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*Published in:*
Clinical and Translational Imaging

*DOI:*
10.1007/s40336-021-00414-3



*Publication date:*
2021

Clinical and Translational Imaging (2021) 9:123–127
https://doi.org/10.1007/s40336-021-00414-3

MINI-REVIEW

# Funding of nuclear medicine research and association with citation impact

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Received: 29 November 2020 / Accepted: 13 January 2021 / Published online: 28 January 2021


## Abstract

**Purpose** There has been no recent investigation on nuclear medicine research funding. Our purpose was to investigate the frequency of funded nuclear medicine research and whether funding is associated with citation impact.

**Methods** Original articles published in three major nuclear medicine journals were assessed for funding.

**Results** 337 (56.2%) of 600 articles declared funding, which included federal sponsoring (47.6%), non-profit foundations (22.5%), intramural institutional foundations (16.0%), and private industry (13.9%). In linear regression analysis (adjusted for journal, continent of origin, mentioning of study findings in the article title, number of authors, open access publishing, and time since online publication), funding was significantly associated with citation impact (beta coefficient = 5.111, 95% CI, 1.005–9.217, $P = 0.015$).

**Conclusions** More than half of research in major nuclear medicine journals declared funding. The far majority were supported federally, followed by non-profit foundations, intramural institutional foundations, and private industry. Funding was associated with higher citation impact.

**Keyword** Financial support · Nuclear medicine · Research

## Introduction

Funding of research is defined as supply of money or pecuniary resources, for research purpose [1]. Major breakthroughs in nuclear medicine have not been possible without funding of research [2]. However, it has become more difficult to obtain research funding because of lower financial yields from clinical work, higher research costs (including personnel salary, material expenses, and article processing charges), and increasing competition between researchers for the relatively few funding sources [3]. Accordingly, there has been a decrease in funding for articles cited in MEDLINE/PubMed in the past few years [4]. Given the relative shortage, funding should be allocated to research which yields the highest scientific impact. The degree of scientific impact may be measured by the number of citations of published articles originating from the research [5]. Although the number of citations does not necessarily reflect quality [6], it is still the most commonly used measure of the scientific impact of a study and directly determines important scientometric indicators such as the author's h-index and journal's impact factor [7–10].

In the 1990s, nuclear medicine research in the USA was well supported by the government [11]. However, there was a considerable drop of federal research support in 2006 [12, 13]. The National Academy of Sciences report which followed as a response, concluded that this financial drop would jeopardize the advancement of nuclear medicine and that it would be critical to enhance funding [13]. To our knowledge, there has been no recent investigation on nuclear medicine research funding and whether funded research achieves a higher citation impact. This information may be valuable to researchers, funding organisations, and the community. Therefore, our purpose was to investigate the frequency of funded nuclear medicine research and whether funding is associated with citation impact.

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## Materials and methods

Ethics committee approval was not applicable for this literature study.

### Data collection

A research fellow (<BLINDED>) included 600 consecutive original articles published by Journal of Nuclear Medicine [14], European Journal of Nuclear Medicine and Molecular Imaging (EJNMMI) [15], and Clinical Nuclear Medicine [16] (200 for each journal) from January 2016. These three journals were selected because they are major general nuclear medicine journals with the highest impact factors in their field [17] and they publish original research mainly led by nuclear medicine physicians. The last included article was published in October 2018. Data extraction was performed in April 2020, so that time to accumulate citations ranged from 1.5 to 4.3 years (median of 3.8 years). The following data were extracted: declared funding (articles in which no funding source was mentioned were considered unfunded), type of funding (federal sponsoring, non-profit foundation, intramural institutional foundation, private industry), continent of origin of the first author, mentioning of study findings in the article title, number of authors, whether the article was published open access, number of days the article has been online, and number of citations [18]).

### Statistical analysis

Characteristics between funded research and unfunded research were compared in order to assess whether there were any relevant differences. Dichotomous variables were compared using the Pearson $\chi^2$ test or Fisher's exact test. Continuous variables were compared using the Mann–Whitney $U$ test. Adjustment for multiple testing was performed because the probability of committing false statistical inferences would considerably increase due to multiple comparisons. Adjustment was done using false positive rate control [19]. The association between funding and citation impact was assessed in accordance with our study purpose. To test this association, linear regression analysis was performed, adjusted for journal, continent of origin, mentioning of study findings in the article title, number of authors, open access publishing, and number of days that the article has been online. The slope of the regression model was expressed by the beta coefficient, which is the degree of change in the dependent variable (number of citations) for a change in the independent variable (funding vs. no funding). Based on seven variables, we a priori estimated that approximately 500 articles were needed to detect a small to medium effect size ($f^2$ of 0.03) with a statistical power of 80% ($\alpha = 0.05$) [20]. In order to test whether studies with different types of funding received different citation counts, we performed a one-way Analysis of Variance (ANOVA) test. Statistical analyses were executed using SPSS Statistics (Version 20.0, IBM Corporation, Armonk, NY, USA).

## Results

The main characteristics of included articles are displayed in Table 1. 337 (56.2%) of 600 articles declared funding, which included federal sponsoring (47.6%), non-profit foundations (22.5%), intramural institutional foundations (16.0%), and private industry (13.9%) (Fig. 1). Many articles were sponsored by a combination of different types of funding (Table 2). Articles in *Journal of Nuclear Medicine* were significantly more frequently funded than articles in *EJNMMI* (71.5% vs. 55.5%, $P = 0.001$) and *Clinical Nuclear Medicine* (71.5% vs. 41.5%, $P < 0.001$). *Articles* in *EJNMMI* were significantly more frequently funded than articles in *Clinical Nuclear Medicine* (55.5% vs. 41.5%, $P = 0.005$). Articles from North America were significantly more frequently funded than articles from Europe (71.0% vs. 48.8%, $P < 0.001$). Funded articles had more authors (median 9 vs. 8, $P < 0.001$) and were more frequently published open access (55.5% vs. 28.5%, $P < 0.001$). Funded articles were longer online (median 1411 days vs. 1351 days, $P < 0.001$). In adjusted linear regression analysis, funding was significantly associated with citation impact (beta coefficient = 5.111, 95% CI, 1.005–9.217, $P = 0.015$). There was no statistically significant difference between the different types of funding (federal sponsoring, non-profit foundation, intramural institutional foundation, private industry) and number of citations as determined by Welch's ANOVA ($P = 0.054$).

## Discussion

Our study shows that more than half (56.2%) of original research published by major nuclear medicine journals was formally funded. The far majority were supported federally, followed by non-profit foundations, intramural institutional foundations, and private industry. This demonstrates the importance of federal commitment to nuclear medicine research: many projects which require funding would not be possible without support from the government. Articles from North America were significantly more frequently funded than articles from Europe. This was also demonstrated by a previous study in the field of radiology [21] and suggests higher availability of funding for imaging research in North America. Articles in *Journal of Nuclear*

**Table 1** Main characteristics of the included articles

| | Funded research $n=337$ | Unfunded research $n=263$ | $P$ value |
|---|---|---|---|
| Journal | | | **< = 0.005*** |
| Journal of nuclear medicine | **143 (71.5%)** | **57 (28.5%)** | |
| EJNMMI | **111 (55.5%)** | **89 (44.5%)** | |
| Clinical nuclear medicine | **83 (41.5%)** | **117 (58.5%)** | |
| Continent of origin | | | **< 0.001*** |
| Asia | 87 (62.1%) | 53 (37.9%) | |
| Australia | 4 (57.1%) | 3 (42.9%) | |
| Europe | **156 (48.4%)** | **166 (51.6%)** | |
| North America | **88 (71.0%)** | **36 (29.0%)** | |
| South America | 2 (33.3%) | 4 (66.7%) | |
| Africa | 0 (0%) | 1 (100%) | |
| Median number of authors (range) | **9 (2–24)** | **8 (2–46)** | **< 0.001** |
| Study findings in article title | 43 (12.8%) | 33 (12.5%) | 0.938 |
| Open access | **187 (55.5%)** | **75 (28.5%)** | **< 0.001** |
| Median number of days online (range) | **1411 (593–1565)** | **1351 (563–1564)** | **< 0.001** |
| Median and mean number of citations (interquartile range, range) | 10 and 15.81 (13, 0–180) | 9 and 17.6 (13, 0–243) | 0.140 |

*Significant after adjustment for multiple testing using false positive rate control

Bold values indicates FDR of 0.05

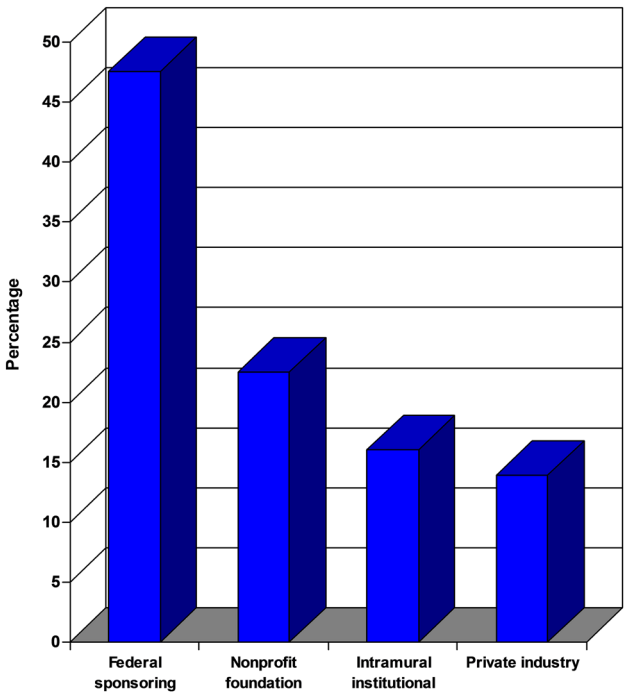


**Fig. 1** Types of funding for the 337 articles which declared funding

**Table 2** Overview of (combinations of) different types of funding for the 337 articles which declared funding

| Federal sponsoring | Non-profit foundation | Intramural institutional | Private industry | Number of articles (%) |
|---|---|---|---|---|
| X | | | | 123 (36.5%) |
| X | X | | | 40 (11.9%) |
| | X | | | 34 (10.1%) |
| | | | X | 33 (9.8%) |
| X | | X | | 29 (8.6%) |
| X | X | X | | 21 (6.2%) |
| X | | | X | 15 (4.5%) |
| | | X | | 12 (3.6%) |
| X | X | | X | 9 (2.7%) |
| | X | X | | 6 (1.8%) |
| | X | | X | 5 (1.5%) |
| X | | X | X | 4 (1.2%) |
| X | | X | X | 4 (1.2%) |
| X | X | X | X | 2 (0.6%) |

*Medicine* were significantly more frequently funded than articles in *EJNMMI* and *Clinical Nuclear Medicine*, whereas articles published in *EJNMMI* were significantly more frequently funded than articles in *Clinical Nuclear Medicine*. Funded articles had more authors and were published more frequently open access. This double difference likely exists because many granting bodies demand the papers to be published in open access, thus influencing researchers through funding to make science more accessible. In addition, funders such as the National Institutes of Health provide open access publishing [22, 23].

To our knowledge, our study is the first to investigate the association between funding and citation impact in nuclear medicine. A previous study among the 500 most cited articles of each science category (total of 236 categories) found a positive association between the number of funding sources and citation impact [24]. A recent study among major radiology journals found no association between funding and citation impact [21], which contrasts our finding that funded articles in the field of nuclear medicine achieved a higher citation impact. We speculate that it may be more expensive to perform impactful nuclear medicine research than radiology research (higher expenses for tracer development, production, and storage, equipment, and required personnel). Thus, more funding may be needed to perform impactful nuclear medicine research than radiology research. Our finding may indicate that funding sources have generally allocated their resources to the best nuclear medicine research projects (i.e., projects which potentially have the highest impact on healthcare improvement). Nevertheless, any funding decision is a guess, based not on only on the potential future impact of the proposed research but also on the name and impact of the researcher in the past (underpinning the Matthew effect in science [25]). Our data also show that formal funding is not a prerequisite to obtain a scientific publication in a major nuclear medicine journal. This information may be encouraging for upcoming researchers for whom acquisition of funding may be more challenging than for senior researchers who already have a certain reputation. The same applies to researchers who live in developed healthcare regions in which funding resources are constrained.

Our study has some limitations. First, we only investigated the presence but not the amount of funding, since this was not reported by any of the included articles. Second, we included only articles from three major nuclear medicine journals, whereas high-impact nuclear medicine-related research is also published in other journals. However, *Journal of Nuclear Medicine*, *EJNMMI*, and *Clinical Nuclear Medicine* are major general nuclear medicine journals with the highest impact factors in their field [17] and they publish original research mainly led by nuclear medicine physicians. Third, multiple articles can originate from one research grant. Therefore, it may be argued that a true measure of the scientific impact of research funding needs to take into account not only the citation impact, but also the number of publications. However, this may impractical to investigate, because there is currently no database which record all funded nuclear medicine projects. Fourth, we relied on the declaration of funding (federal sponsoring, non-profit foundation, intramural institutional foundation, private industry) by included studies, As such, we cannot fully exclude that some "unfunded" studies were supported by nonreported funding. Fifth, because we only investigated published articles, the total frequency of funding for both published and unpublished work is unclear. However, peer-reviewed publication is the scientific standard.

In conclusion, more than half of research published in major nuclear medicine journals declared funding. The far majority of funded articles were supported federally, followed by non-profit foundations, intramural institutional foundations, and private industry. Funding was associated with higher citation impact.

**Author contributions** RHMA: Literature search, Literature review, Data extraction, Writing. TCK: Literature search, Literature review, Writing, Editing, Content planning, Supervision. RMK: Literature search, Literature review, Writing, Editing, Content planning, Supervision.

**Funding** None.

## Compliance with ethical standards

**Conflicts of interest** None.

**Consent for publication** All authors give consent for publication.

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