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# Bibliometric analysis of research relating to hypertension reported over the period 1997–2016

Patrick Devos<sup>a,b</sup> and Joël Menard<sup>c,d</sup>

**Objective:** Hypertension, a major cardiovascular risk factor, may reach a global prevalence of 1.56 billion by 2025. Much research has been conducted in this field, but few bibliometric studies have been performed. We aimed to analyse the changes in scientific output relating to hypertension over the past two decades.

**Methods:** We analysed, via PubMed and Web of Science, the scientific output relating to hypertension from 1997 to 2016. Quantitative (number of publications) and citation (top 1 and 10%) analyses were performed for output globally and by major countries/regions, with a particular focus on the European Union.

**Results:** In total, 100 789 articles relating to hypertension were identified in Web of Science. The number of publications increased by 52.7% (3989 in 1997, 6092 in 2016). Of the 100 789 articles, 38% had authors from the European Union, 32.1% had authors from the USA, and 26.7% had authors from Asia, with a marked increase in contributions from China over the period analysed. Articles appeared in more than 400 journals and were cited nearly 2 556 000 times. The relative weights of different research fields have also changed over time.

**Conclusion:** Combined use of PubMed and Web of Science enabled robust bibliometric analysis of the studies into hypertension published in the period 1997–2016, including assessment of the contributions from major countries, particularly those in the European Union. This study also allowed us to validate our methodology, which could be used to evaluate research policies and to promote international cooperation.

**Keywords:** bibliometric analysis, hypertension, research evaluation studies

## INTRODUCTION

Hypertension is a major cardiovascular risk factor and is expected to reach a global prevalence of 1.56 billion by 2025 [1,2]. Despite major therapeutic advances and public health efforts, the awareness, treatment and control of hypertension remain less than optimal, and vary between countries [3]. Given the overall burden of hypertension, it is not surprising that there has been considerable research in this field over the past several decades, involving many medical and other scientific specialties. This has led to the development of specialist journals, such as *Hypertension* [4] and *Journal of Hypertension* [5], which were

launched in 1979 and 1983, respectively. In PubMed, the search term ‘hypertension’ returns approximately 450 000 articles published since 1960. In addition to hypertension, these articles consider disorders related to hypertension, including obesity, diabetes, metabolic syndrome, and neurological conditions, such as stroke and Alzheimer’s disease.

Biomedical research has expanded markedly in recent years, with the number of articles indexed in PubMed more than doubling from 414 000 articles in 1997 to 1 023 000 articles in 2016. Has the number of publications in hypertension doubled over the same period? Which countries are most active in this research? What kind of research has been performed?

Few bibliometric studies have been performed on research relating to hypertension. A search of PubMed using the medical subject headings (MeSH) terms ‘Bibliometrics’ and ‘Hypertension’ identified 12 articles, of which only 3 were reporting true bibliometric studies: one of the 100 most cited articles in *Hypertension* [6], an analysis of citations in the *Journal of Hypertension* [7], and a study on journals related to hypertension [8].

The aim of our work was to analyse, via PubMed and InCites (based on the Web of Science), the scientific output in the field of hypertension and its evolution worldwide and by major countries or regions, with a particular focus on the European Union and international collaborations.

## METHODS

Data were extracted from the PubMed database [9], which has a precise and specific search engine. However, PubMed does not allow analyses based on addresses or citations. Bibliometric analysis was, therefore, performed using InCites, an analytical tool developed and marketed by Clarivate Analytics [10].

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## Search terms

Preliminary individual analyses were performed on several key researchers in hypertension in order to identify the most commonly used MeSH terms [11]. These terms were then used in the MeSH tree to conduct a thorough search. Only documents with these MeSH terms declared as major topics [12] were extracted. However, MeSH terms are available only for articles already indexed in MedLine; therefore, we also searched the PubMed database based on the article title and a list of journals specializing in hypertension. Exclusion terms were added in order to exclude disorders not related to hypertension. Only documents defined as 'journal article' in PubMed were included in the analysis; other documents, such as reviews, letters or editorials were excluded. All guidelines were also excluded.

After several iterations, we finally used the following search: [(Hypertension[majr] or Antihypertensive Agents [majr] or Pheochromocytoma [majr] or Hyperaldosteronism[majr] or Renin[majr] or Angiotensin-Converting Enzyme Inhibitors[majr] or Aldosterone[majr] or Renin-Angiotensin System[majr] or Angiotensin II[majr] or Receptors, Angiotensin[majr] or Angiotensinogen[majr] or Vascular Stiffness[majr] or Angiotensin II Type 1 Receptor Blockers[majr] or Angiotensin Receptor Antagonists[majr] OR hypertension[ti] or aldosterone\*[ti] OR angiotensin\*[ti] or hyperaldosteronism[ti] or pheochromocytoma[ti] OR renin\*[ti] or 'arterial stiffness'[ti] or 'vascular stiffness'[ti] or (J Hypertens[Journal] or Hypertension[Journal] or Am J Hypertens[Journal] or J Hum Hypertens[Journal] or *J Renin Angiotensin Aldosterone Syst* [Journal]) not ('Hypertension, Pulmonary'[mh] or 'Ocular Hypertension'[mh] or 'Hypertension, Portal'[mh] or pulmonary[ti] or intracranial[ti] or 'Practice Guideline'[Publication Type] or Guideline[Publication Type])) and 'journal article'[Publication Type].

Analysis was performed on articles published in the 20-year period 1997–2016, and on articles published in the four 5-year periods (1997–2001, 2002–2006, 2007–2011 and 2012–2016) that constituted the total study period.

## Analysis

After extraction, data were transferred into InCites for bibliometric analysis. InCites allows analysis of several bibliometric indicators relating to researchers, institutions, countries and regions. It also allows investigators to focus on thematic fields, with different levels of analysis. For example, the focus can be on specific fields (Web of Science categories), such as 'peripheral vascular disease' or 'pharmacology and pharmacy' [13] or on a larger area, such as 'medical and health sciences', which groups all Web of Science categories related to the biomedical domain.

We first compared the total global output relating to hypertension with that for 'peripheral vascular disease' and 'medical and health sciences'. We then looked at the contributions from major countries to the global output, assessed on the basis of number of articles with authors from each country.

In addition, the impact of the research was evaluated by analysis of the frequency of citations. However, the number of citations depends in part on the year of publication (older articles have had more opportunity to be cited) and the

scientific field. We, therefore, used the following two normalized classical bibliometric indicators: the number (and percentage) of articles classified as being in the top 1% (i.e. the 1% most cited articles globally, adjusted by publication year and Web of Science category) and the number (and percentage) of articles classified as being in the top 10% (i.e. the 10% most cited articles globally, adjusted by publication year and Web of Science category).

For the subset of articles in the top 1%, analysis was performed for articles published in the period 2007–2016. All summaries and, when necessary, full articles were read in order to identify the subfields most cited. The abstract of each article was read by one of the authors (J.M.) in order to exclude those not directly relating to hypertension, as well as some guidelines and nonsystematic reviews that had not been excluded by the initial search strategy.

Finally, we focused on the output from the European Union countries over four 5-year periods in order to identify trends in publication. VosViewer software developed by the Centre for Science and Technology Studies (bibliometric department of Leiden University, Leiden, Netherlands) was used to enable collaborations between European Union countries to be visualized [14,15]. This software analyses the addresses provided in bibliographic files. It allows computation of the collaborations to produce a graphical representation that indicates clustering and numbers of publications. The size of each coloured circle is proportional to the total number of articles with authors from a particular country. The distance between two countries is inversely proportional to the number of cooperative articles from those two countries. Colours are used by the software in order to show clusters.

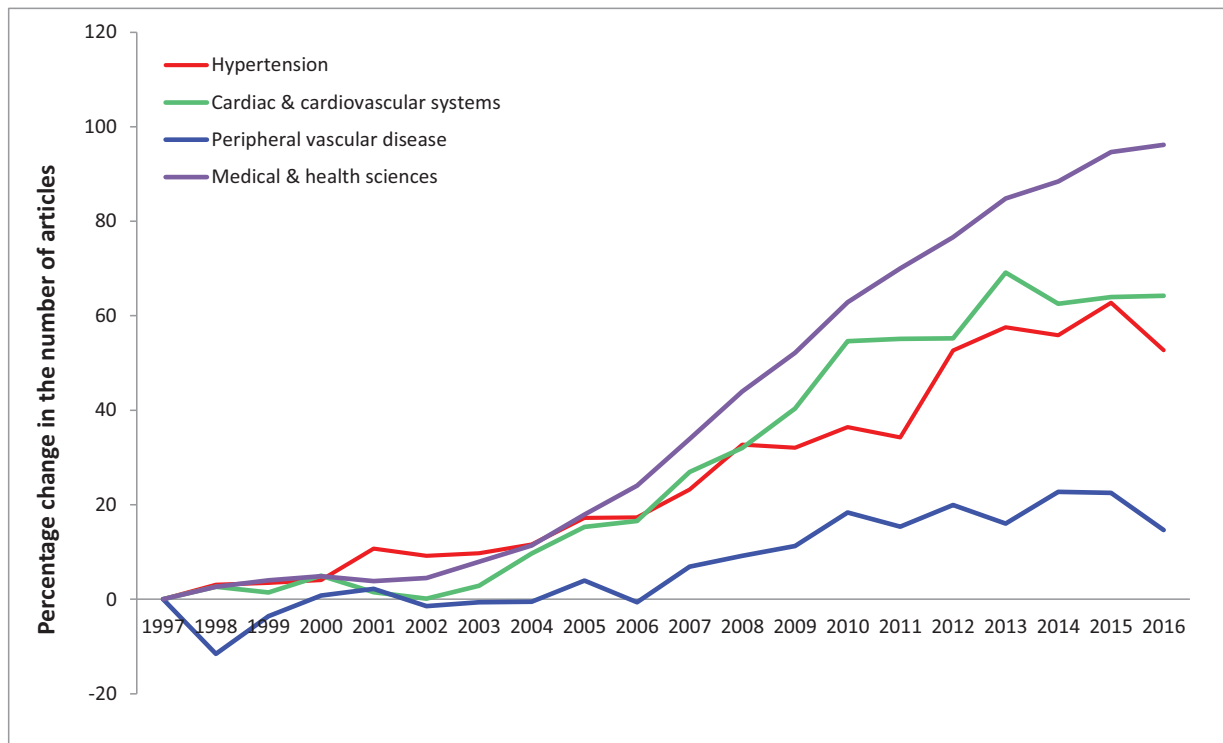
## RESULTS

On the basis of defined search, 127 634 articles were extracted from PubMed for the period 1997–2016. In total, 100 789 of these articles (79%) were indexed in Web of Science, and were therefore, available via the InCites platform. The percentage of PubMed articles that are indexed in Web of Science is similar from 1997 to 2016.

### Evolution over the period 1997–2016

The number of articles in Web of Science relating to hypertension increased from 3989 in 1997 to 6092 in 2016 (52.7% increase). This increase is similar to that in the Web of Science category 'cardiac & cardiovascular systems', greater than the increase in the 'peripheral vascular disease' (14%), and smaller than the increase in 'medical and health sciences' (95%) (Fig. 1).

Among the 100 789 articles relating to hypertension that were published in the period 1997–2016, 38 287 (38.0%) had authors from the European Union, 32 335 (32.1%) had authors from the USA, and 26 903 (26.7%) had authors from Asia (Table 1). Trends in the numbers of articles that had authors from each of the three main regions (European Union, USA, Asia) are shown in Fig. 2. Strong growth in the contribution from Asia can be seen, reflecting in particular an increase from 21 articles with Chinese authors in 1997 to 952 articles in 2016.



**FIGURE 1** Percentage change relative to 1997 in the number of Web of Science articles in the fields of ‘medical and health sciences’, ‘peripheral vascular disease’, ‘cardiac & cardiovascular systems’, and ‘hypertension’.

### Analysis of the four 5-year intervals within the study period

Table 1 presents the number of articles published in the four 5-year intervals within the overall analysis period for the main contributors, as well as the proportions of the published articles that are in the top 1% and top 10%. We also examined the impact of these publications in terms of citations. Researchers from some countries were more likely than others to have authored publications in the top 1% and 10% most cited articles. A higher rate was seen for those from Canada and Australia than for those from the USA and Europe, and those from Asia were least likely to have authored articles in the top 1% and 10% of citations

In Web of Science and InCites, journals are classified into 254 categories. Figure 3 shows the major changes that have occurred in the categories for the 100 789 articles. Several

categories (peripheral vascular disease, cardiac & cardiovascular systems] were stable and are not included in Fig. 3. Marked decreases between the periods 1997–2001 and 2012–2016 were noted in ‘pharmacology & pharmacy’ (34%), ‘physiology’ (22%), and ‘transplantation’ (49%). Marked increases were noted in ‘public, environmental & occupational health’ (171%), ‘nutrition & dietetics’ (181%) and ‘oncology’ (265%). These changes reflect evolution in the fields of research relating to hypertension.

Analysis by journal was also performed: during the entire study period, 7042 articles were published in *Hypertension*, 5633 in *Journal of Hypertension*, 4214 in *American Journal of Hypertension*, and 2525 in *Journal in Human Hypertension*; 1044 articles were published in *PLoS One* (in the past 10 years, since its foundation); and 934 in *American Journal of Physiology*, Heart and Circulation section, 904 in *Circulation* and 860 in *Journal of Cardiovascular Pharmacology*.

**TABLE 1.** Overall numbers of articles and numbers that are in the 1% and 10% most cited articles by major country/region of origin of authors

|                   | Total   | Number of articles |           |            | Number of top 1% citations |           |            | Number of top 10% citations |           |            |
|-------------------|---------|--------------------|-----------|------------|----------------------------|-----------|------------|-----------------------------|-----------|------------|
|                   |         | 1997–2001          | 2012–2016 | Change (%) | 1997–2001                  | 2012–2016 | Change (%) | 1997–2001                   | 2012–2016 | Change (%) |
| Worldwide         | 100 789 | 20 794             | 31 177    | 49.9       | 176                        | 229       | 30.1       | 1987                        | 2969      | 49.4       |
| European Union-28 | 38 287  | 8844               | 10 767    | 21.7       | 89                         | 132       | 48.3       | 837                         | 1363      | 62.8       |
| USA               | 32 335  | 6786               | 9598      | 41.4       | 96                         | 125       | 30.2       | 982                         | 1434      | 46.0       |
| Asia              | 26 903  | 4168               | 10 501    | 151.9      | 22                         | 59        | 168.2      | 298                         | 779       | 161.4      |
| Japan             | 10 635  | 2530               | 2652      | 4.8        | 11                         | 10        | –9.1       | 173                         | 173       | 0.0        |
| China             | 6548    | 195                | 4034      | 1968.7     | 1                          | 22        | 2100.0     | 12                          | 283       | 2258.3     |
| Canada            | 4900    | 991                | 1522      | 53.6       | 13                         | 28        | 115.4      | 102                         | 260       | 154.9      |
| Australia         | 4099    | 786                | 1393      | 77.2       | 8                          | 33        | 312.5      | 74                          | 233       | 214.9      |

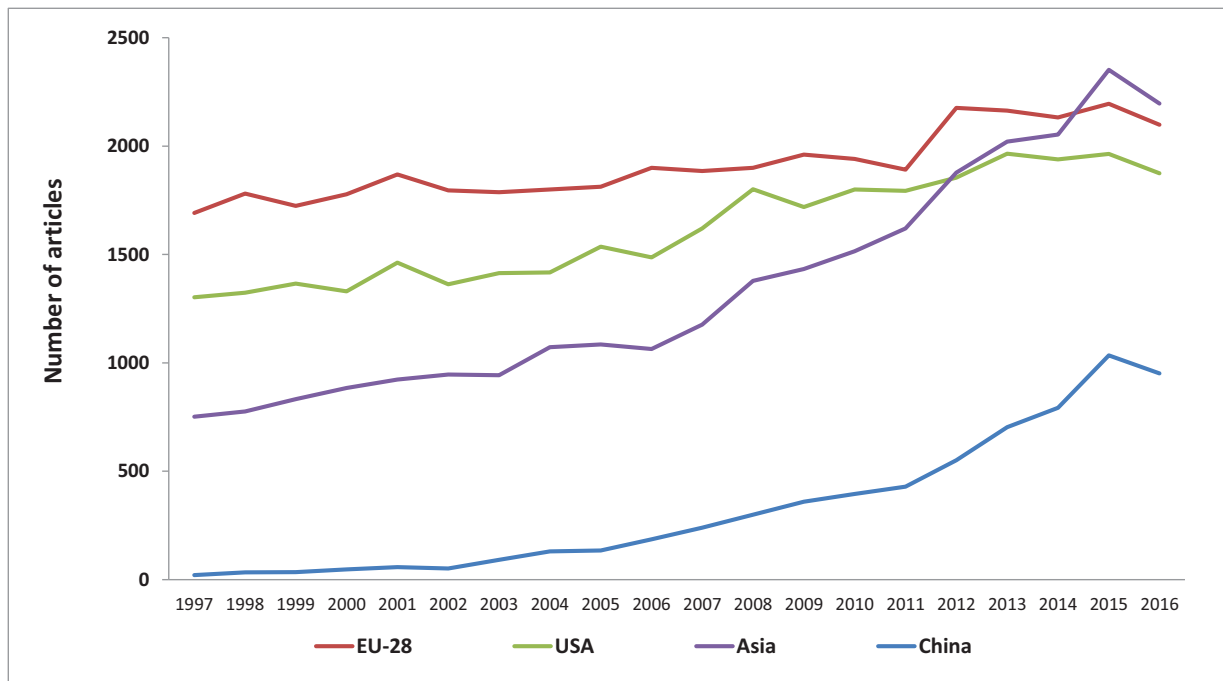


FIGURE 2 Growth in the numbers of articles relating to hypertension with authors from the main geographic countries and regions.

A complete list is provided in the Supplementary Data, <http://links.lww.com/HJH/B104>.

The 100 789 articles have been cited almost 2 556 000 times during the period 1997–2016 (a mean of about 25 citations per article). The most citations were in *Hypertension* (7042 articles cited 374 948 times), followed by *Journal*

*of Hypertension* (5633 articles, 157 526 citations), *Circulation* (904 articles, 101 286 citations), *American Journal of Hypertension* (4214 articles, 96 209 citations), *American Journal of Physiology* (2729 articles, 80 263 citations), *Lancet* (312 articles, 69 166 citations), *New England Journal of Medicine* (160 articles, 62 720 citations), *Journal of Human*

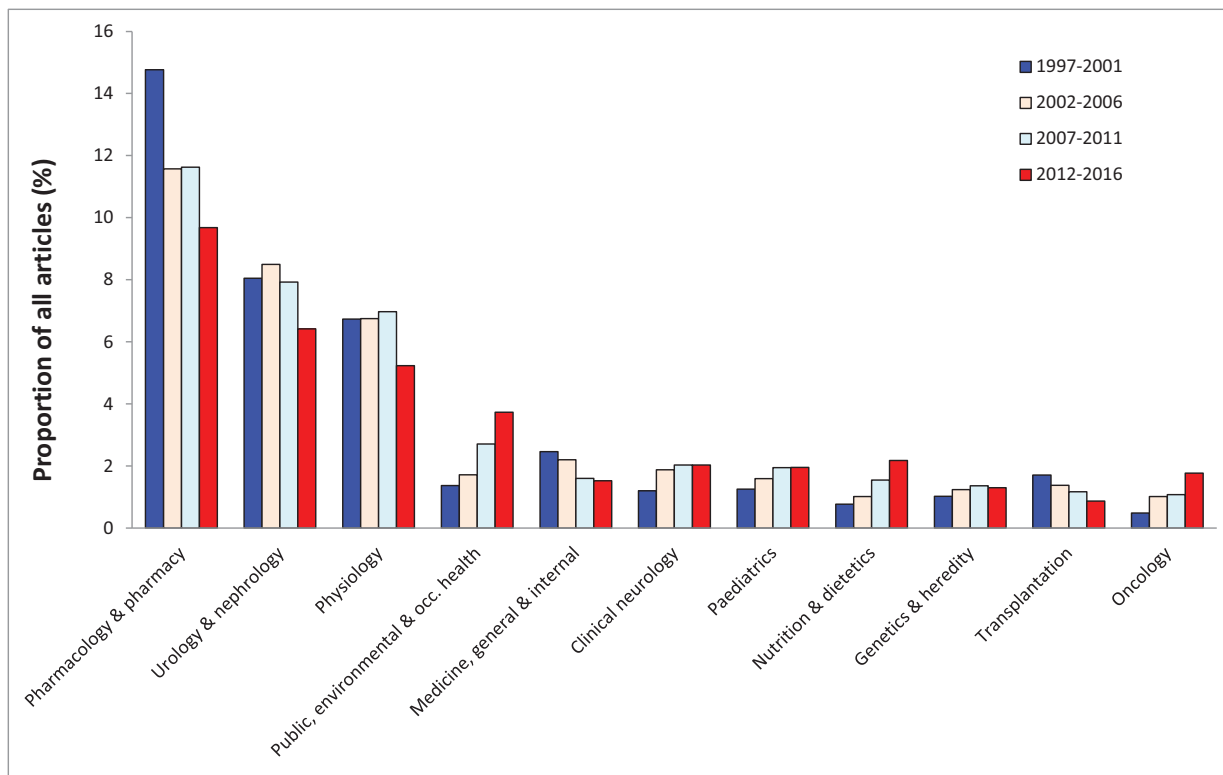


FIGURE 3 Major changes in the categories of articles (categories that were relatively stable are not shown).



**TABLE 2. The 1% most cited articles with authors from the European Union and USA, classified by type of research**

| Type of research             | Europe |      | USA    |      |
|------------------------------|--------|------|--------|------|
|                              | Number | %    | Number | %    |
| Clinical investigations      | 37     | 20.2 | 28     | 16.0 |
| Epidemiology                 | 32     | 17.5 | 55     | 31.4 |
| Experimental research        | 22     | 12.0 | 28     | 16.0 |
| Genetics                     | 11     | 6.0  | 7      | 4.0  |
| Meta-analyses                | 20     | 10.9 | 8      | 4.6  |
| Randomized controlled trials | 61     | 33.3 | 49     | 28.0 |

*Hypertension* (2525 articles, 43 083 citations), *Kidney International* (786 articles, 36 447 citations), and *Journal of the American Medical Association* (154 articles, 33 729 citations). A complete list is provided in the Supplementary Data, <http://links.lww.com/HJH/B104>.

### Analysis of the top 1% of articles

To determine the most influential articles in the past decade, we analysed the 433 articles that, of all those published in the period 2007–2016, were classified as being among the 1% most frequently cited in the world (top 1%). In order to compare types of research in the European Union and USA, we analysed the 239 articles in the global top 1% that had authors from the European Union and the 250 articles in the top 1% that had authors from the USA. Exclusion of guidelines, nonsystematic reviews and articles not directly relating to hypertension resulted in the retention of 183 articles with European Union authors and 175 with US authors (of these, 52 articles had authors from both the European Union and USA). These articles were then classified by type of research (Table 2). Distribution across these types of research differed statistically between the US and European Union subsets (chi-squared test,  $P=0.0095$ ); the difference was greatest in epidemiological research, which was more prominent in the USA.

### Analysis of European Union authorship

Table 3 shows the numbers of publications for the 12 European countries with at least 1000 articles published in the period 1997–2016. The first-ranked country based on the number of articles with authors from that country was the UK (19.5% of all articles with European Union authors), followed by Germany (18.3%), Italy (18.0%), France (12.8%), Netherlands (9.2%), Spain (8.6%) and Sweden (6.0%). When comparing the output in 1997–2006 with that in 2007–2017, all of these countries showed an increase, except for France and Finland, where output decreased.

Strongest increases in both the top 1% and top 10% impact indicators in 2012–2016 relative to the earlier 5-year periods were observed for Germany, Spain, Netherlands, Belgium and Poland (2–12 articles in top 1%). It should be noted, however, that the proportions of articles in the top 1% and top 10% must be interpreted with caution for countries with small numbers of articles.

### European Union collaborations

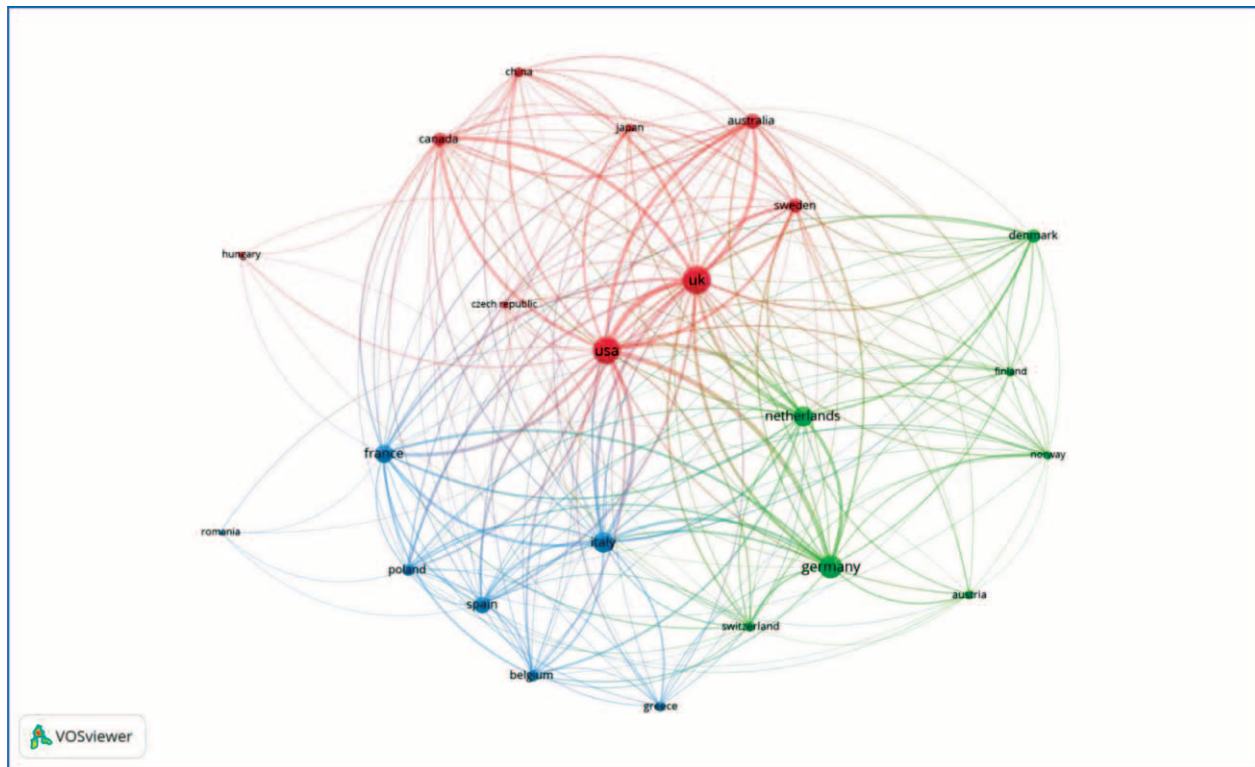
Finally, we looked at collaborations between European Union countries in the final 5-year period. In order to analyse only articles with an important scientific impact, we extracted the 1363 articles that were among the 10% most cited articles and that had also been authored by at least one researcher in the European Union. Analysis was then performed using VosViewer software (Fig. 4).

The VosViewer results show the importance of the UK, Germany, Italy, Netherlands and France in the European Union collaboration network relating to the top 10% most cited articles. It positions USA (which is present because of co-authoring with European Union authors) at the centre, with UK very close. Countries are divided into three clusters: Italy, France, Poland, Spain, Belgium, Greece and Romania are grouped in the blue cluster. Germany, Netherlands, Denmark, Finland, Norway, Austria and Switzerland (not in European Union, but present because of co-authoring) are grouped in the green cluster. The UK

**TABLE 3. Overall numbers of articles and numbers that are in the 1% and 10% most cited articles by major country/region of origin of authors**

| Country           | Total  | Number of articles |           |            | Number of top 1% citations |           |            | Number of top 10% citations |           |            |
|-------------------|--------|--------------------|-----------|------------|----------------------------|-----------|------------|-----------------------------|-----------|------------|
|                   |        | 1997–2001          | 2012–2016 | Change (%) | 1997–2001                  | 2012–2016 | Change (%) | 1997–2001                   | 2012–2016 | Change (%) |
| European Union-28 | 38 287 | 8844               | 10 767    | 21.7       | 89                         | 132       | 48.3       | 837                         | 1363      | 62.8       |
| UK                | 7453   | 1725               | 2186      | 26.7       | 29                         | 50        | 72.4       | 188                         | 425       | 126.1      |
| Germany           | 6993   | 1719               | 1830      | 6.5        | 17                         | 43        | 152.9      | 179                         | 309       | 72.6       |
| Italy             | 6875   | 1517               | 1898      | 25.1       | 21                         | 32        | 52.4       | 178                         | 256       | 43.8       |
| France            | 4898   | 1406               | 1193      | –15.1      | 21                         | 27        | 28.6       | 134                         | 198       | 47.8       |
| Netherlands       | 3533   | 614                | 1192      | 94.1       | 12                         | 22        | 83.3       | 75                          | 225       | 200.0      |
| Spain             | 3305   | 590                | 997       | 69.0       | 9                          | 19        | 111.1      | 55                          | 167       | 203.6      |
| Sweden            | 2315   | 567                | 613       | 8.1        | 12                         | 15        | 25.0       | 74                          | 116       | 56.8       |
| Poland            | 1724   | 190                | 763       | 301.6      | 2                          | 12        | 500.0      | 4                           | 86        | 2050.0     |
| Denmark           | 1544   | 284                | 518       | 82.4       | 12                         | 10        | –16.7      | 40                          | 104       | 160.0      |
| Belgium           | 1415   | 274                | 451       | 64.6       | 7                          | 12        | 71.4       | 44                          | 87        | 97.7       |
| Greece            | 1390   | 119                | 538       | 352.1      | 0                          | 7         | –          | 8                           | 61        | 662.5      |
| Finland           | 1111   | 298                | 267       | –10.4      | 11                         | 7         | –36.4      | 41                          | 42        | 2.4        |

European countries with at least 1000 publications in the period 1997–2016.



**FIGURE 4** European Union collaboration network based on analysis of the articles relating to hypertension that were among the 10% most cited articles. The size of each coloured circle is proportional to the total number of articles with authors from that country. The distance between two countries is inversely proportional to the number of articles from those two countries.

has strong links with the USA, Sweden, Australia, Japan, China, Canada, Hungary and Czech Republic (red cluster).

## DISCUSSION

This bibliometric analysis of the global research output in the field of hypertension shows an increase in the number of publications over the 20-year analysis period, although the rate of increase is less than that seen for all medical and health sciences articles during the same period.

We chose PubMed for the extraction as it is the largest database in the biomedical field and it provides a precise and specific search engine. PubMed also provides wider coverage of the biomedical field than Web of Science. However, not all journals indexed in PubMed are indexed in the Science Citation Index (used to compute impact factors), so PubMed articles published in journals without impact factors are not indexed in Web of Science and InCites. Results depend not only on the database used but are also strongly dependent on the search strategy. Despite using an iterative process to develop the strategy, a few articles not directly related to hypertension were identified in the search, mainly in the fields of congestive heart failure and diabetes. However, the influence of these articles is likely to be limited because of the large number of articles overall and because analyses were performed for several consecutive periods (so it is likely that there would be a similar influence in all periods).

The growth in the number of publications from China has been impressive in all fields, including hypertension. This has not been accompanied by an increase in the

proportion of articles from China that are in the top 1% and top 10% most frequently cited articles about hypertension. It is important to note, however, that citation frequency does not necessarily reflect the intrinsic scientific value of an article. The likelihood of citation may be reduced because the names of the Chinese researchers are not yet recognized by the English-speaking community. Australia and Canada (predominantly English-speaking) are two countries outside the USA and the European Union that provide an above-average contribution.

Differences between European countries were observed in all four 5-year periods. These differences can be interpreted with reference to the gross domestic product (GDP) at purchasing power parity exchange rate (PPP). It would be particularly interesting, for example, to conduct an in-depth analysis of the research and care systems of the Netherlands (GDP at PPP: US\$915.2 billion) because researchers from this country produce a high absolute number of publications and a high proportion of articles in the top 1% and top 10% categories, with sustained growth in the absolute numbers and an increase in the proportions in the top 1% and top 10% in 2012–2016 relative to 1997–2006. The Netherlands aside, the largest nations of the European Union are the most productive, led by the UK (GDP at PPP: US\$2880 billion), Germany (US\$4150 billion), and Italy (US\$2307 billion), whereas France's performance is declining (US\$2826 billion). Among the countries that joined the European Union more recently, contributions are increasing from Spain (GDP at PPP: US\$1769 billion) and Poland (US\$1111 billion).

Hypertension studies are published in a wide range of journals covering many specialties. Observed changes in the numbers of hypertension articles published may reflect developments in specific research fields. For example, better management of immunosuppression might explain the decrease in the number of articles published about transplantation, or hypertension as an adverse effect of new anticancer drugs might explain the rise in the number of articles relating to hypertension published in oncology journals. Not surprisingly, given that few new chemical entities with antihypertensive potential have been discovered in recent years, there have been few pharmacology articles published; by contrast, new lines of research are increasing in areas, such as genetics, resulting in increased numbers of publications.

Instead of looking at the impact factors of journals in which hypertension research is published, we considered citation frequency. Although impact factors are used in the evaluation of research careers and in decisions regarding funding research, these factors are journal-level metrics and so change with time and with journal publication policies – which often have an economic basis. By contrast, if an article has been cited frequently, this suggests that the findings reported have been useful to other researchers for initiating, performing, or interpreting their own research. It must be acknowledged that the citation frequency does not provide any information on the internal validity of the results – an article might be cited in a negative as well as a positive context (e.g. to refute the results it reports) – but even such negative citations indicate that the results have been of interest to other researchers. By contrast, it is clear that the many articles that are never or rarely cited have not generated widespread interest, and are therefore, unlikely to have contributed significantly to the wider body of scientific knowledge.

We focused on the 1% and 10% of articles that had been most frequently cited in the period 2007–2016. As the results of an automatic extraction depend on the search strategy used, we manually checked the top 1% of citations to allow exclusion of guidelines, expert consensus statements and opinion-based general reviews, as well as articles reporting animal studies and articles whose main focus were identified, after careful reading, as congestive heart failure, renal insufficiency or diabetes. Studies were classified as clinical investigations when the patient cohorts were from hospitals, and as epidemiology when performed in the general population. Clinical investigations included some controlled randomized studies involving small numbers of patients, mainly on biomarkers or surrogate endpoints.

Differences between the USA and the European Union were identified: while various types of research were represented in both regions, there were more articles on epidemiology and experimental research authored by US investigators, whereas articles on clinical investigations, genetics and meta-analyses were more numerous in research published by European Union authors.

Research is becoming increasingly collaborative, so it is important to analyse links between investigators in different countries. Use of VosViewer to visualize the main collaborations identified countries whose predominant language is English as being in a central position; these countries

were also the most productive in terms of publications relating to hypertension. This cluster visualization may help to stimulate more collaborations between countries, either to reinforce existing ones because of their productivity, or to encourage new ones.

In conclusion, about 80% of the burden of hypertension occurs in low- and middle-income economies, so it will be important to undertake research specific to these countries in the near future. The problems that will be encountered in hypertension management and research in these regions are likely to be very similar to those that have been seen in high-income countries over the past 50 years. Worldwide monitoring of publications in hypertension might be useful to all.

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Contributions: J.M. and P.D. developed the study concept, P.D. conducted the extractions and analyses, J.M. checked the content of all top 1% publications. J.M. and P.D. interpreted the results and prepared the manuscript for publication.

## Conflicts of interest

There are no conflicts of interest.

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