Review

Current State of Bibliometric Research on the Scholarly Activity of Academic Radiologists

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In this review article, we discuss the literature pertaining to the bibliometric analysis of academic radiologists' scholarly activity in order to identify current trends, knowledge gaps, and potential future directions. Current research provides cross-sectional analyses of bibliometrics on three main themes: academic ranking, gender disparity, and research funding. The most commonly used parameters are the publication and the citation counts, the h-index and the number of years in academia. The h-index correlates positively with academic ranking and, in the case of editorial board members, with the journal's impact factor. Scholars who have secured National Institutes of Health funding tend to have higher h-indexes than those who have not. Whereas gender balance has been achieved in medical school and in several medical specialties, women remain significantly fewer than men in most areas of radiology. The underrepresentation of women is particularly noticeable at higher academic ranks and in leadership positions, suggesting that significant barriers to female radiologists' career advancement exist. Scholarly productivity of radiology residents and the impact of research on academic productivity are subjects that have received less attention in the published literature. Future studies should focus on whether bibliometric parameters can be used as reliable measurements of scholarly activity to help determine appointments, promotions and grant allocations, and to assess interventions that promote gender parity.

Key Words: H-index; Bibliometrics; Research productivity; Academic radiology; Gender disparity; Impact factor; Publications.

INTRODUCTION

The role of academic physicians has evolved significantly from the rudimentary "three-legged stool" model of academic medicine, comprising patient care, teaching, and research, since it was first defined at the turn of the 20th century (1). Whereas the concept of patient care has not changed considerably, *scholarly activity* has become an umbrella term to include the broad array of tasks performed by, and expected from, academic physicians. These involve not only teaching and research, but also administrative and leadership roles. There are four dimensions to scholarly activity: *discovery,* to generate new knowledge or expand on current concepts; *teaching,* to instill active learning and critical thinking in learners through the development of innovative pedagogical methods; *integration,* to elaborate multi-disciplinary approaches on a subject; and *application,* to transfer knowledge into practical intervention (2,3).

Evaluating the ability of academic physicians to effectively communicate the results of their scholarly activity through publication is an important part of overall scholarly performance assessment, as it often represents the finality of their efforts. For example, this may take the form of original research published in a peer-reviewed journal in terms of *discovery*, educational pictorial essays for *teaching*, multidisciplinary clinical practice guidelines when it comes to *integration*, and public healthcare policies for the *application* dimension. Although the scholarly work of an academic physician should be assessed with several criteria (4), it can be argued that the researcher's productivity and the impact of dissemination through publications may serve as a surrogate to determine overall scholarly activity performance.

The concept of *bibliometrics* refers to the quantification of scholarly productivity and has given rise to numerous evaluation tools and parameters (5). Among these, the most commonly employed is the h-index, which is defined as the *h* number of publications that were cited a minimum of *h* times (6). The h-index was introduced in 2005 by John Hirsch, a physicist from the University of California San Diego, and

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appraises both the quantity and the quality or impact of a scholar's productivity (6). Bibliometric research in academic medicine has evolved rapidly in several medical specialties, including radiology. A growing body of knowledge has emerged since the first article by Rad et al. (7) in 2010 on the academic productivity of radiologists based on bibliometric parameters. Considering the increasing interest in this area, our review aims to analyze the body of knowledge on scholarly productivity in academic radiology in order to identify current trends, knowledge gaps, and potential future directions.

METHODS

A literature search of PubMed, Embase, and Google Scholar was performed in August 2019 to identify all relevant studies investigating the scholarly activity of academic radiologists using advanced bibliometric parameters. Any study outside this scope or without any stated objectives was eliminated. The search strategy in PubMed was (radiology OR imaging) AND ((bibliometr* OR academic activity OR academic productivity) AND (citation* OR publication* OR h*index OR m*quotient OR e*index OR g*index OR i10*index)), and this was adapted to the other databases. There were no restrictions on publishing dates, study methodology, or journal. The first 30 most relevant results were evaluated on Google Scholar. The reference list of the selected articles was manually searched to screen for additional studies. A standardized form was employed to record study characteristics, notably a description of the study population, the stated objectives, bibliometric parameters used, and the main study findings. The process of identifying relevant studies for this review was conducted by the first and last authors.

RESULTS

Article Characteristics

The literature search yielded 376 results and their titles and abstracts were screened for relevance. Thirty-one full text articles were then read to determine if the study met the eligibility criteria of this review. Seventeen papers were included in the final review. A study conducted by the authors of this review (Lungu et al. 2018, unpublished data) was also considered, for a total of 18 studies included.

The 17 full-text papers included were published between 2010 and 2019. The list comprises general radiology journals, including *Academic Radiology* with 7 articles, the *American Journal of Roentgenology* with 4 articles, and the *Canadian Association of Radiologists Journal* and the *Journal of the American College of Radiology* with one article each. There were also subspecialty radiology journals: *American Journal of Neuroradiology, Skeletal Radiology, Journal of Vascular and Interventional Radiology* and *Emergency Radiology*, with one article each.

The studies provided cross-sectional analyses of various bibliometric parameters in relation to three main themes: ranking (individual (7–9) [Lungu et al. 2018, unpublished data], journal, (10) or department (11)), gender disparity (12-20) and research funding (21-23). The publication count, the citation count and the number of years in academia or since the first publication were frequently reported. The most commonly analysed advanced bibliometric parameter was the h-index. Two studies also used other advanced bibliometrics, which are ancillary to the h-index (8,23). The bibliometric parameters with their definitions are presented in Table 1. Fifteen studies used the Scopus database (Elsevier) to collect data on individual scholars, whereas three studies employed Web of Science. Along with Web of Science and Google Scholar, Scopus is one of the scientific databases that track citations (5). One distinctive advantage of the Scopus database is individual author identification making it possible to discriminate between scholars with similar names.

Themes Identified

Scholarly Productivity and Ranking

Six studies examined the relationship between scholarly productivity and either individual, journal, or departmental academic ranking. (Table 2) In their landmark paper, Rad and his colleagues demonstrated that in their sample of 683 radiologists from 47 American radiology programs, the h-index was positively associated with academic rank in an independent manner (7). Two other studies, respectively investigating the academic productivity of 313 Canadian academic radiologists (Lungu et al. 2018, unpublished data) and that of 583 members of the Association of University radiologists (8) found similar results. The range in mean h-indexes reported in those three studies was 2.3–5 for assistant professors, 4–11 for associate professors, and 12.5–27 for full professors. Interestingly, in the latter report, the authors also identified a higher m-quotient, defined as the h-index divided by the number of years since the first publication (Table 1), as a negative predictor of academic ranking, suggesting a greater publication output in a scholar's early career (8). As such, scholars with a higher academic rank may have a lower m-quotient compared to more junior scholars. The authors posited that, in addition to research productivity, higher academic standing requires demonstration of excellence in other areas such as patient care, teaching and administrative duties, which is achieved over time.

The study by Asnafi et al. (10) analyzed the academic productivity of 2204 radiology journal editors and determined their median h-index to be 23 (interquartile range of 13–35). They also found that editorial board members of journals with an impact factor above the median, had significantly higher h-indexes and overall bibliometric parameters compared to editors of lower impact journals.

A study by Rad et al. (9) of 487 radiologists found that self-citation did not influence the individual h-index. Finally, Tyrell et al. (11) investigated the impact of increasing the number of staff members on the group h-index at the Department of Medical Imaging of the University of Toronto, Canada. The authors reported that between 2000 and 2014, for every additional staff member the h-index increased by 1.5, whereas raising the median h-index of all members by 1 increased the departmental h-index by 15.7.

TABLE 1. Definitions of Basic and Advanced Bibliometric Parameters

Parameters		Definition	Examples
Basic	Advanced		
Publication count		A scholar's total number of peer-reviewed publications in journals indexed in a database such as PubMed or Index Medicus.	
Citation count		Total number of times the scholar's publications were cited.	
	h-index	*h* number of publications that were cited ≥ *h* times.	If 40 publications with 20 publications cited ≥ 20 times, then h-index is 20.
	i-10 (i-*n*) index	Total number of publications that were cited ≥ 10 or ≥ *n* times. May be used to dissociate impactful from less significant work.	If 20 publications were cited ≥ 10 times, then i-10 index is 20.
	m-quotient (or m-index)	h-index divided by number of years since first publication. Time-weighted citation to dissociate from temporal bias.	If h-index is 20 and first publication was 10 years ago, then m-quotient is 2.
	e-index	Average number of extra citations among the top *h* articles that do not count towards the h-index. Emphasizes frequently cited publications.	If h-index is 20, and the 20 publications counting towards the h-index have an average of 30 citations (i.e. 10 excess citations), then e-index is 10.
	g-index	Given a set of publications ranked in decreasing order for the number of times they were cited, the g-index is the number that the top *g* publications are cited an average of *g* times or are cited g^2 or more times. Gives an account of citations that are beyond the h-index.	If author has 20 publications, and the sum of the number of citations of the top 15 publications ranked decreasingly by number of citations is 225 (15^2), then *g*-index is 15.
	h_c-index	To calculate the contemporary h-index (h_c), each publication's citation count is multiplied by 4 and then divided by the number of years since publication. This index emphasizes more recent publications.	If scholar A has one paper published 2 years ago that was cited 8 times, then its h_c-index is $(8 \times 4)/2 = 16$.
			If scholar B has one paper published 4 years ago that was cited 8 times, then its h_c-index is $(8 \times 4)/4 = 8$.

Choudhri AF, Siddiqui A, Khan NR, Cohen HL. Understanding bibliometric parameters and analysis. *Radiographics* 2015; 35:736-746. doi: 10.1148/rg.2015140036. (reference #5).

Scholarly Productivity and Gender Disparity

Nine articles investigated the relationship between academic productivity and gender across several radiology subspecialties. (Table 3) Notably, Ahmadi et al. (13) showed in their sample of 465 neuroradiologists that, when adjusting for confounders including academic rank, female faculty members had odds of 0.84 compared with male faculty members, of having a higher h-index. In their group of 99 emergency radiologists, Battaglia et al. (14) found that female faculty had 1.15 times the odds of having a lower h-index when compared to male faculty, while adjusting for confounders including academic rank. A study by Khurshid et al., evaluating the gender disparity in 370 breast radiologists, found that women made up 70% of the faculty members and held 60% of the leadership positions. However, men were 2.1 times more likely to have a higher h-index when adjusting for confounders (17). Qamar et al. (19) investigated the relationship between gender and academic productivity and advancement in 274 academic musculoskeletal (MSK) radiologists in the US and Canadca. Women constituted 31% of faculty members and accounted for 26% of radiologists in leadership roles. The percentage distribution of female MSK radiologists relative to male MSK radiologists was highest at the assistant professor level (36%) and lowest at the full professor level (20%). When controlling for confounders, male MSK radiologists had 1.31 times the odds of having a higher h-index than female radiologists. Only one study investigating gender disparities in 420 interventional radiologists in North America found no significant differences in bibliometrics between men and women (20).

Two studies examined the impact of gender in academic publishing. Campbell and colleagues assessed the impact of

TABLE 2. Studies Investigating Scholarly Productivity and Ranking

Study	Study Population	Stated Objectives	Bibliometrics	Main Findings
Asnafi et al. 2017 (10)	2204 editorial board members of 62 Radiology journals with IF greater than 1	To determine whether editorial board members of Radiology journals with higher IF have higher h-indexes.	Publication count; citation count; non-self-citation count; citation per publication count; h-index;	• The median h-index of editorial board members was 23. • The median IF of the 62 journals was 2.27. • Board members of Radiology journals with IF $\geq$ 2.27 have significantly higher h-index and other evaluated bibliometrics.
Jiang et al. 2016 (8)	538 radiologists from the Association of University Radiologists	To evaluate associations between traditional and advanced bibliometrics and academic rank for radiologists in the US.	Publication count; citation count; h-index; i-10 index; h_c-index; m-quotient; e-index; g-index	• The h-index is the primary independent positive predictor of academic rank in a multivariate analysis. • The m-quotient is a strong independent negative predictor of academic rank when controlling for the h-index. • Other indices were not significantly associated with academic rank in a multivariate analysis.
Lungu et al. 2018, unpublished data	313 academic radiologists in the Province of Québec, Canada	To assess the publication and citation counts and the h-index of academic radiologists and examine whether academic rank is associated with scholarly productivity and gender.	Publication count; citation count; h-index	• The h-index but not gender is an independent determinant of academic rank.
Rad et al. 2010 (7)	683 radiologists in 47 randomly selected US residency programs (including 11 of the 25 departments benefiting from the highest amount of NIH funding)	To evaluate the h-index among US academic radiologists.	Publication count; citation count; h-index; citation per publication count	• The h-index, citation count and publication count, but not the citation per publication count, significantly correlate with academic rank. • The h-index for the top 25 NIH-funded radiology programs is significantly higher for associate professors, professors and chairpersons compared to the other programs.

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TABLE 2. (Continued)

Study	Study Population	Stated Objectives	Bibliometrics	Main Findings
Rad et al. 2012 (9)	487 chairpersons and full professors in 47 random academic departments in the USA	To evaluate the impact of self-citation on the h-index in academic radiology.	H-index; citation count with and without self-citations; publication count.	• The average h-index of radiologists at each academic rank appears to be lower than that for other fields of medicine. • Self-citation in academic radiology has no meaningful impact on the h-index. • Self-citation is responsible for a 2% increase in h-index. • Self-citation is responsible for a 1% to 3% increase in the number of citations.
Tyrell et al. 2017 (11)	Faculty members from the University of Toronto Medical Imaging department	To assess the combined h-index of the faculty members between 2000 and 2014 and to examine what factors influence a positive increase in departmental h-index.	Academic rank; total number of years in academia; publication count; citation count; h-index.	• Number of faculty members increased from 117 in 2000 to 186 in 2014. • Faculty members ranking correlates positively with their h-index. • The departmental h-index increased over time. • For every additional staff member, the departmental h-index increased by 1.5. • An increase in faculty member median h-index of 1 leads to an increase in departmental h-index of 15.7.

IF = impact factor.

TABLE 3. Studies Investigating Scholarly Productivity and Gender Disparity

Study	Study Population	Stated Objectives	Bibliometrics	Main Findings
Abdellatif et al. 2019 (12)	460 editorial members from 6 international general radiology journals	To assess the extent of the gender disparities reflected within the journal editorial boards of international radiology societies.	Publication count; citation count; h-index; total number of publishing years.	• 19% of members are women. • Men have longer publishing careers. • Men have higher publication and citation counts and h-index. • Women at higher academic ranks are less represented on editorial boards.
Ahmadi et al. 2018 (13)	465 neuroradiologists from 85 US and 8 Canadian radiology programs	To quantify the gender imbalance in neuroradiology faculty rankings, and explore factors that may contribute to such a disparity.	Publication count; citation count; h-index; total number of years in academia.	• 23% of faculty members are women. • Number of years spent in academia is greater among men. • Median h-index of men is almost twice that of women. • Women have 0.84 times the odds of having a higher h-index when adjusting for confounders.
Battaglia et al. 2019 (14)	99 emergency radiologists from 84 US and 8 Canadian radiology programs	To assess bibliometrics for women and men in academic emergency radiology sections.	Publication count; citation count; h-index; total number of publishing years.	• 22% of faculty members are women. • 95% of women are assistant professors. • Women have 1.15 times the odds of having a lower h-index when adjusting for confounders.
Campbell et al. 2019 (15)	1,934 original articles in *Radiology, American Journal of Roentgenology* and *Academic Radiology* (2011-2015)	To quantify the relationship between author gender and publication topic, and the impact of gender-related research.	H-index; years of practice; academic rank; Citation count; Authors' gender.	• Female last authors have a lower h-index, fewer years in practice and similar academic ranking than male last authors.

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TABLE 3. (Continued)

Study	Study Population	Stated Objectives	Bibliometrics	Main Findings
				• Citation count is greater for articles on women's and men's health than gender-neutral articles. • Researchers are more likely to publish on topics related to their own gender.
Hamidizadeh et al. 2018 (16)	2,826 executive, board and committee members from 18 North-American radiology societies	To outline and analyze the gender distribution in North American radiology society committee members and leadership.	Publication count; citation count; h-index; total number of years in academia.	• 33% of members are women. • Women hold 28% of the leadership positions. • Overall, higher bibliometrics values in men. • Lower representation of women at higher academic rank. • Women have 1.04 times the odds of having a higher h-index when adjusting for confounders.
Khurshid et al. 2018 (17)	370 radiologists from 170 US and 13 Canadian radiology programs	To assess the gender disparity among breast imaging radiologists.	Publication count; citation count; h-index; total number of publishing years.	• 70% of faculty members are women. • Women hold 60% of the leadership positions. • Men have 2.1 times the odds of having a higher h-index when adjusting for confounders.
Perez et al. 2019 (18)	511 coordinators invited to lead podium sessions at the Society of Interventional Radiology (SIR)	To assess gender diversity among session coordinators and to compare the academic productivity of the most published female IR (2012-2017) to that of recurring male faculty.	Publication count; h-index; first/last author publication count.	• From 2015 to 2017, women coordinated 7.1%, 4.3% and 13.7% of the podium sessions, and none of the plenary sessions at the SIR annual meeting.

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TABLE 3. (Continued)

Study	Study Population	Stated Objectives	Bibliometrics	Main Findings
Qamar et al. 2018 (19)	274 academic musculoskeletal (MSK) radiologists in the US and Canada	To quantify the relationship between gender, research productivity, and academic advancements in MSK radiology.	Publication count; citation count; h-index; total number of years in academia.	• Top published female interventional radiologists have equivalent bibliometrics than recurring male faculty. • 31% of faculty members are women. • 36% of assistant, 29% of associate and 20% of full professors are women. • Women account for 26% of radiologists in leadership roles. • Men have 1.31 times the odds of having a higher h-index when adjusting for confounders
Wang et al. 2019 (20)	420 interventional radiologists (IR) from 92 US and Canadian academic institutions	To investigate the effect of academic productivity measured using bibliometrics, on the academic advancements in interventional radiology.	Publication count; citation count; h-index; total number of years in academia.	• 10% of faculty members are women. • Equal gender representation at assistant and associate professor levels but lower representation of women (8%) at full professor level compared to men (15%). • Equivalent representation of women in primary leadership positions (15%) compared to men (15%). • No significant difference between genders in terms of stated bibliometrics

the last author's gender in 1934 radiology publications between 2011 and 2015, and found that female senior authors had significantly lower h-indexes, fewer years of practice, and similar academic ranking compared to male senior authors (15). Abdelattif et al. showed that male editorial board members from six international general radiology journals had significantly higher bibliometric parameters compared to female board members. Additionally, female radiologists with higher academic ranks were less represented on editorial boards (12). Two studies investigated the role of gender in scientific radiology societies (16,18). The larger study by Hamidizadeh et al. (16) demonstrated that among the 2826 North American radiology society board and committee members, there was a larger representation of male radiologists in proportion to leadership positions and greater values in bibliometric indexes for males. Perez et al. (18) examined the gender disparity among 511 coordinators invited to lead podium sessions at the Society of Interventional Radiology's annual meeting from 2015 to 2017. During that time period, men coordinated more than 85% of the meeting's podium sessions and 100% of the plenary sessions each year. Paradoxically, the authors found that the top published female interventional radiologists from 2012 to 2017 had equivalent bibliometrics to the recurring male faculty, suggesting an underrepresentation of academically productive female interventional radiologists.

Scholarly Productivity and Research Funding

Three studies assessed the relationship between academic productivity and funding (Table 4). In a study of 210 full professors of radiology, those who had secured at least one National Institutes of Health (NIH) grant had a higher *h* index, and those with an h-index of at least 10 were more likely to secure NIH funding (21). The same study reported no difference in the amount of funding received, whether researchers had an h-index above or below 10. Rosenkrantz et al. (23) showed that among 400 radiology investigators benefiting from NIH grants, the m-quotient was the only statistically significant predictor of funding for MD-only investigators, whereas the number of publications was most strongly correlated with funding for PhD investigators. A study by Rezek et al. (22) found that in 269 radiologists who had graduated from the Mayo Clinic between 1975 and 2005, a higher number of publications, a higher h-index, and more NIH funding were associated with a greater number of pre-residency publications.

DISCUSSION

Scholarly productivity is an important component of an academic portfolio and there has been a significant interest in identifying means to standardize performance assessment in the promotion process in recent years (24). Many academic institutions recognize two different academic pathways for appointments and promotion that are defined by the relative proportions in clinical work and teaching versus scientific research activities (25). Bibliometrics is best suited to assess research and publication activities. When it comes to publications in the field of radiology, the publication count, the citation count, the number of years in academia, and the h-index have been the most commonly evaluated bibliometric parameters.

Scholarly activity in radiology has been studied using three main themes: academic ranking, gender disparity, and research funding. Academic radiologists appear to be more prolific in the early years of their career, progressively expanding their accomplishments in the other areas of patient care, teaching, and administration with time (8). Interestingly, the publication rate of a scholar before entering the residency program is positively correlated with a successful academic career, which is worth considering when selecting candidates for residency or departmental appointments (22).

The h-index, which measures the quantity and quality of a scholar's publications, correlates positively with academic rank (7,8) and, in the case of editorial board members, with the journal's impact factor (10). Scholars who have secured NIH funding tend to have higher h-indexes than those who have not (21). Increasing the number of faculty members in a radiology department can lead to a significant increase in the group's h-index (11).

Although it is difficult to compare raw bibliometric values between specialties because of different publication and citation practices (36), trends similar to the ones identified in the current study have been reported in other medical and surgical specialties. Hence, a positive association between h-index values and academic rank has been shown in the fields of otorhinolaryngology (37) and ophthalmology (38). Similarly, scholars with higher academic productivity as measured with bibliometric indices tend to secure greater NIH funding in anesthesiology (39). Gender disparities in terms of scholarly productivity, namely significantly higher values of h-index for male compared to female faculty at the same academic ranking, have been demonstrated in the field of surgery (40). These similarities suggest that the findings regarding the dominant themes in this study transcend the field of radiology.

Any observations derived from bibliometric research should be interpreted in light of the inherent shortcomings of the studied parameters. The number of publications, citations and consequently the h-index can vary, sometimes substantially, among databases (5). The number of citations can be a flawed metric if a publication is receiving a high number of citations critical of the publication, as negative and positive citations carry the same weight (5). Moreover, a high quality educational publication may receive a small number of citations, but it's scholarly impact can be nevertheless significant (5). Finally, the number of years in academia can be biased by time devoted to non-scholarly professional activities such as administrative duties or by leaves of absence. One important limitation of the publication count and of the h-index, as emphasized by Rad et al. (7), is the *"minor co-author role limitation."* Accordingly, co-authors who have contributed less in

TABLE 4. Studies Investigating Scholarly Productivity and Research Funding

Study	Study Population	Stated Objectives	Bibliometrics	Main Findings
Rezek et al. 2011 (21)	210 full professors of radiology from 47 random academic departments in the USA	To determine if NIH grant funding status is correlated with the h-index among radiology professors.	Number of grants awarded and renewed from 2001 to 2010; total number of years of funding; grant category; total awarded funds from 2001 to 2010; h-index.	• 23% (48 professors) secured at least one NIH grant. • Having secured at least one NIH grant is associated with a higher h-index. • H-indexes greater than 10 are not significantly predictive of greater funding. • No significant correlation between h-index and: number of grant awards, years of funding; grant award amount or category.
Rezek et al. 2012 (22)	269 radiologists who graduated from Mayo Clinic Department of Radiology between 1975 and 2005	To determine whether publication prior to matriculation into residency is predictive of long-term academic productivity.	Pre-residency, during, and after residency publication count; NIH awarded grant count, type and amount; status as principal investigator; h-index.	• 68% (182) without publications prior to residency; 10% (27) with one; 22% (60) with more than one. • Higher number of publications, higher h-index and greater amount of NIH funding in radiologists with more than one pre-residency publications. • NIH funding status correlates significantly with pre-residency publication history.
Rosenkrantz et al. 2016 (23)	400 investigators with NIH grant funding (44 MD and 356 PhD or MD/PhD) with an appointment in a radiology department in the USA	To compare associations between bibliometric indices and the amount of NIH grant funding.	Publication count; citation count; h-index; i-10 index; hc-index; m-quotient; e-index; g-index.	• Bibliometric indices are moderately associated with grant funding for PhD and weakly associated for MD investigators. • For MD, the m-quotient exhibited the largest, albeit weak, correlation, with funding. • For PhD and MD/PhD investigators, publication count and hc-index were the strongest predictors of NIH grant funding.

NIH = National Institutes of Health.

the making of a publication benefit from the same h-index advancement as the primary authors, who would typically appear as first, second or last author of a given paper. This may lead to an overestimation of the recognition of scholars who, as part of a research team, are consistently involved as collaborators rather than principal investigators. Therefore, when assessing academic accomplishments, the percentage contributed by a scholar to his or her publications should be acknowledged in order to modulate the scholar's h-index and publication count. Another limitation of the h-index is that it does not take into consideration the hierarchical rank of the journal, for example the two-year Impact Factor, which is supposed to represent the average quality of the accepted paper. The h-index is also oblivious to the research capacity of a scholar's institution. Hence, academicians working at smaller institutions, which do not have the financial resources, research infrastructure or expertise of peers that might be found at larger institutions, may have less opportunity to carry out high quality research and improve their h-indexes. In fact, one study reported that the h-index for the top 25 NIH-funded radiology programs were significantly higher for associate professors, professors and chairpersons compared to non-NIH funded radiology programs (7). Finally, it is worth mentioning that more complex bibliometric parameters can provide complementary information, such as the rate at which the author publishes (m-quotient) or the emphasis on more impactful scholarly work (i-*n* index), among others. Their main limitation includes the fact that they are not automatically provided by most bibliographic databases, and that their computation can be cumbersome.

Whereas in recent years gender balance has been achieved in medical school and in many medical specialties, women remain significantly underrepresented in radiology (26,27). Although the proportion of female editorial members has increased in the past two decades (28), men still outnumber women by at least 70%−30% in radiology, in subspecialties and on journal editorial boards (12−14,16,19). Only in breast imaging is the distribution reversed in favor of women, including for the number of faculty members and of leadership positions held (17). The representation and bibliometrics of men and women at the assistant and associate professor levels tend to be similar, however, there is an underrepresentation of women at higher academic ranks suggesting that significant barriers to female radiologists' career advancement exist (20). This observation is further supported by studies which have shown that when controlling for age and the number of years in academia, which are generally lower for women in radiology, the female radiologists' average publication count, citation count and h-index tend to be smaller than those of their male counterparts (13,14,17,19). More part-time work, time taken for maternity leave or preference for clinical and educational track appointments have been suggested as external factors likely to prevent female radiologists from achieving the same level of scholarly productivity as male radiologists (29-32). A survey of NIH-funded young physician-researchers found that women researchers with children spent significantly more time on parenting and domestic activities then their male counterparts, to the detriment of time dedicated to research activities (33)]. These observations underline the necessity to implement creative interventions to promote the integration of the professional and parental roles for women in order to empower them to reach their potential, as suggested by Wang & Mahoney (34). Strategies such as introducing integrated interventional radiology/diagnostic radiology residency programs that draw candidates from a pool of medical students consisting predominantly of women instead of the traditional fellowship path that recruits candidates from a more male-represented pool of radiology residents may also contribute to diminish the underrepresentation of women in our field (35).

Likely due to the relative infancy of the subject, bibliometric research on the scholarly productivity of academic radiologists remains descriptive, reporting mostly on cross-sectional samples. As the evidence on dominant themes becomes more consistent, the main challenge will be to investigate whether these parameters can successfully be applied in the field. Questions such as whether the h-index or other parameters can be used as reliable measures of academic performance to inform decisions regarding appointment, promotion, tenure, compensation, as well as grant allocation, and whether they outperform current practices, may be the focus of future studies. Additionally, the research area will ultimately benefit from longitudinal studies evaluating the situation over time, thus establishing the efficacy of specific interventions, such as the promotion of gender parity. Further research may also provide evidence on themes that have received less attention in the published literature, for example the scholarly productivity of radiology residents and the impact of research infrastructure on academic productivity.

CONCLUSION

In brief, we identified 18 studies on advanced bibliometric parameters evaluating academic productivity in radiology. The predominant themes were the cross-sectional characterization of the scholarly achievements of a group of radiologists, the impact of gender on academic productivity and scholarly productivity in correlation with academic ranking and research funding. There is a positive association between academic ranking and scholarly activity. There is an important disparity in female representation at higher academic ranks and in leadership positions. Considering that most studies are descriptive in nature, the main challenge will be the implementation of bibliometrics in current practice. Understanding these realities is paramount for academic heads and other individuals in leadership positions.

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