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Original Article

Publication trends in noninvasive cardiovascular imaging: 1991-2011: a retrospective observational study

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Abstract: The last twenty years have seen an explosive growth in cardiovascular disease research. The purpose of our study was to evaluate the characteristics of published research in the field of non-invasive cardiovascular imaging research from 1991-2011. Our aims were to determine: (1) the origin of the studies (international or from the U.S.) (2) differences in funding sources for U.S. publications and (3) if there has been an evolving trend pertaining to the mode of imaging. We evaluated characteristics of original research articles from Circulation, Circulation cardiovascular imaging, Journal of the American College of Cardiology (JACC), Journal of the American College of Cardiology cardiovascular imaging, Journal of the American Medical Association and the New England Journal of Medicine for the years 1991-91, 2001-02 and 2010-11. To establish trends for contributions for U.S. based studies and proportions of U.S. based studies receiving NIH funding in the study period, data was compared using a *chi-square test*. A two sided *p* value of less than or equal to 0.05 was used as the threshold for significance. Differences in modes of imaging under study were made by comparing average number of publications between the data sets in the study period using a *t*-test analysis. A total of 5431 studies were reviewed; 594 studies were selected as per the standardized abstraction criteria. U.S. based publications outnumbered international publications; its' share declined from 77% in 1991-92 to 57% in 2010-2011 ($p<0.0001$). Funding for U.S. publications by the National Institutes of Health (NIH) remained static (1991-92: 40%; 2001-02: 49%; 2010-11: 42%). A decline was seen in the investigation of echocardiography (47%, $p=0.44$); cardiac computed tomography and cardiac magnetic resonance imaging studies grew 6.5 times ($p=0.002$) and 7-fold ($p=0.01$) respectively. Nuclear cardiology imaging fell by more than 50% ($p=0.02$). The last twenty years have seen a globalization of research in non-invasive cardiovascular imaging with a shift in focus towards investigation of cardiac magnetic resonance imaging. The decline in U.S. based publications coupled with a stasis in NIH funding may call for increased federal support for non-invasive imaging research.

Keywords: Cardiac, imaging, cardiovascular research, National Institutes of Health, funding, diagnostic techniques, echocardiography, Doppler, MRI, computed tomography

Introduction

The increasing utility of diagnostic imaging over the past two decades has attracted the attention of various stakeholders including patients, physicians, health policy makers and the news media [1-3]. Furthermore, the increasing burden of cardiovascular disease has led to cardiovascular imaging becoming a key player in cardiovascular research, and a cornerstone of diagnosis and management. Despite the proliferation of cardiovascular imaging, little is known about trends in cardiovascular imaging research.

The purpose of our study was to evaluate secular trends in published non-invasive cardiovascular imaging research. Specifically, we sought to determine trends in country of origin of studies being published, sources of funding, and modes of imaging under investigation.

Methods

Source of data

This study was a retrospective observational study of published data and was exempt from Institutional Review Board approval.

We collected data by reviewing original research articles evaluating a non-invasive cardiac imaging modality. To ensure diversity in the data we collected, we reviewed publications from six high impact American journals. Of the six journals that were selected for review, four were journals dedicated to the field of cardiovascular medicine, while the other two were Internal Medicine journals. The six journals were Circulation, Circulation cardiovascular Imaging, Journal of the American College of Cardiology (JACC), JACC cardiovascular imaging, New England Journal of Medicine (NEJM) and the Journal of the American Medical Association (JAMA).

Data selection

All the journals were reviewed in their entirety for the years 1991-1992, 2001-2002 and 2010-2011, with the exception of Circulation cardiovascular imaging and JACC cardiovascular imaging, where the data was available only for the time period of 2010-2011. The search was initiated by the key words "imaging" or "cardiac imaging". The data was subsequently narrowed down for inclusion in the study based on the following criteria: (1) Original research articles including clinical and basic science reports and (2) the study design was based on assessment of diagnostic and/or predictive value of a device/tool (non-invasive imaging modality) as a novel method for cardiovascular imaging or comparison versus a pre-existing modality. A publication was excluded if: (1) the manuscript was a review article, brief report, correspondence or letter, (2) investigations that involved noninvasive cardiovascular imaging as part of the study design but did not include the assessment of the imaging modality as the primary objective of the study, (3) studies based on cardiovascular imaging involving invasive modalities e.g. angiography, intravascular ultrasound or optical coherence tomography and/or (4) investigations that focused on non-invasive imaging not pertaining to cardiovascular medicine e.g. neuroimaging.

Data extraction and analysis

All selected studies were abstracted based on the above defined selection criteria. The data abstraction was done by either S.M. or M.P. The abstracted studies were categorized on basis of origin of the study, source of funding for publications emanating from U.S. institutions and the mode of imaging that was investigated.

The origin of the studies was designated as being from the U.S. or as international. The two criteria that were used to define U.S. based publications were if (1) the study was based solely in the U.S. and (2) the publication was contributed to, at least in part by the U.S., as in the case of certain large multicenter studies. Funding sources were categorized as (1) National Institutes of Health (NIH), (2) other industry including private sector, national society/non-profit agency sponsored, or (3) undisclosed funding sources. NIH support was acknowledged if it was the sole funding source for a study or where it had contributed along with other sources. The modes of imaging were broadly divided categorized as echocardiography, cardiac computed tomography scans (CCT), nuclear cardiology imaging and cardiac magnetic resonance imaging (CMR). The data was subdivided as data set 1, data set 2 and data set 3. Comparisons of percentages were made between the data sets to establish trends for contributions for U.S. based studies and proportions of U.S. based studies receiving NIH funding in the study period. Data was compared using a *chi-square test*. A two sided *p* value of less than or equal to 0.05 was used as the threshold for significance.

Differences in modes of imaging under study were made by comparing average number of publications between the data sets in the study period using a *t*-test analysis.

Results

Study demographics

A total of 5341 studies were reviewed. The total number of non-invasive cardiovascular imaging studies increased by nearly 29% (N=193 in 1991-1992; N=249 in 2010-2011) during the study period. The studies were analyzed as per the abstraction criteria; 594 studies were included in the final review (**Figure 1**). Notably for the 2010-2011 data, when compared to the 1991-1992 trends, nearly 3.5 times more data (i.e. a total of 2,828 studies) were available for review. This coincides with the inclusion of two additional imaging journals, Circulation cardiovascular imaging and JACC cardiovascular imaging.

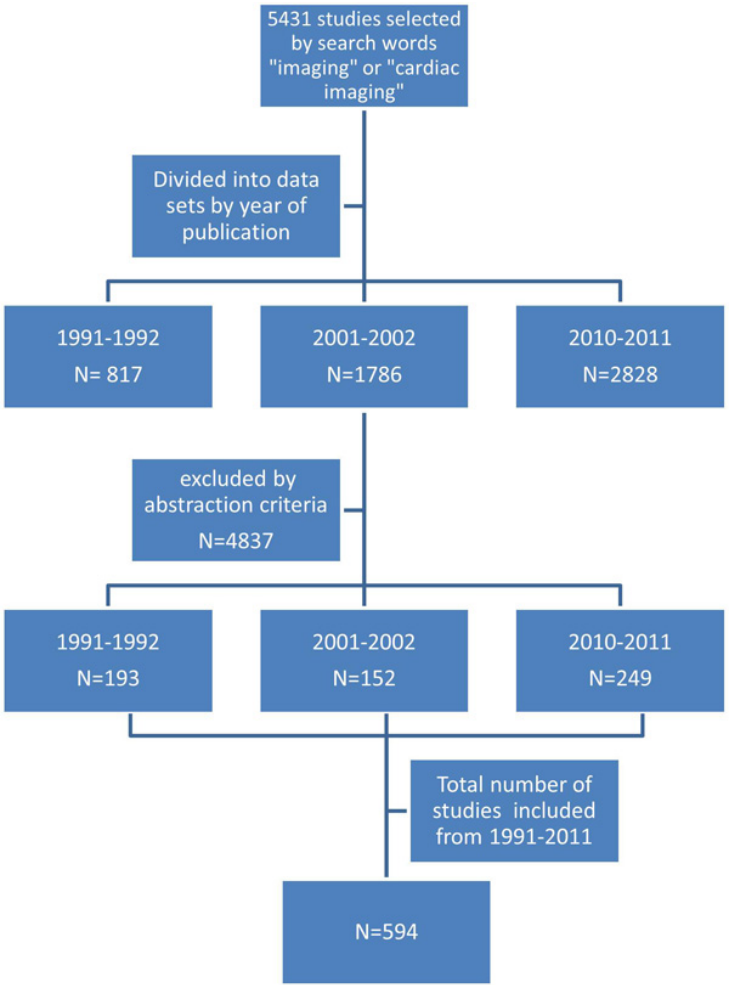

Figure 1. Flow chart depicting selection of data. 5431 studies were found using the words ''imaging'' or ''cardiac imaging''. The studies were divided into three data sets for the years 1991-1992, 2001-2002 and 2010-2011. A standardized abstraction criterion was used to exclude 4837 studies. Cumulatively, 594 studies were included in the final review for the study period.

Contribution of publications from the United States

We first sought to determine trends in country of origin of published noninvasive imaging reports. The United States contributed to 65% of total number of studies that were included. However, in spite of being the lead contributor in our review, a steady decline was noted in the percentage of publications from the U.S. over the three time periods studied. For example, from 1991-1992, 77% of publications were of U.S origin as compared with 57% in 2010-2011 ($p<0.0001$). Concurrently, the proportion of international publications nearly doubled from 23% to 43% over the same period ($p<0.0001$).

Trends in source of funding

Of the 385 U.S publications that were included in our review, a total of 165 received funding from the NIH, whereas 220 received funding from other industry, including undisclosed sources. Notably, the NIH support for U.S based publications remained relatively static during the study period (**Figure 2**). The percentage of U.S studies that were funded by the NIH was 40% in 1991-1992, 49% in 2001-2002 and 42% in 2010-2011. No difference was seen in the proportion of NIH funding when comparing the data trends from 1991-92 with 2001-2002 ($p=0.18$) or between 2001-2002 and 2010-2011 ($p=0.12$). Cumulatively, non NIH sources funded 33% more publications as compared with the NIH. The percentage of studies that did not disclose a funding source during the study period remained similar, 30.2% vs. 27.5% ($p=0.66$).

Trends in imaging modalities

Last, we evaluated trends in the type of non-invasive imaging under investigation. A comparison between the average numbers of publications in the years 1991-1992 to the years 2010-2011, revealed the following results (**Figure 3**): research studies focusing on echocardiography and CMR cumulatively accounted for more than half of the investigations which were included in the study period. However, studies which focused on echocardiography as a primary imaging modality showed a steady decline of almost 47% ($p=0.44$) over the study period while studies based on CMR showed a 7-fold increase ($p=0.01$). CCT based studies were fewer when compared with other imaging modalities in the study (13% of total), but the number of publications increased by 6.5 times ($p=0.002$). Investigations focusing on nuclear cardiology fell by more than 50% in 2010-2011 when compared with the 1991-1992 data trend ($p=0.02$) (**Figure 3**).

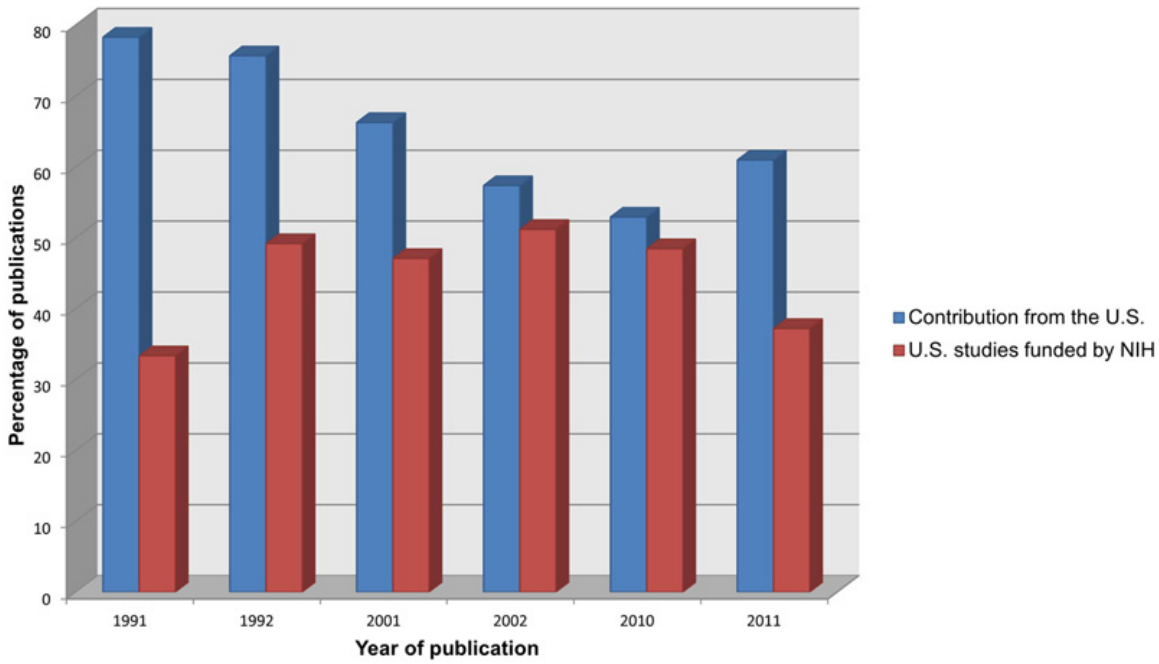

Figure 2. Comparison of total contribution of U.S. studies and NIH support. Data showing the contribution of studies from the U.S. as a percentage of the total publications for the years 1991-1992, 2001-2002 and 2010-2011. U.S. based studies that acknowledged receipt of NIH funding is expressed as a percentage of the U.S. based publications.

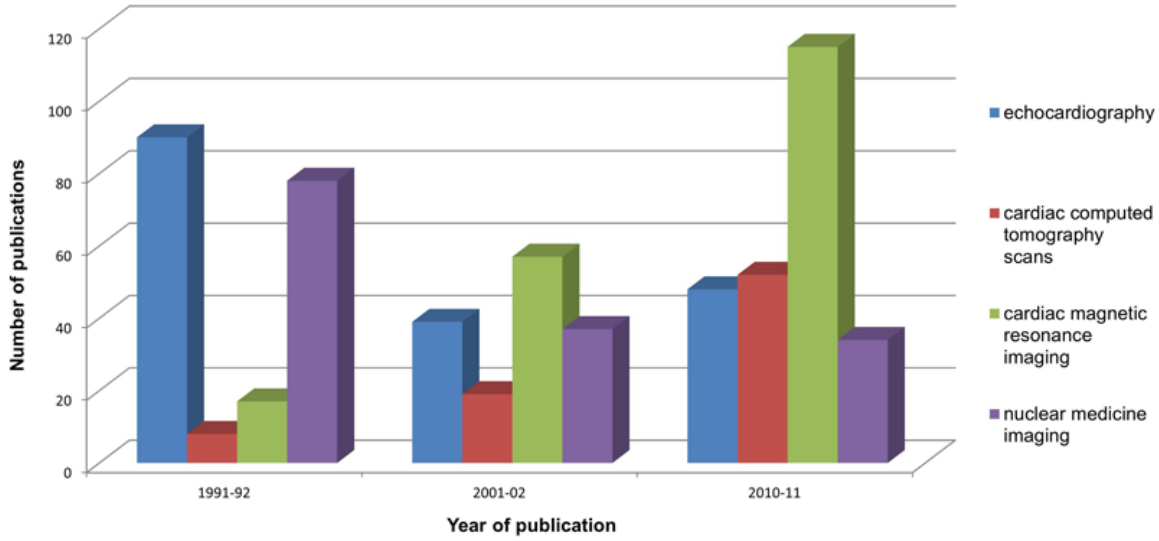

Figure 3. Comparison between different modes of imaging. Figure showing the total number of publications for each mode of imaging i.e. echocardiography, cardiac computed tomography, cardiac magnetic resonance and nuclear medicine imaging divided into three separate data sets for the study period 1991-2011.

Discussion

In this analysis of secular trends in published cardiovascular imaging research from 6 high impact journals, we observed an increase in international contributions to the literature, and a decrease in echocardiography and nuclear cardiology based imaging studies published with a concurrent increase in CMR and CCT based studies. Despite the strength of U.S. contribution, NIH funding did not exhibit any significant growth, both in terms of absolute num-

ber of publications that were funded and the relative proportion of the U.S. studies that were funded. In total, only 43% of U.S. based publications acknowledged receipt of NIH support; non NIH sources funded 33% more publications that the NIH.

In recent years, several studies have examined characteristics of cardiovascular research. Many studies have attempted to explore the relationship between various funding sources and their impact on published research in the field of cardiovascular medicine [4-6]. Some of the notable observations made from the studies included the following: (1) U.S. publications (including review articles, case reports, meta-analyses, general research and clinical trials) on general cardiovascular disease and the corresponding support from the NIH showed a steady, parallel growth in the years 1996-2006 [4], (2) the last 20 years have seen a globalization of clinical research, with a growing presence of industry sponsorship; however there has been a decrease in the clinical studies emerging from the U.S. alone [5] and (3) A sizeable portion of published cardiovascular research is being carried out without any direct financial support; authors from the United States are more likely to be funded than non-American authors; basic science researchers were more likely to receive funding as compared with clinical investigators [6].

Cardiac imaging has been the source of much discussion both among radiologists and cardiologists [1, 7]. The studies that emerged, have largely sought to define the diagnostic and clinical utility of all the available imaging modalities, both invasive and non-invasive, in relation to disease outcomes and costs of healthcare [8-10].

To our knowledge, our data are the first to characterize trends and characteristics of published research on non-invasive cardiovascular imaging.

In our study, the U.S. was noted to play a central role in non-invasive cardiovascular imaging research. However, of the 385 U.S. publications that were included in the study, only 165 acknowledged receipt of funding from the NIH, with an average of 27.5 (+/-3) papers being supported by the NIH annually. The stasis in the funding does not imply a decrease in the total dollars available from the NIH. A brief review of the NIH budget over the last two decades [11, 12] shows that the NIH budget increased by 90.6% from 1987 to 1997 [13]. From 1998 to 2003, the NIH budget, including that of the National Heart, Lung and Blood Institute (NHLBI), which is the strongest contributor to cardiovascular research, nearly doubled from $13.7 billion to $27.2 billion [11]. The years 2004 to 2008 marked a stagnation in the budget [4] along with a decreased spending for research by 8.6% from 2003-2007 (2004: $2.8 billion; 2008: $29.6 billion) [6]. However, in 2009, under the American Recovery and Reinvestment Act (ARRA) [14], the NIH received an additional $10.4 billion in funding (raising the 2009 and 2010 budgets to $30.5 billion and $31.2 billion respectively) which was to be spent by the end of the fiscal year 2010. The two periods of surge in the NIH budget between the years of 1987 to 1997 and 1998 to 2003, did not translate into an increase in either the absolute number of publications or a relative increase in the proportion of U.S based cardiovascular imaging studies in the years that followed. The published data for 2001-2002 and 2010-2011, which ideally, should have shown a boost in imaging publications, instead showed a continuing decline in the percentage contribution by the U.S. and no significant changes in the proportion of studies acknowledging NIH funding. Notably, the youngest of the NIH institutes, the National Institute of Biomedical Imaging and Biotechnology (NIBIB) which is dedicated to funding bioengineering and imaging research, has shown dramatic growth since its inception in the year 2000 [4]. The NBIB could have served as a potential catalyst for the growth of cardiac imaging research in the U.S.; however, the NIBIB has maintained its focus on clinical research in radiology with relatively fewer contributions thus far to cardiac imaging [15].

The final question that was addressed was if there was an evolving trend with regard to the modes of imaging that were investigated in the study period, namely echocardiography, nuclear cardiology including PET (positron emission tomography) scans, CCT and CMR. The decade of the 1970s heralded the advent of clinical 2-dimensional echocardiography, followed by pulsed Doppler and then color Doppler in the 1980s [16]. This is well reflected with the data

trends in 1990-1992 which show a predominance of investigations centered on echocardiography. While a relative decline was seen in published research in 2001-02, echocardiography remained one of the most frequently performed cardiac exams even at that time [17]. Progressive advancements in contrast echocardiography [16] and the introduction of real time 3D echo in first decade of the 21st century [18] have provided the impetus to sustain the role of echocardiography as a versatile tool for cardiac imaging. The last twenty years have seen an explosion in research on CMR [19]. The potential of CMR as a single imaging modality with the ability to accurately depict myocardial structure, function, perfusion and viability has led it to become a focal point of imaging research. There has been a steady increase in the number of scientific publications pertaining to CMR with a growing trend for publications to be authored solely by cardiologists [7, 19]. The intense focus on investigation of CMR has resulted in a wealth of emerging data and experience regarding the use of CMR with broad clinical implications in the coming years. Another imaging modality that has made great strides is CCT imaging, particularly with the advent of multidetector array scanners (MDCT). The role of CCT has evolved from non-invasive imaging of vessels by coronary angiography (CTA), coronary calcium scoring, to now being a viable alternative to traditional stress perfusion studies for the assessment of myocardial perfusion by CT computed tomography (CT-MPI) [20]. The gain in momentum in utilization of CMR and CCT is a recent phenomenon. Interestingly, a survey of the Medicare and Medicaid databases of the U.S. [21] showed that CPT-4 (All Current Procedural Terminology, Version 4) codes did not even exist for CCT or CMR in 1993. By the year 2002, CCT, CMR and PET (positron emission tomography) only accounted for 2% of all cardiovascular imaging that was utilized [21].

Study strengths

To the best our knowledge, our study is the first to investigate publications trends in non-invasive cardiovascular imaging. The data was extracted from American journals with high impact factors. By limiting our review to American journals, we were able to collect data that was representative of the contribution of the U.S. to imaging research. One of the focal points of our study was to investigate the sources of funding for U.S based publications. NIH funded studies typically represent high quality research work that is more likely to be published in journals with high impact factors [4]; hence the inclusion of Circulation, JACC, JAMA and NEJM may have increased the likelihood of capturing a subset of data that was reflective of NIH sponsorship. The selection of two general medicine journals, two scientific journals pertaining to cardiovascular disease and two dedicated cardiovascular imaging journals ensured that our data was sufficiently extensive and diverse to establish trends pertaining to different imaging modalities. The results of our study showed a remarkable growth in research on state of the art imaging modalities such as CCT and CMR. This trend has important clinical implications for physicians; a better understanding of the clinical utility of the available imaging modalities can enable physicians to assimilate these advances into superior patient care.

Study limitations

There are several limitations of our investigation that should be considered when interpreting our findings. First, given our study design, we are unable to account for publication bias in explaining our findings. It is possible for example that there has been a great increase in U.S based studies cardiovascular imaging studies that have gone unpublished because of null findings. We sampled a relatively limited number of journals. Although this was pragmatically necessary, there are several other cardiovascular and general internal medicine journals, both from within and outside the U.S. that may contain more published data on noninvasive cardiac imaging. In addition, our review was restricted to journals with high impact factor; hence publications that were published in journals with lower impact factor were excluded. Our final selection may have excluded some studies in which imaging played a pivotal role, however the abstraction criteria were defined as to ensure the highest chance of the selected studies being truly based on assessment of non-invasive cardiovascular imaging. Finally, although our review was spread over a time interval of two decades, the data extraction was limited to two year samples over the period of two decades. The goal was not to capture all articles on non-invasive cardiovascular imaging,

but rather to capture a large representative subset.

Conclusions

The last two decades have seen a dramatic growth in cardiovascular imaging research. An expanding armamentarium of diagnostic tools has enabled a shift in focus of imaging research toward cutting edge modalities such as CMR. We found that while the U.S. has emerged as a key player in research on noninvasive cardiovascular imaging, further work is needed to elucidate the interplay between federal support and published research, in order to foster a climate that is more conducive to non-invasive cardiovascular imaging research.

Disclosure of conflict of interest

None.

Abbreviations

JACC, Journal of the American College of Cardiology; JAMA, Journal of the American Medical Association; NEJM, New England Journal of Medicine; NIH, National Institutes of Health; CCT, cardiac computed tomography; CMR, cardiac magnetic resonance; NHLBI, National Heart, Lung and Blood Institute; ARRA, American Recovery and Reinvestment Act; NIBIB, National Institute of Biomedical Imaging and Biotechnology; PET, Positron emission tomography; MDCT, Multidetector computed tomography; CTA, Computed tomography angiography; CT-MPI, Computed tomography myocardial perfusion imaging; CPT-4, All Current Procedural Terminology, Version 4.

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