies, and researchers have used social network mapping as an alternative to statistical analysis to describe and explore better complex patterns between organizations and individuals. This methodology was applied to the interrelationships between inventors and their associated institutions both to look for any major trends that exist and to investigate how these might influence inventiveness.

Analysis of the inventiveness of members of the Society of Interventional Radiology (SIR) could provide valuable insight into factors that enabled or inhibited inventors to succeed. The aim of this study was to find a metric of the inventiveness of the SIR membership and a sense of the contribution SIR members have made to the creation of the field of image-guided therapy, to investigate patterns of connectedness among SIR inventors, and to gauge what influenced the inventors and assisted their creativity.

MATERIALS AND METHODS

Patent Filing Analysis and Survey

An investigation was performed into the number of patents or patent filings SIR members collectively possessed and who among them held these filings. The SIR membership database (a cohort of 6,200) was cross-referenced with filings of the United States Patent and Trademark Office (USPTO) and Patent Cooperation Treaty (PCT). The membership count was assessed in July 2009 and provided by the SIR. Mailing addresses of the SIR members were cross-referenced with the filing address of record to ensure the names of members were the same as the inventors who filed. Because patents are confidential for 18 months after filings, the data gathered in July through August 2009 represented the published patents filed between December 2007 and January 2008. The patents and patent filings were sorted by field of invention (eg, stent, balloon, needle, drug, genetic)

The online questionnaire tool Survey Monkey (www.surveymonkey.com) was used to develop a digital survey; this was distributed to all SIR members who held or submitted patents. The survey (Fig 1) consisted of 10 individual questions relating to intellectual property (IP) and the patenting process, some requiring yes/no answers and some allowing for open-ended responses. Questions 1, 2, 5, 6, 7, and 8 were intended to generate contextual information about each respondent, their mentors, and IP activity. Questions 3 and 4, asked about institutional associations through education and employment, were intended to elicit a list of institutions that could be assembled into a network of SIR inventors. Questions 9 and 10 inquired about enablers and inhibitors of the patenting process to facilitate an examination of the factors influencing medical innovation.

Data Manipulation and Social Network Mapping

Two approaches were taken when analyzing and manipulating the survey data. The first approach was social network mapping, a method of graphic analysis that creates and displays a system of connections and interrelationships based on data input from spreadsheets such as Excel (Microsoft, Redmond, Washington) and allows for manipulation and sophisticated presentation of that data. To generate these social network maps, the online software programs UCINET and NETDRAW (both from Analytic Technologies, Lexington, Kentucky) were used to create the social network maps.

1	Do you have a patent or a patent in process (provisional or pending approval)?
2	Please state your name
3 a)	Please state the institution where you conducted your undergraduate degree
3 b)	What did you study for your undergraduate degree?
3 c)	Please list the institution where you attended Medical School
3 d)	Please list the institution where you conducted your Residency
3 e)	Please list the institutions where you conducted your Fellowship
4	Please list your places of employment
5	Did someone inspire, advise or guide you to invent? If so, who?
6	Have you shown others how to invent, or mentored them in the practice of medical invention? If so, who?
7	Is all of your intellectual property licensed?
8	Is it currently in production, on sale, or in the FDA process?
9	What has been the biggest enabler of this process for you?
10	What has been the largest impairment?

Figure 1. Survey Monkey online questionnaire.

Microsoft Excel was used to reformat the raw survey data into a 1-node matrix to facilitate manipulation in UCINET. Further manipulation in UCINET rendered a modified dataset that was used to construct social network maps in NETDRAW. The social network maps (Figs 2, 3) were tailored to illustrate the relationship between institutions and inventors and to demonstrate visually any patterns that might exist among these members. Each institution (universities, medical schools, and hospitals) and each SIR member respondent was

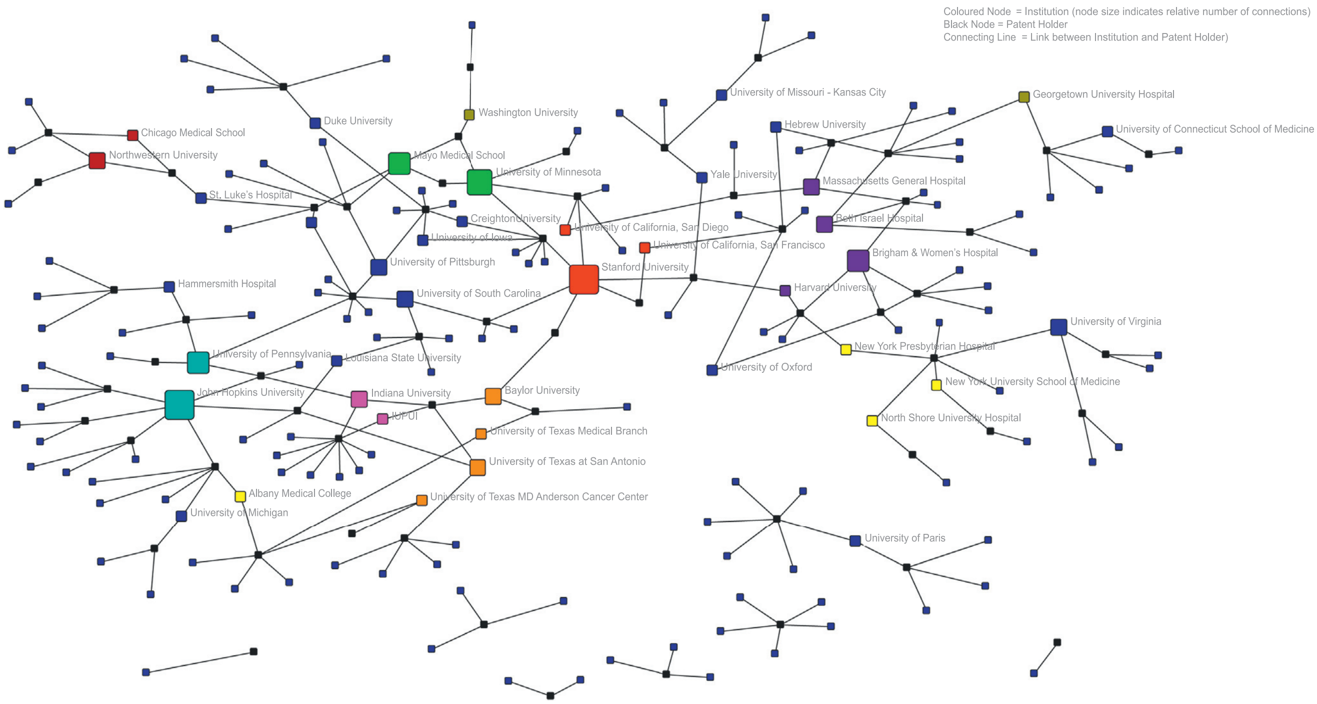

Figure 2. Social network map of institutions and the SIR inventors associated with each. The size of each node indicates number of connections that the institution, as the hub of innovation, possesses with SIR inventors.

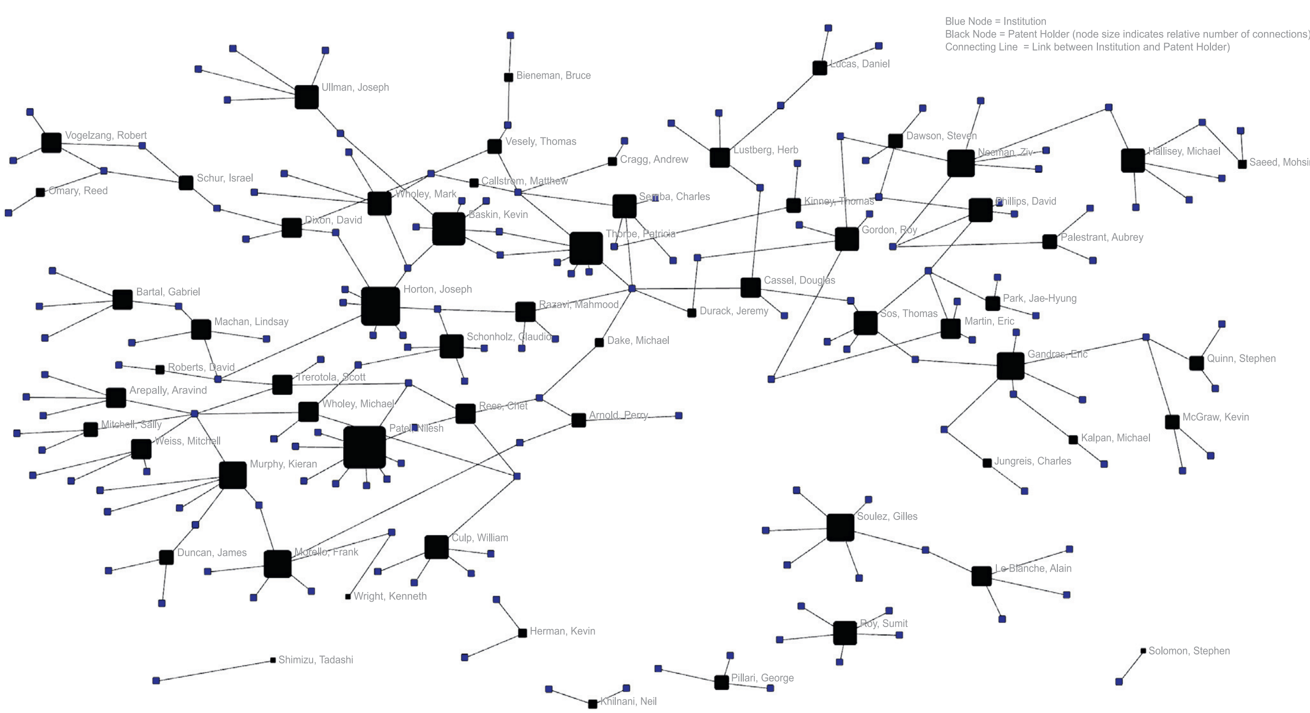

Figure 3. Social network map of SIR inventors and their connections to institutions. The size of each node indicates number of connections a particular SIR member had to institutions. This figure demonstrates the close collaboration network among SIR inventors. It also shows that particular SIR individuals act as innovation hubs themselves.

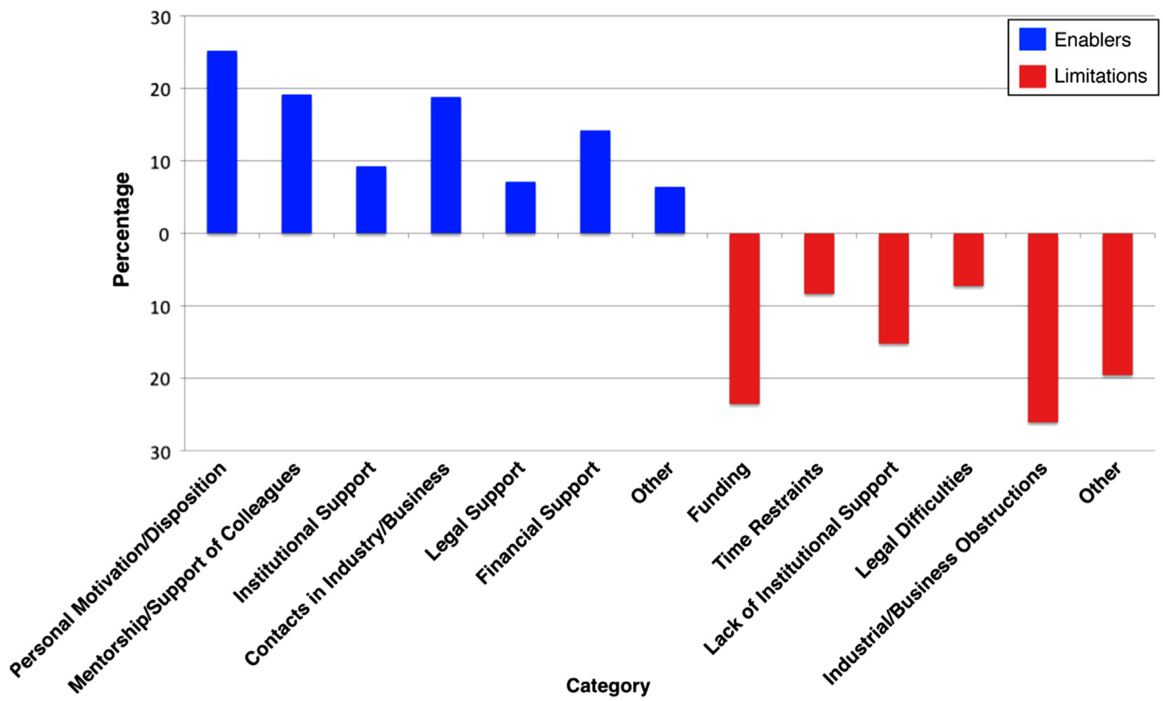

Figure 4. Enablers and inhibitors of successful inventiveness among SIR members.

assigned a node in the social networks. The lines linking nodes represented a connection between two entities. Individuals were connected only to institutions and not directly to other SIR members; the lines specifically denoted an individual's association with an institution through education or employment.

The second approach was thematic analysis of responses to questions 9 and 10, open-ended questions relating to the primary facilitators and hindrances each SIR inventor had faced throughout his or her own experiences. Responses to questions 9 and 10 were classified into six categories (Fig 4). The relative importance and prevalence of each category of enabler or inhibitor was identified to ascertain which influences were considered by inventors to be most beneficial or obstructive to the innovation process.

RESULTS

Patents and Patent Filings

The 6,200 names and addresses listed in the SIR membership directory were queried at the USPTO and PCT. There were 457 members of the SIR found to hold or have submitted 2,492 patents and applications. There were 622 issued patents and 938 patent applications at the USPTO and 629 issued patents and 303 patent applications at the PCT. Of SIR members, 211 filed 1 patent, 175 filed 2–10 patents, 29 filed 10–20 patents, 10 filed 20–30 patents, and 14 filed 30–170 patents. After 1995, there was a considerable increase in patent filings; the mean number of patents filed per year before 1995 was 11, whereas the mean number filed after 1995 was 143. By nationality, the number of U.S. patents and applications (n = 1617) were followed by European (n = 629), Japanese (n = 94), Korean (n = 28), Czech (n = 26), Australian (n = 19), and Canadian (n = 16).

Fig 5 illustrates the growth of SIR membership patent filings from 1960–2009. Landmark individual patents are seen in the early filings, such as the hydrophilic guide wire, as well as later, such as the angioplasty balloon and stent patents. Fig 6 illustrates the types of patents filed from 1975–2010.

Survey Results and Social Network Maps

Of the 457 targeted members, 73 inventors holding 470 patents and patent filings from five countries responded. These patents include important devices in modern medicine such as the aortic endograft, drug-eluting beads for hepatocellular carcinoma, and the drug-eluting stent. They represent a set of inventors' experiences that are valuable and knowledgeable.

Based on the appearance of the social network maps (Figs 2, 3), it is apparent that there is a complex relationship between the SIR physicians and the institutions with which they are associated. Using node size to indicate an institution's connectedness within the network (as measured by the number of respondents associated with it), Fig 2 demonstrates that there are many institutions with direct links to multiple SIR members. Certain institutions stood out as central hubs or focal points in the network, possessing a particularly high number of links and a strong degree of immediate connectivity, or *local centrality*. Stanford University and Johns Hopkins University were found to be the largest of these hubs with six inventors

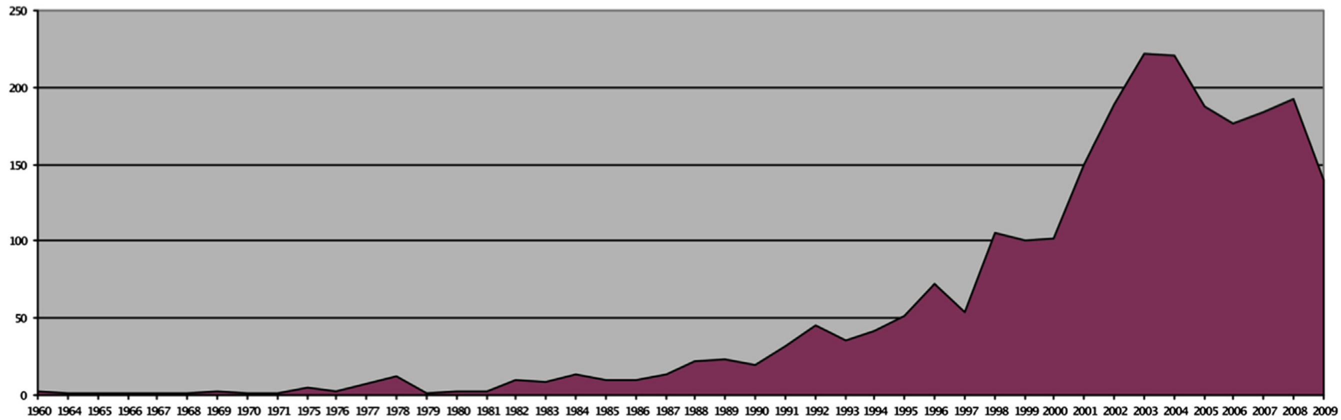

Figure 5. Growth of SIR membership patent filings from 1960–2009. Key individual patents are seen in the early years, including the hydrophilic guide wire and, later, the angioplasty balloon. Palmaz's seminal coronary stent patent correlates with a massive growth in IP filings beginning in 1986.

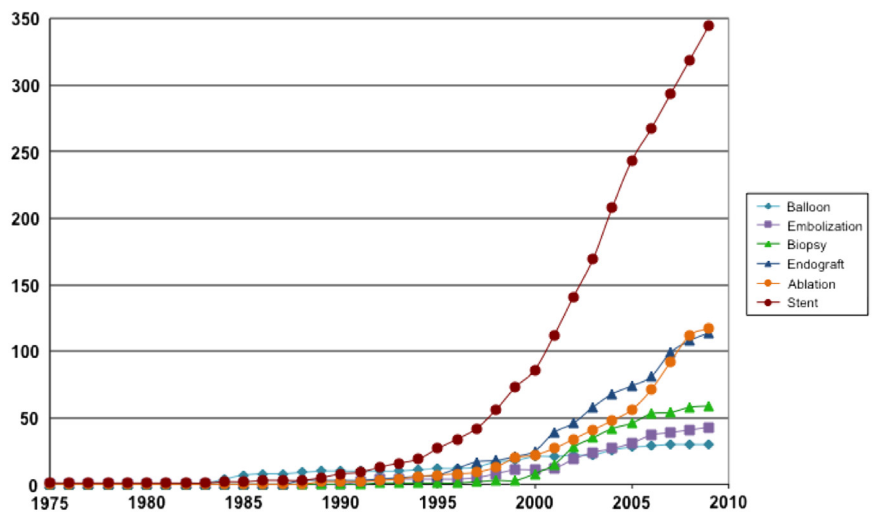

Figure 6. Patents filed over time from 1975–2010. Types of patents filed from 1975–2010 included angioplasty balloons, embolization materials (coils, polyvinyl alcohol glues, and drug-eluting beads), biopsy devices, aortic endografts, tumor ablation devices, and vascular stent devices (the largest group).

directly linked to them; however, many other institutions had four or five connections. Of 73 inventors, 65 could be indirectly traced back to such institutions via two or more intermediate connections, indicating their broader influence in the network as well as the interconnectedness of respondents as a whole.

Many of the hub institutions could be associated with each other via factors external to the informal innovation social network, such as formal affiliations or physical proximity. For example, Harvard University, Brigham & Women's Hospital, Beth Israel Hospital, and Massachusetts General Hospital not only are based in the same city but also are members of Partner's Healthcare, an integrated not-for-profit health care system in Boston. The external network associations between these institutions were graphically denoted in Fig 2 by purple coding their representative nodes. They appear to form a cluster within the network, closely intertwined with each other through shared associated inventors. A plethora of other institutional clusters following this principle were also apparent; these included Johns Hopkins University and University of Pennsylvania (turquoise nodes); Mayo Medical School and University of Minnesota (bright green nodes); Washington University and Georgetown University Hospital (olive green nodes); Chicago Medical School and Northwestern University (brown nodes); Baylor University and the University of Texas branches (orange nodes); Indiana University and Indiana University–Purdue University Indianapolis (pink nodes); New York Presbyterian Hospital, New York University School of Medicine, North Shore University Hospital, and Albany Medical College (yellow nodes); and Stanford University, University of California Los Angeles, and University of California San Francisco (red nodes).

Fig 3 shows an identical system but differs in its emphasis; it graphically represents the number of connections to institutions that each SIR member respondent possessed with the relative size of their nodes. All but six respondents were connected to each other indirectly (ie, via institutions of mutual association), indicating a high degree of interconnectivity among SIR inventors. These indirect connections also convey that individuals act as network hubs themselves; similar to the central institutions highlighted in **Fig 2**, many SIR members were shown to have five or more direct connections to different institutions and individuals, with some members possessing seven or more associations. Most respondents were indirectly linked to others, but these "hub inventors" were particularly connected to others, with up to nine fellow inventors separated by only one degree. Additionally, **Fig 3** demonstrates that even members who were not linked to a hub institution (as suggested by degree of connectivity demonstrated in this study) frequently had three or more associations with other establishments.

SIR respondents reported seven distinct enablers to innovation (**Fig 4**). The most common enabling factor was found to be personal motivation and disposition, with 25% of responses falling under this category. Mentorship and the support of colleagues were also cited as a prime facilitator of the process, as were contacts in industry and business (19% and 18%, respectively). Additionally, financial support, institutional support, and legal support were shown to be considerable enablers, accounting for 14%, 9%, and 7% of responses. Other miscellaneous factors amounted to 6% of responses.

The major impairments to the patenting/innovation process fell into six categories (**Fig 4**). Industrial and business-related obstruction was the most common factor cited, accounting for 26% of responses. Funding challenges were cited by 23% as an inhibitor, whereas other desultory inhibitors occupied 19%. A lack of institutional support was cited by 15%; time restraints, 8%; and legal difficulties, 7%.

DISCUSSION

The findings of this study suggest that inventors and procedural pioneers are a small subset of all interventional radiologists. Of the SIR membership, < 4% has actively participated in filing patents related to interventional radiology, interventional neuroradiology, interventional cardiology, and modern vascular surgery as well as renal replacement therapy and intensive care unit medicine. These 4% are credited as inventors in this study as a result of their patent filings, but progress in our field is dependent on the array of contributing SIR members and nonmembers, from individuals involved in basic science research to clinicians that build on and refine the procedures and devices and are credited by publication.

The growth of SIR membership patent filings from 1960–2009 shows a change in behavior of the inventors. The boom of filings that occurred in the mid to late 1990s parallels the rapid growth of the Internet and technology sectors and a growing awareness of the value of IP. The Bayh-Dole Act of 1980 and the Federal Transfer Act of 1986 provided the impetus; the legislation created incentives for academic institutions to patent the findings of their research (7,8). The emergence of the Stanford Research Park and its successful translation of IP to initial public offerings coincided with a massive growth in IP filings by SIR members. Until this time, interventional radiology was an artisanal specialty —largely off-label and driven by clinical demand that predated regulatory approvals. The early pioneers in interventional radiology did not consider filing a patent for their innovative ideas but instead tended to share their knowledge freely.

As demonstrated by the social network maps, there is a considerable degree of interconnectedness among SIR respondents, with both clusters of institutions (particularly linked to Stanford, Johns Hopkins, and Brigham and Women's Hospital) and major inventors serving as hubs for networks of innovation. It is suggested that connections to major research institutions may facilitate medical innovation. However, according to the queried inventors, the institutions with which they are associated do not always facilitate or encourage the development and patenting of new technology. Although some respondents cited institutional support as a considerable enabling factor, a greater proportion singled out the lack of such support as a key inhibitor of the process. Rather than major institutions directly supporting inventors or promoting innovation, their more important quality may be to act as gathering points for cutting-edge thinkers. These thinkers may congregate because of factors such as greater challenges, better access to funding, or superior research facilities and attract other like-minded physicians and scientists. This interpretation is supported by the finding that many SIR respondents themselves stood out as focal points in the network, possessing a high degree of centrality and connectivity. Even inventors with fewer direct links appeared likely to be hubs of other, potential and unseen networks of innovators. Respondents' emphasis on personal motivation and mentorship also bolster this inventor-driven view.

We have stated previously that there are four types of innovation (9). Quantum innovation includes the random acts of brilliance that form a field. Experimental innovation is derived from deliberate focused effort to understand a process. Observational innovations are ideas created by association when under intense pressure out of desperation during a procedure. Finally, iterative innovation describes the act of modifying and improving existing devices with repetitive incremental development. Tertiary referral centers such as Johns Hopkins may emerge as innovation hubs precisely because their clinical environment is conducive for experimental and observational innovation. The culture of these institutions is necessarily one of accepting challenges in taking on complex, high-acuity cases, of being the hospital of last resort, and of persevering to find the difficult solutions. Such a culture is arguably at the heart of integrative and assimilative innovation. Kegan and Lahey contended in their book *Immunity to Change* (10) that the lack of satisfaction with being merely good enough and willingness to act on creative impulses is at the heart of corporate and financial inventiveness, as it allows individuals to overcome their natural inclination toward maintaining the status quo. Large institutions appear as focal points within networks of inventors not only because of the people they attract but also because of the constructive and problem-solving mentality they engender.

There are several limitations of this study. The online survey asked members to identify only the primary enabling or hindering factor to their successful patenting of an idea. There might have been several other factors of great importance that were not the primary one. The survey was administered only to members successful in receiving or filing patents and did not account for the inhibiting factors of members who failed to do so or failed to protect their IP. Although this study used patent filings as a metric of inventiveness, many SIR members contribute to the progress of procedures and devices by other means, including publications, and are not represented in this sample.

Perhaps most significantly, the low response rate of 16% subjects the results of this study to nonresponse bias. In such a situation, it is possible that SIR members with the most positive and negative experiences with patent filing and commercialization are expected to have a vested interest in responding, whereas the experience of the majority may be missed. The low response rate may be correlated with the timing of the survey coinciding with summer vacation months, a lack of interest in participating, or a lack of current e-mail addresses. Finally, although the analysis provided very generalizable insight to general innovation dynamics, it was limited to one type of medical innovation—interventional radiology and interventional neuroradiology.

In conclusion, the creativity and inventiveness of the 4% of SIR members holding patents or patent filings are seen to stem from institutions that are hubs of innovation and networks of key innovators who create entire new fields, facilitated by personal motivation, mentorship, and strong industry contacts. Fields in medicine go through windows of innovation similar to periods of incandescence (11), and these fields attract the best people at times of exuberant development, as interventional radiology and interventional neuroradiology experienced in the 1990s and early 2000s. Maintaining a healthy level of innovation when such periods end is much more difficult and, as this study indicates, requires a concerted effort on the part of high-level institutions and previously established inventors alike to foster bold thinking, risk taking, and pragmatism-based constructive creativity. John Stuart Mill (12) stated in *On Liberty* (1859): "The amount of eccentricity in society has generally been proportional to the amount of genius, mental vigour and moral courage which it contained. That so few now dare to be eccentrics marks the chief danger of the time."

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