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Funding of Radiology Research: Frequency and Association With Citation Rate

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OBJECTIVE. The purpose of this study is to investigate the frequency of funded research published in major radiology journals and to determine whether funding is associated with the article citation rate.

MATERIALS AND METHODS. A total of 600 consecutive original research articles published in three journals—*AJR*, *Radiology*, and *European Radiology*—were included. Linear regression analysis was performed to determine the association between research funding and the article citation rate, as adjusted for journal, continent of origin of the first author, subspecialty, study findings included in the article title, number of authors, immediate open access publication, and time since publication online.

RESULTS. Funding was declared for 286 of 600 included articles (47.7%). Sources of funding were as follows: federal sponsorship (29.4%), a nonprofit foundation (16.4%), both federal sponsorship and a nonprofit foundation (16.1%), private industry (10.1%), intramural institutional research funding (9.8%), and other funding sources (18.2%). Articles with first authors whose continent of origin was Europe ($p < 0.001$), vascular and interventional radiology articles ($p < 0.001$), and articles published in *AJR* ($p < 0.001$) were significantly more frequently unfunded than funded. Articles published in *Radiology* were significantly more frequently funded ($p < 0.001$). The citation rate was not significantly different between funded and unfunded articles ($p = 0.166$). In adjusted linear regression analysis, funding was not significantly associated with the citation rate (β coefficient, –0.31; 95% CI, –3.27 to 2.66; $p = 0.838$).

CONCLUSION. Almost half of the research articles published in major radiology journals declared funding, a proportion that has increased compared with findings from previous studies (17% of articles in a study from 1994 and 26.9% of articles in a study of literature published between 2001 and 2010). Most funded articles received support from federal sponsors or nonprofit foundations, whereas only a minority of funded articles were supported by private industry. Funding was not associated with a higher citation rate.

Keywords: bibliometrics, financial support, financing, organized, radiology

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Medical research is essential to improving health care. The costs of conducting research include salary for personnel, material expenses, and publication charges. However, obtaining funding for medical research has become increasingly difficult in an environment of decreasing clinical revenues, increasing research costs, and growing competition for less available funding [1]. Accordingly, data from the U.S. National Library of Medicine show that there has been a decline in funding support for articles in MEDLINE in the past few years [2]. Sources of funding should allocate financial resources to research projects that achieve the highest scientific impact, which may be measured by the citation rate of published research [3]. A study published in 1994 showed that, at that time, only a small percentage (17%) of radiology research attracted formal financial support [4]. Researchers were concerned about this low percentage and suggested that action was required to procure funds to support the radiology research necessary for the vitality of the specialty [4]. A later study analyzing radiology literature published between 2001 and 2010 showed that a larger percentage (26.9%) was funded [5]. To our knowledge, there has been no recent investigation of the status of radiology research funding and whether funded radiology research has a higher citation rate than nonfunded research. This information may be valuable to both researchers and funding organizations that plan to generate and dissem-

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inate the most impactful research in radiology. Therefore, the purpose of the present study was to investigate the frequency of funded research published in major radiology journals and to determine whether funding is associated with the citation rate.

Materials and Methods

Ethics committee approval was not applicable to this literature study.

Data Collection

A research fellow included 600 consecutive original research articles electronically published by *AJR*, *Radiology*, and *European Radiology* (200 articles from each journal) beginning in January 2016. The last included article was electronically published in October 2016. A start date of 2016 was chosen to ensure both that funding data were still sufficiently up to date and that the follow-up was sufficiently long for published articles to accumulate citations (it has previously been shown that the mean number of citations that an article receives annually reaches a peak in the third year after publication [6]). Data extraction was performed in October and November 2019, so that the time during which an article could accumulate citations was at least 3.1 years (mean, 3.6 years). Review articles (including guidelines, consensus developments, narrative reviews, and systematic reviews and meta-analyses), editorials, letters to the editor, and case reports were excluded. The following data were extracted from each included article: declared funding (articles in which no funding source was mentioned were considered unfunded), type of funding (federal sponsoring, private industry, nonprofit foundation, or intramural institutional research funding), continent of origin of the first author, subspecialty (breast imaging, cardiac imaging, contrast media, experimental studies, gastrointestinal imaging, genitourinary imaging, head and neck imaging, health care policy and quality, medical physics and technical developments, musculoskeletal imaging, neuroradiology, nuclear medicine and molecular imaging, pediatric imaging, special article, thoracic imaging, and vascular and interventional radiology), inclusion of study findings in the article title, the number of authors, whether or not the article had immediate open access publication, the number of days the article had been online (calculated as the number of days between the date that the article was analyzed for the present study and the date of electronic publication as indicated on MEDLINE), citation rate (as indicated on Clarivate Analytics's Web of Science research platform), and total number of article downloads (as indicated on the *Radiology* and *European Radiology* websites; number of downloads are not provided on *AJR* Online) as shown on the website on the date that the article was analyzed for this study.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows software (version 20.0, IBM). Differences in dichotomous variables between articles with and without declared funding were assessed using the Pearson chi-square test. However, when the number of articles in any cell of the contingency cell was five or less, the Fisher exact test was used instead of the Pearson chi-square test. Differences in continuous variables were assessed using the Mann-Whitney *U* test. Adjustment for multiple testing was done using false-positive rate control [7]. Linear regression analysis was performed to determine the association between funding and the citation rate, as adjusted for journal, continent of origin of the first author subspecialty, inclusion of study findings in the article title, number of authors, immediate open access publication, and number of days that the article had been online. With the use of eight variables and an a priori sample size calculator for multiple regression (available at Free Statistics Calculator website), it was determined that approximately 500 articles needed to be included to detect a small-to-medium effect size ($f^2 = 0.03$) with a statistical power of 80% ($\alpha = 0.05$). We also determined the association between funding and the number of article downloads (for *Radiology* and *European Radiology* only). Statistical significance was denoted by $p < 0.05$.

Results

Funding was declared in 286 of 600 included articles (47.7%). Sources of funding were as follows: federal sponsorship (29.4% of articles), a nonprofit foundation (16.4%), both federal sponsorship and a nonprofit foundation (16.1%), private industry (10.1%), intramural institutional research funding (9.8%), and other combinations of funding sources (18.2%). The main characteristics of the included articles are presented in Table 1. Articles with corresponding authors from Europe were significantly more frequently unfunded than funded (33.8% vs 21.7%; $p < 0.001$). Articles in the vascular and interventional radiology subspecialty were significantly more frequently unfunded than funded (12.1% vs 4.5%; $p < 0.001$). Articles published in *AJR* were significantly more frequently unfunded than funded (45.2% vs 20.3%; $p < 0.001$). Articles published in *Radiology* were significantly more frequently funded than unfunded (44.8% vs 22.9%; $p < 0.001$). Funded articles had a higher number of authors (mean, 8.7 vs 6.9; $p < 0.001$) and were more frequently published immediately as open access articles (32.2% vs 7.0%; $p < 0.001$). The citation rate was not significantly different ($p = 0.166$) between funded articles (mean, 13.4 citations; range, 0–134 citations) and unfunded articles (mean, 111.8 citations; range, 0–148 citations). In adjusted linear regression analysis, funding was not significantly associated with the citation rate (β coefficient, –0.31; 95% CI, –3.27 to 2.66; $p = 0.838$). Declared funding also was not significantly associated with the number of downloads (β coefficient, –30.18; 95% CI, –331.81 to 271.44; $p = 0.844$).

Discussion

The results of the present study show that almost half (47.7%) of original research articles published by major radiology journals in 2016 were formally funded. This is an increase compared with findings from previous studies, which indicated that only 17% and 26.9% of original articles published in *AJR* and *Radiology* were formally funded in 1990 and between 2001 and 2010, respectively [4, 5].

Most funded articles were supported federally or by nonprofit foundations, whereas a smaller number of funded articles were supported by private industry. Articles with corresponding authors from Europe were significantly more frequently unfunded. We also found that vascular and interventional radiology articles were significantly more frequently unfunded. Original articles published in *Radiology* were significantly more frequently funded, whereas those published in *AJR* were significantly more frequently unfunded. Compared with unfunded articles, funded articles more frequently received immediate open access publication. This may be explained by study funders providing open access publishing. Accordingly, the U.S. National Institutes of Health, which is the largest source of funding for medical research in the world, makes all peer-reviewed articles that it funds publicly available on PubMed Central [8].

A previous study of the most cited articles in more than 200 science categories found a positive correlation between the number of funding sources and the citation rate [9]. Another study of nanotechnology articles found that funded research had a higher citation rate than unfunded research [10]. To our knowledge, the present study is the first to investigate the association between study funding

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TABLE 1: Main Characteristics of Included Research Articles

Characteristic	Funded Research (*n* = 286)	Unfunded Research (*n* = 314)	*p*
Continent of origin of the first author			
Asia	95 (33.2)	78 (24.8)	0.024[a]
Australia	3 (1.0)	6 (1.9)	0.509
Europe	62 (21.7)	106 (33.8)	< 0.001[b]
North America	126 (44.1)	122 (38.9)	0.196
South America	0 (0)	2 (0.6)	0.500
Subspecialty			
Breast imaging	26 (9.1)	26 (8.3)	0.724
Cardiac imaging	17 (5.9)	8 (2.5)	0.038[a]
Contrast media	0 (0)	3 (1.0)	0.097
Experimental studies	14 (4.9)	4 (1.3)	0.014[a]
Gastrointestinal imaging	35 (12.2)	40 (12.7)	0.853
Genitourinary imaging	17 (5.9)	34 (10.8)	0.032[a]
Head and neck imaging	7 (2.5)	12 (3.8)	0.337
Health care policy and quality	7 (2.5)	9 (2.9)	0.751
Medical physics and technical developments	38 (13.3)	25 (8.0)	0.034[a]
Musculoskeletal imaging	19 (6.6)	35 (11.1)	0.054
Neuroradiology	40 (14.0)	29 (9.2)	0.069
Nuclear medicine and molecular imaging	16 (5.6)	6 (1.9)	0.016[a]
Pediatric imaging	9 (3.1)	22 (7.0)	0.033[a]
Special article	2 (0.7)	5 (1.6)	0.454
Thoracic imaging	26 (9.1)	18 (5.7)	0.115
Vascular and interventional radiology	13 (4.5)	38 (12.1)	< 0.001[b]
Journal			
AJR	58 (20.3)	142 (45.2)	< 0.001[b]
Radiology	128 (44.8)	72 (22.9)	< 0.001[b]
European Radiology	100 (35.0)	100 (31.8)	0.418
No. of authors, mean (range)	8.7 (2–31)	6.9 (1–17)	< 0.001[b]
Immediate open access publication	92 (32.2)	22 (7.0)	< 0.001[b]
Citation rate, mean (range)	13.4 (0–134.0)	11.8 (0–148.0)	0.166
No. of downloads, mean (range)[c]	1611 (216–12,384)	1687 (168–53,317)	0.011[b]

Note—Except where otherwise indicated, data are number (%) of research articles.
[a]Significance lost after adjustment for multiple testing using false-positive rate control.
[b]Statistically significant.
[c]Applies to *Radiology* and *European Radiology* articles only.

and the citation rate in the field of radiology. We found that funded articles did not have a higher citation rate and that they also were not downloaded more frequently. This raises the question of whether funding sources currently allocate their financial resources to the best radiology research projects (i.e., projects that potentially have the highest impact on the improvement of health care). On the other hand, our data also suggest that formal funding may not be necessary to achieve equal scientific impact in the field of radiology. This information may be encouraging for junior researchers who do not yet have an established track record and for whom acquisition of funding may be more challenging than it is for senior researchers who have a certain reputation in their field. The same applies to researchers who live in regions in which funding resources are constrained.

The present study has some limitations. First, it includes only original articles from the *AJR*, *Radiology*, and *European Radiology*, whereas high-impact radiology-related research is also published in nonradiology journals. However, the *AJR*, *Radiology*, and *European Radiology* are major general radiology journals that publish original research mainly led by radiologists. Historical data [5] and data from the present study do indeed show that in 87% of articles published in one of these three journals, the first author was affiliated with a department of radiology or a radiology-related specialty. Second, the citation rate may not be the best indicator of the scientific impact of an article [11]. However, we did not find any significant association between funding and the number of article downloads either. It should also be noted though that multiple articles can be written using one research grant (and published in different journals). Therefore, it may be argued that a true measure of the scientific impact of research funding needs to take into account not only the cumulative citation rate related to the research funding but also the quantity of the publications produced. However, this may be impractical to investigate because there currently is no database that has a record of all funded radiology projects. Third, we investigated only the presence or absence of funding and not the amount of funding because this was not reported by any of the included articles. Fourth, because we investigated published articles only, the total frequency of funding for both published and unpublished work is unclear. However, peer-reviewed publication is the standard in science and the major medium through which researchers make information available to the public.

In conclusion, almost half the research articles published in major radiology journals declared funding, a proportion that has increased compared with findings from previous studies (17% of articles in a 1994 study and 26.9% of articles in a study assessing articles published between 2001 and 2010). Most funded articles were supported federally or by nonprofit foundations, whereas only a minority of funded articles were supported by private industry. Funding was not associated with a higher citation rate.

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