**International comparisons of research outputs : cardiovascular research 1981-1991 / J. Anderson, L. Rogers & M. O'Driscoll.**

# International comparisons of research outputs

*Cardiovascular research 1981–1991*

PRISM
Unit for Policy Research in Science and Medicine

# INTERNATIONAL COMPARISONS OF RESEARCH OUTPUTS

## *Cardiovascular research 1981–1991*

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This report presents the findings of a detailed bibliographic analysis of several thousands of publications in the field of cardiovascular research. The study was part of a larger experimental foresight project on the future of cardiovascular research in the UK.

The authors would like to thank the project Steering Committee and expert advisory group for their valuable contributions to this study (Dr M B Davis, Professor A Henderson, Professor P Poole-Wilson, Dr D Julian and Dr L Smaje).

This study was funded by the Wellcome Trust, the British Heart Foundation and the Medical Research Council.

This report presents the findings of a bibliometric study of cardiovascular research outputs. The study was part of a wider project on foresight analysis which included a large-scale survey of scientists on issues concerning the future of cardiovascular research in the UK. The analysis focused on cardiovascular research published in refereed journals and covered several thousand papers. The five countries considered were the UK, the USA, Germany, France and Japan. Cardiovascular research activity in the UK was considered in more detail to identify the most active institutions and individuals.

A key step was the development of a novel method to define the field of cardiovascular research and to identify papers published in this area. The study employed two data sources – the Science Citation Index (SCI) and Medline – which together cover thousands of biomedical journals. The Medical Subject Headings (MeSH) index was used to identify a set of papers of relevance to cardiovascular research. This set was then validated by an iterative process which incorporated the views of an expert Steering Committee.

This process resulted in a definition of the cardiovascular field that captured basic and clinical research papers drawn from a wide range of biomedical disciplines, a sample that effectively represented the total production of papers in this field worldwide. The sample was then analysed to give information on publishing productivity, impact (as measured by citations), and collaboration patterns.

**Main findings**

- Of all biomedical papers published worldwide, 1 in 5 was found to be relevant to cardiovascular research.
- The USA dominated cardiovascular research in terms of the number of papers published worldwide. Japan was the second most prolific publisher, and in recent years increased its lead over the UK. However, the UK produced more cardiovascular papers than did the two other European nations, Germany and France.
- Cardiovascular research did not stand out as a specially active field within the UK's national research portfolio, unlike in Japan and Germany.
- Japan appears to have conducted little research on cardiovascular surgery and emphasised research with a focus on cardiovascular agents.
- Using citations as a measure of impact, the US and UK have had the highest impact internationally. Citation rates for cardiovascular papers were higher in these countries than the world norm for this field. In Germany, Japan and France, however, citation rates were below average.
- The UK collaborated more than might be expected with Germany and France, given the level of research activity in these countries. Geographic proximity might be an important determinant in research collaboration.
- Within the UK, London dominated cardiovascular research in terms of activity levels. Between 1988 and 1991, 60 of the top 100 authors of cardiovascular research were based in the capital.

## 1.1 Objectives of the study

The study was commissioned by the British Heart Foundation, the Medical Research Council and the Wellcome Trust, the three main UK funding bodies with an interest in cardiovascular biology. It aimed to provide data on the published outputs of the UK cardiovascular research community together with international comparisons. Representatives from each of the three funding bodies formed a Steering Committee for the project. They were mainly senior cardiovascular research scientists and administrators who served as both customers for the project and as a source of expert advice.

The study set out to assess international activity in cardiovascular research using a bibliometric approach that measured research outputs in the form of publications. The aim was to look in detail at the output of cardiovascular research and its place in biomedical research as a whole. The five countries chosen for inclusion in the study were the UK, Germany, France, Japan and the USA.

As well as measuring absolute numbers of publications, the study also aimed to measure the relative importance of cardiovascular research in the five countries, to assess the level of collaboration between countries and to review topics of key importance. In addition, the UK cardiovascular scene was studied in more detail to show areas of greatest activity.

## 1.2 Background to the cardiovascular study

Internationally, cardiovascular disorders are a major health problem in the developed world.[1] In the UK, cardiovascular disease remains the single most common cause of death. According to the latest available figures in England and Wales, 'circulatory disease' caused 21% of all deaths in people up to the age of 65 in 1988.[2] The financial cost is also high. In 1986/87, circulatory disease accounted for 13% of National Health Service expenditure in England and Wales, almost double that of cancer and second only to mental illness.[3] In Scotland, 4% of total NHS costs in 1988 were due to stroke alone.[4] It was against this background that cardiovascular research was selected by the UK Government as a key area in the 1992 Health of the Nation white paper[5] as well as a research and development priority in the National Health Service.[6]

In 1990, a Medical Research Council joint working group was set up to review the biology of cardiovascular disorders. Concluding that future funding decisions and strategy would have to be based on broader consultation and more comprehensive data, the group agreed to support an experimental 'foresight' study in the field of cardiovascular research. The aim was not to attempt to make predictions as such, but to examine key areas of research that may be of significance in the future and to identify trends, nationally and internationally.

The work presented here formed part of that larger foresight project on the future of cardiovascular research in the UK. The foresight project comprised a number of components, including a poll of expert opinion on issues of concern to both users and practitioners of cardiovascular research, the results of which are reported elsewhere.[7] This present study attempted to provide a basis for discussions on the future of the field, by describing previous patterns of research activity in the UK and internationally.

### 1.3 Assessing research output: a bibliometric approach

The most widely employed method of evaluating research is peer review, in which experts in the field assess the quality of the research and identify strengths and weaknesses.[8] Bibliometric analysis provides a mechanism of supporting this qualitative method of assessment with quantitative data about research outputs. Several studies have addressed the issue of how to measure outputs,[9–17] the most common measures to date being counts of inventions, patents, publications, citations, prizes and research grants or contracts.

The work presented in this report employed analysis of research publications to examine the international output of cardiovascular research, trends in cardiovascular research and subfields, citation impact and patterns of collaboration between researchers in different countries.

## 2.1 Bibliometric analysis

A number of assumptions underpin bibliometric techniques, and recent reviews of the use of bibliometrics in research evaluation have highlighted its limitations.[18,19] It presupposes, firstly, that the output of scientific research is consistently represented by publications; secondly, that the number of citations is an indicator of impact; thirdly, that accurate databases are available.[20]

However, a survey of 24 studies in which bibliometric measures were compared with other non-literature measures found a high correlation between bibliometric statistics and other indices.[21] A study by Narin in 1987 concluded that the results of bibliometrics are 'seldom counter-intuitive'.[14] In addition, a survey of academics' views of the quantitative assessment of departmental research found cautious acceptance of bibliometrics on the part of academic scientists, although the importance of consulting with members of the research community under study was emphasised.[22] The study reported here addressed this last concern by the extensive use of a group of cardiovascular research scientists and administrators from each of the three funding bodies involved.*

Three key stages may be identified in bibliometric analysis:

- definition of the subject field (in this case, cardiovascular research)
- construction of a bibliography confined to appropriate types of publication
- analysis of the results

## 2.2 Defining the field: what constitutes cardiovascular research?

The first stage in the assessment of research output of a particular discipline is to set the boundaries of that discipline. This poses particular difficulties with a field such as cardiovascular biology, which is multidisciplinary and encompasses basic and clinical science.

Previous bibliometric studies have employed a number of methods of field definition and each of these was considered for this study. One such method is to define a field through a set of journals. The Science Literature Indicators Database (SLID), derived from the Science Citation Index produced by CHI Research Inc., is divided into research subfields on this basis; in 1986, the cardiovascular subfield comprised publications from international journals. However, use of a fixed number of journals inevitably excludes a wide range of non-specialist journals which can carry papers of relevance to cardiovascular biology. This could be a serious omission, for example, in the case of journals such as the *British Medical Journal*, the *Lancet* or *Nature*.

* Members of the Steering Group were Professor Andrew Henderson (University of Wales, Cardiff), Dr Megan Davies and Dr Jane Rogers (Medical Research Council, London), Professor Desmond Julian (British Heart Foundation, London), Professor Philip A Poole-Wilson (National Heart and Lung Institute, London) and Dr Laurence Smaje (the Wellcome Centre for Medical Science, London).

Another method of subject field definition is the use of a specialist database, which covers a core set of journals but which also includes a wider range of non-specialist journals. Nevertheless, by definition this implies a rigid boundary and relevant research on peripheral topics may be excluded.

A third method is co-citation analysis. This has been used to map the structure of a research area and link seemingly disparate research disciplines.[25–28] Because this method relies on citations to past publications, it is less effective for constructing field definitions that are current or for identifying researchers who are currently active.

Finally, it is possible to apply key words to a general biomedical database. This method is effective for well-defined, discrete areas of research, but is less useful for a diffuse, broad field such as cardiovascular research, which has evolved over several years.

Faced with the limitations of existing methods of field definition, an alternative method was developed to define the boundaries of cardiovascular research.

### 2.3 Construction of a MeSH filter for cardiovascular research

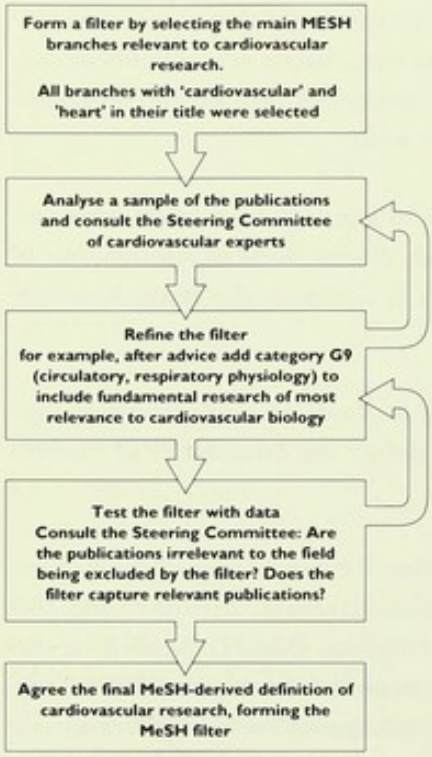
The method that was developed to define the boundaries of biomedical research combined a general biomedical database, Medline, and the classification scheme, Medical Subject Headings (MeSH). Medline is the online version of *Index Medicus*, with records dating from 1966 to the present. Some 300 000 publications from approximately 3500 journals are indexed annually using a classification scheme called Medical Subject Headings (MeSH). MeSH is a structured classification scheme within which terms derived from the international biomedical literature are arranged into tree structures based on a main subject category. The scheme has evolved from terms used by and familiar to the international research community, and it is a major resource for biomedical researchers when searching for research publications.

The MeSH approach differed from the use of keywords in a flat classification scheme because MeSH forms a structured hierarchical network of terms which are also cognitively linked – that is, the structure of the classification scheme mirrors that of the subject area under study at different levels. MeSH is also applied to each publication in the database at a variety of levels and therefore all publications can be probed, regardless of where the terms used to classify the paper are located in the MeSH hierarchy.

The field of cardiovascular research was defined using MeSH as a 'filter'. This is shown schematically in figure 1.

**Figure 1**

**Construction of a MeSH 'filter' for cardiovascular research**




The main MeSH branches relevant to cardiovascular research were selected by choosing all branches with 'cardiovascular' and 'heart' in their title. A sample of the publications thus identified was analysed by the Steering Committee of cardiovascular experts. The filter was refined in the light of advice received (to include, for example, areas of fundamental research). This process of empirical testing and consultation was repeated several times, until an accepted definition was agreed.

The MeSH filter was finally validated by comparing the results of a CD-ROM computer search for key UK university departments working in the field with lists of publications provided by each department. Publications in peer-reviewed journals in 1989 from four UK university research departments were analysed. The results showed that out of a possible 90 papers, 87 (97%) were retrieved using the search strategy based on the MeSH-derived filter.

A second test confirmed the accuracy of the filter. A sample of 100 cardiovascular papers was selected at random from the UK cardiovascular publications identified by the MeSH filter and examined by cardiovascular researchers on the project Steering Committee for relevance to cardiovascular science. Only 12 were considered to be of marginal interest and these were mainly concerned with stroke research.

The Steering Committee concluded that the MeSH-derived filter was sufficiently sensitive to capture all papers relevant to cardiovascular research and to exclude those considered irrelevant.

For bibliometric purposes, it is generally accepted that substantial original, new scientific information is contained in three types of publication: original articles, notes or reviews.[29–30] Letters (apart from those to *Nature*), meeting reports, news and editorials are seen as peripheral and were excluded from the analysis.

### 2.4 Analysing international trends in cardiovascular research

A key objective of the study was to track cardiovascular research publications from five countries. To do this, and to assess the level of collaboration, the addresses of every author on a paper were required. Although Medline allowed the field of cardiovascular research to be defined, it did not include the addresses of every author on a paper and so could not be used to identify the authors. The vast majority of Medline papers from before 1988 do not have an address entered at all,[31] and for papers from 1988 onwards, only that of the first author is listed. Therefore, Medline could not be used to examine trends in research

publication output by specific institutions in the UK or elsewhere nor, for pre-1988 papers, could these data be disaggregated according to the country of publication. Although Medline was used to analyse the global production of biomedical and cardiovascular papers published from 1981 to 1991, it was used to examine specific national trends in output from 1988 to 1991 only.

A second database was therefore needed for the analysis of international trends during the first half of the 1980s. The Science Citation Index, which covers over 3000 journals, includes the addresses of every author of a particular paper, thus facilitating the analysis of scientific collaboration between nations and between research institutions. Papers were initially identified through the MeSH filter on Medline as described above and were then matched to the Science Citation Index using a special computer routine. Thus, while cardiovascular papers could be accurately identified using Medline, full bibliographic details were obtainable only from the Science Citation Index.

In summary, international trends in cardiovascular publications from 1981 to 1986 were analysed using data from the Science Citation Index and from 1988 to 1991 using Medline.

### 2.5 Analysing cardiovascular research by subfield

Cardiovascular papers published between 1981 and 1986 were selected from the Science Citation Index by matching publications drawn from Medline using the MeSH filter. The papers were then disaggregated by subfield and further by the institutional source of the researchers.

### 2.6 Citation analysis – assessing impact

Citation analysis (the number of times a paper is cited in subsequent publications) may be used to measure the 'impact' (rather than 'quality' or 'influence') of a given publication. The citations received by each cardiovascular publication in subsequent years were analysed for each country. The Relative Citation Index (RCI) gives a measure of the impact of one country's scientific papers compared with the world average. An RCI greater than 1.0 suggests that papers were quoted more often than the world average; a value less than 1.0 suggests a lower impact in relation to the world average.

### 2.7 Identifying cardiovascular researchers in the UK

The study made a more detailed examination of UK cardiovascular publications, aiming in particular to identify 'hot spots' in publication activity by looking at research outputs from different centres.

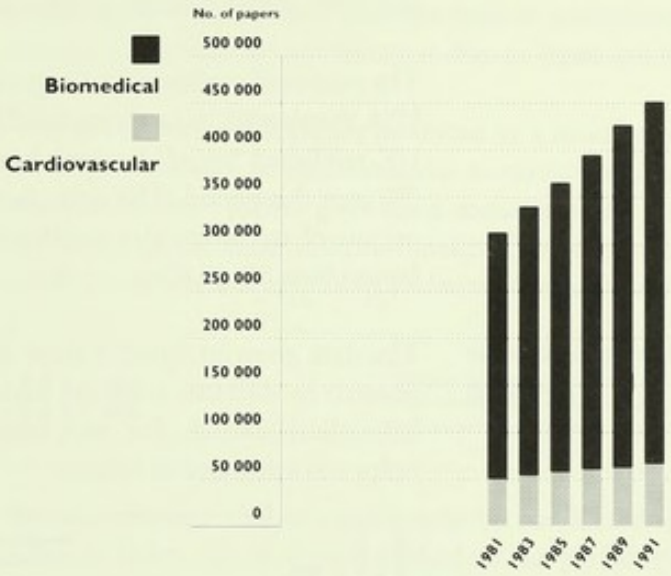
The Science Citation Index was used to identify the top 25 institutions producing publications relevant to cardiovascular research between 1981 and 1986. The data were analysed at the level of institutions to show the total number of cardiovascular papers produced and the citations received during this period. More detailed analysis at the level of individual

researchers was carried out for the years 1988–1991. All cardiovascular papers published in this period (14 064 in total) were analysed by author, institution and bibliography, and transformed into an SPSS/PC+ (Statistical Package for the Social Sciences) readable format. Out of the 21 000 authors on these 14 064 papers, the 100 most frequently occurring names were recorded. These were referred to as the most 'visible' researchers during the period studied. Their institutional addresses were traced using the *Commonwealth Universities Yearbook, Current Research in Britain* and the *Medical Directory.*

## 3.1 Cardiovascular research in the biomedical field

Figure 2 shows the global contribution made by cardiovascular research to biomedical research between 1981 and 1991. The total number of cardiovascular papers published rose from 58 560 in 1981 to 70 144 in 1991. Overall, cardiovascular research made a substantial contribution to biomedical research as a whole, accounting for 19% of all biomedical papers.

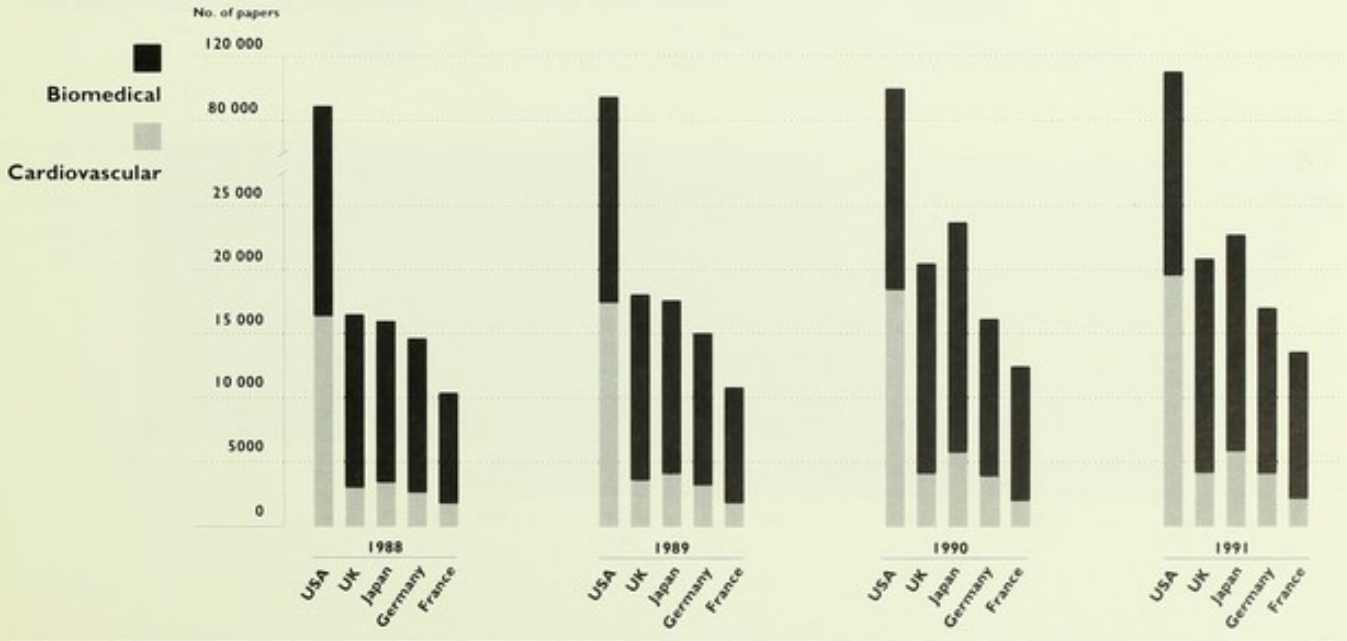
**Figure 2** **Biomedical and cardiovascular publications for all countries: 1981–1991**
**(Medline analysis)**




## 3.2 International comparisons

The study examined the relative position of cardiovascular research in five countries: the USA, the UK, Japan, Germany and France. The data are presented in figure 3.

**Figure 3** **Biomedical and cardiovascular publications in five countries: 1988–1991**
**(Medline analysis)**



The data show that, over time, there was a steady increase in the number of biomedical papers published. The greatest activity is found in the USA which published over four times more papers than the UK between 1988 and 1991. In general, the USA dominated biomedical publications, increasing its share from 25% in 1988 to 30% of all biomedical papers in Medline in 1991. During this time, the share of biomedical publications from the other countries remained steady. The UK and Japan each accounted for an average of 6% of Medline publications between 1988 and 1991, whilst Germany's share was 5% and that of France 3%.

The output of cardiovascular papers followed the same pattern. Again, the USA dominated, accounting for 27% of cardiovascular publications; the UK published 5% of the total, as did Germany, whilst France published 3% over this period. The only country to increase its share of the world's output of cardiovascular publications over the period 1988–1991 was Japan (from 6% to 8%).

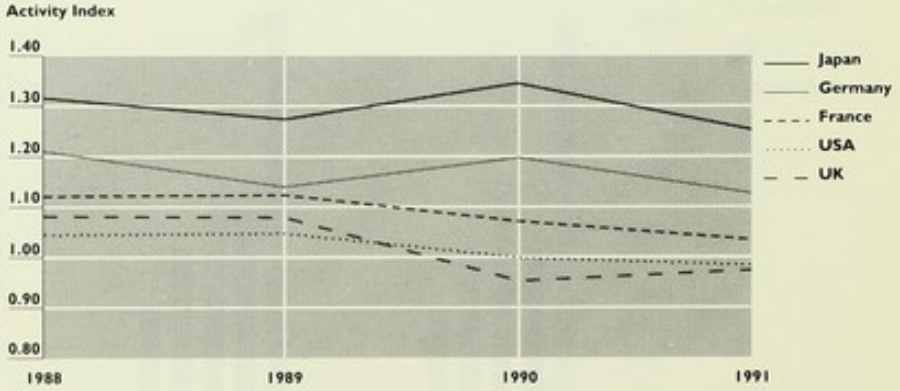
### 3.3 Trends in cardiovascular research

The data given in figure 4 show the emphasis placed on cardiovascular research by different countries relative to their overall national activity in biomedical research. For each country, a cardiovascular research activity index was calculated as follows:

$$\text{Cardiovascular Research Activity Index} = \frac{\text{Number of national cardiovascular papers / Number of national biomedical papers}}{\text{Number of world cardiovascular papers / Number of world biomedical papers}}$$

An index greater than 1.00 reveals a greater than expected output of cardiovascular activity in relation to the world norm, while a value below 1.00 suggests lower than expected activity.

**Figure 4** **International comparison of cardiovascular publications activity indices: 1988–1991 (Medline analysis)**



From 1988 to 1991 Japan and Germany had activity indices above 1.00, suggesting that in these countries cardiovascular biology had some prominence within their national research portfolios.

In contrast, cardiovascular research in the UK, USA and France had less prominence, with lower activity indices. From 1989, the activity indices began to decline, falling to below 1.00 by 1991 in the UK and USA. Despite the fact that both of these countries publish large numbers of cardiovascular papers each year, the field of cardiovascular research does not stand out in these countries as it does in Japan and Germany.

### 3.4 The impact of cardiovascular research

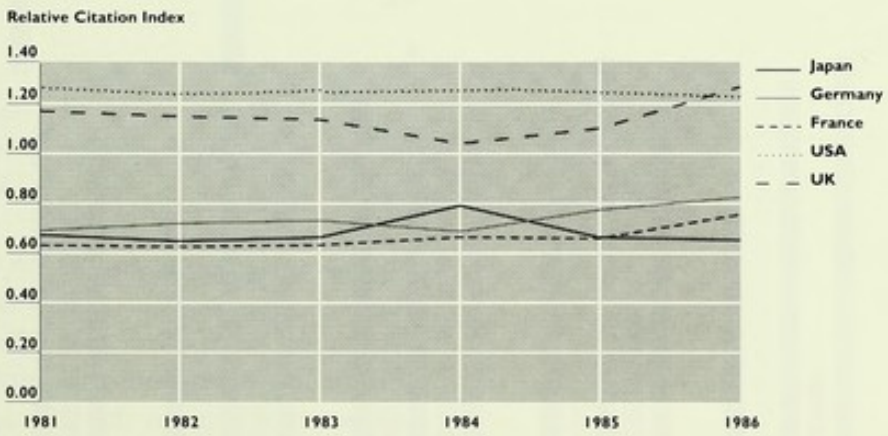
Whilst the numbers of papers produced by a country gives some measure of its productivity in cardiovascular research, the number of citations received by these papers gives some measure of the country's impact or influence in the field internationally. The impact of each country's publications was analysed using a relative citation index:

$$\text{Relative Citation Index} = \frac{\text{Citations per paper for country A}}{\text{Citations per paper for all countries}}$$

Because citation analysis could only be conducted using the Science Citation Index, the analysis is limited to the period 1981–1986. Values above 1.00 denote a citation impact higher than the world norm.

Figure 5 shows the results of this analysis. Both the UK and USA had a citation index above 1.00, suggesting above average impact internationally. But, although Germany and Japan appeared to be relatively active in cardiovascular research (see figure 4), they appear to have below average impact as judged by citations.

**Figure 5** **Citation impact of cardiovascular papers: 1981–1986 (SCI analysis)**



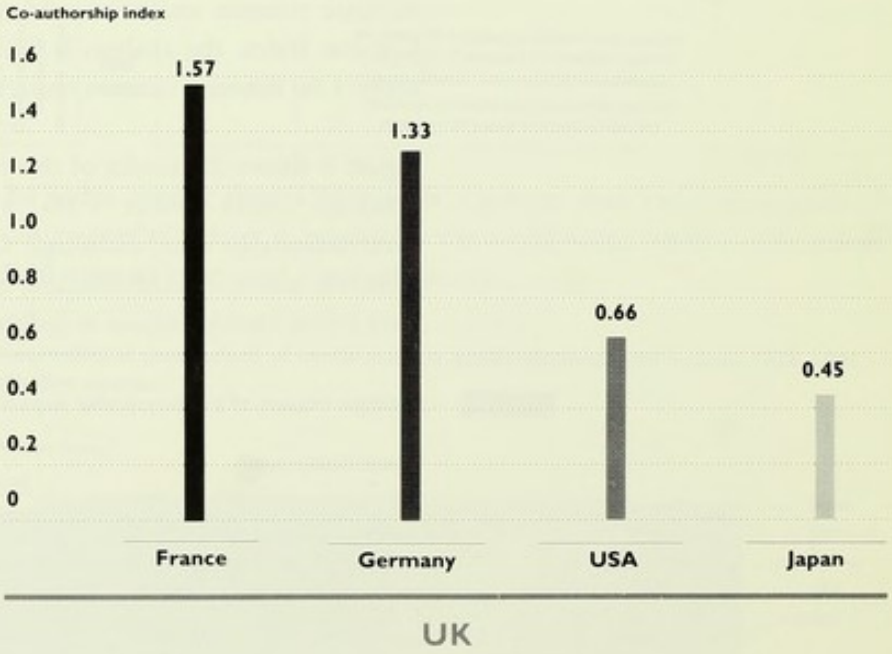
## 3.5 International collaboration in cardiovascular research

As research becomes more international, there is increasing interest in patterns of collaboration between countries. The degree to which scientists in one country collaborate with those in another can be measured by examining the address on each paper. This can be done electronically on the Science Citation Index but the analysis has to be confined to 1981–1986.

The co-authorship index is used to indicate the strength of collaboration between two countries. It reveals whether the UK's cardiovascular researchers collaborate with scientists from another country more than might be expected, given the total number of UK–foreign collaborations and the number of papers produced by the UK and the country being studied. The higher the index, the stronger the association between the UK and that country.

$$\text{Co-authorship index} = \frac{\text{Number of UK papers co-authored with country X / Number of UK papers internationally co-authored}}{\text{Total number of papers with at least one country X author / Number of world's papers – number of papers with only UK authors}}$$

**Figure 6** **International collaboration in cardiovascular research: 1981–1986 (SCI analysis).**




The UK co-authorship index with both France and Germany was greater than 1.0, suggesting that collaboration with these countries was greater than might be expected, given the number of papers produced and co-authored by these countries internationally (figure 6). In contrast, collaboration between the USA and the UK was lower than expected given the volume of research activity in that country. This suggests that geographic proximity might be a determining factor in research collaboration.

### 3.6 International comparison of the emphasis on different subfields

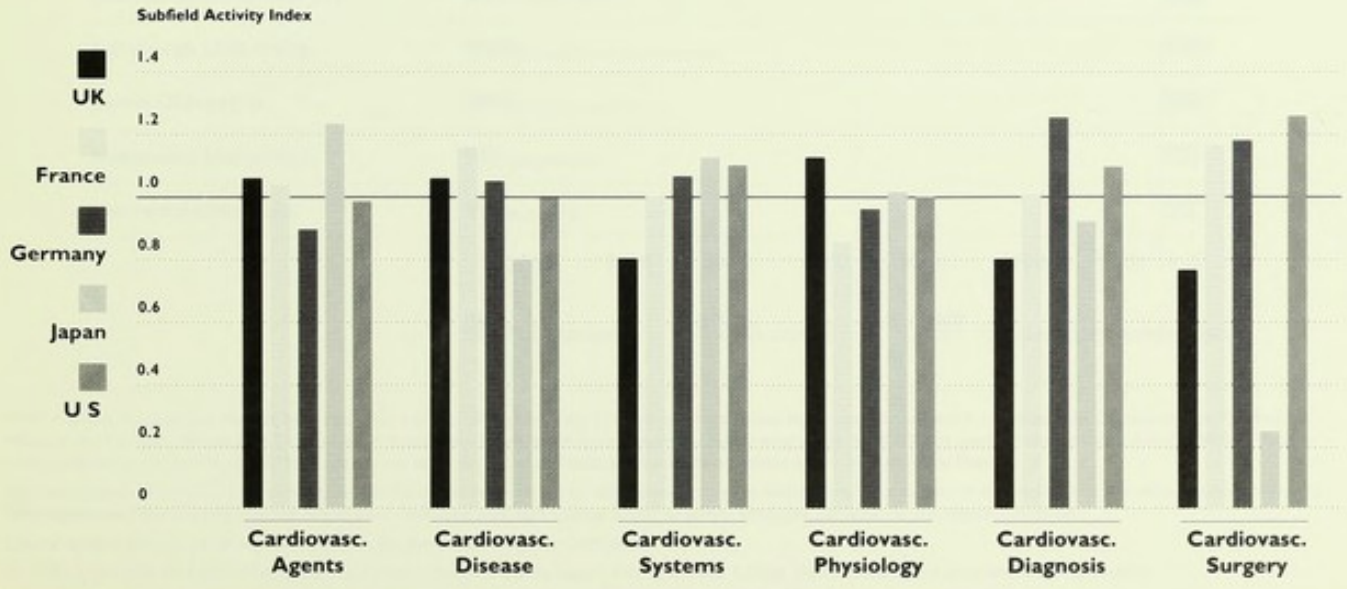
The publications output data from 1981 to 1986 were fractionated not only according to which country produced each paper but also according to which categories of MeSH were used to index each paper. A paper may be indexed with terms from a number of MeSH categories with the result that it is 'counted' in two or more of the subfields. Therefore, such an analysis can only show the total frequency with which different MeSH terms were used by Medline indexers to describe the papers from a particular country. However, the large sample of papers used in this study made it possible to provide an approximate guide to the relative activity in different subfields in different countries.

The data were expressed as subfield activity indices, using the formula below. An activity greater than 1.0 suggests a concentration of effort in a particular subfield of cardiovascular research, whilst an index of less than 1.0 suggests a lower than expected activity.

$$\text{Subfield Activity Index} = \frac{\text{Number of country A's papers in subfield S/ Number of country A's papers in all subfields}}{\text{Number of world's papers in subfield S/ Number of world's papers in all subfields}}$$

The most striking contrast in activity was found for Japan (figure 7) which appeared to be relatively inactive in research on cardiovascular surgery and much more active in research on cardiovascular agents. Differences were less dramatic for the UK, although physiology and cardiovascular agents appeared to be more active subfields than diagnostic techniques and cardiovascular surgery. In Germany, the subfield with the highest relative activity was research on diagnostic techniques and in the USA it was research on cardiovascular surgery.

**Figure 7** **International comparison of the emphasis on different subfields: 1981–1986 (SCI analysis)**



### 3.7 Distribution of cardiovascular research activity in the UK

The Science Citation Index was used to identify the 25 UK institutions with the greatest number of publications between 1981 and 1986 relevant to cardiovascular research. The data were also analysed by the number of citations received during this period.

Figure 8 shows the result of the analysis. The institutions are ranked by the number of citations received per paper. The British Postgraduate Medical Federation, the Royal Postgraduate Medical School and the Medical Research Council Laboratory of Molecular Biology form a cluster at the top of the table, with each paper receiving 8.5 citations on average. But it is clear that the institutions vary markedly in their activity. Glasgow is at the top with over 900 publications and the AFRC Institute of Animal Physiology is at the bottom with less than 100 publications. As for citations, the greatest number was received by Oxford. Thus, there is not a linear relationship between the number of publications produced and the citations received.

**Figure 8** **The 25 top producers of publications relevant to cardiovascular science: 1981-1986 (SCI analysis)**


BPMF = British Postgraduate Medical Federation. It is a school of the University of London and comprises eight research and teaching institutes, the Departments of Postgraduate Medicine and Dentistry for the four Thames Health Regions and a central administrative office. Papers where only the BPMF was specified were attributed to the BPMF. Where a specific institution falling under the BPMF umbrella was listed the paper, or fraction thereof, was attributed to the institution specified.

The vast majority of cardiovascular publications listed above were produced by researchers working in departments forming part of the medical faculty or school in each university. The publications from teaching hospitals which were associated with each medical faculty or school were also attributed to the relevant university.

London medical schools are listed separately from the University of London publications.

UL UNIV COLLEGE: All papers from University College London (including papers from University College Medical School) and associated teaching hospitals.

UL KING'S COLLEGE: All papers from King's College London (including papers from King's College Medical School) and associated teaching hospitals.

Because of the inaccuracy of the address field in Medline, the above analysis was confined to the period 1981–1986. To get more up-to-date information, a special sampling technique (see 2.8) was used to identify the 100 most prolific or 'visible' authors in the UK between 1988 and 1991. Their addresses were then checked using a variety of directories such as the *Commonwealth Universities Yearbook*. The results are shown in diagrammatic form in figures 9 and 10. London, shown separately in figure 10, dominated UK cardiovascular research, with 69 of the nation's most visible researchers working there. The largest centres in London were the Royal Postgraduate Medical School, with 13 researchers in the top 100, the National Heart and Lung Institute with 12, and St George's Hospital Medical School with 10.

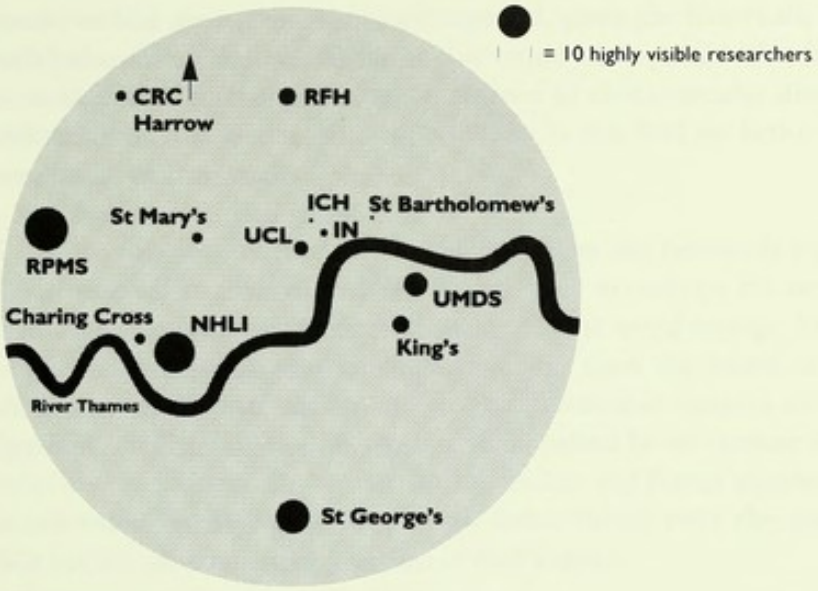
**Figure 9** **Hot spots of publication activity in UK cardiovascular research: 1988-1991 inclusive (Medline analysis)**

**(Diameters of circles relate to the number of highly visible researchers in country's top 100)**


* Denotes that London is not represented on this map. It is shown overleaf in Fig 10.

The most active centres outside London were Cambridge, with seven of the most visible researchers, Glasgow with six and Oxford and Nottingham with five each.

**Figure 10** **London centres of publication activity in cardiovascular research: 1988-1991**
**(Medline analysis)**
**(Diameters of circles relate to the number of highly visible researchers in country's top 100)**




**Key:**
**CRC** Clinical Research Centre (MRC) **ICH** Institute of Child Health **IN** Institute of Neurology **NHLI** National Heart and Lung Institute **RFH** Royal Free Hospital **RPMS** Royal Postgraduate Medical School **UCL** University College London **UMDS** United Medical and Dental School (Guy's and St Thomas's)

### 4.1 Solving the problem of field definition

The study addressed the problem of defining a multidisciplinary field by developing a novel method that did not rely solely on the use of keywords or a fixed journal set. This method, which combined the use of the largest biomedical research database in the world, a highly evolved classification and indexing system, and an iterative process involving expert scientists, could be appropriate for other disciplinary fields in the biomedical area (e.g. cancer, mental health). Alternatively, this approach might be suitable for analysis of non-biomedical fields where a large database exists (e.g. Chemical Abstracts, Physics Abstracts) which has a classification scheme or indexing language attached to it.

The involvement of the Steering Committee in the development of the research field definition helped shape the framework within which data on publications were collected. The involvement of subject experts in the bibliometric analysis was crucial since it added value to the study overall and enhanced its credibility and legitimacy.

The Science Citation Index was used to examine in more detail international patterns of the output and impact of research in the field in the early 1980s, as well as to produce a more detailed picture of the priorities that different countries had in the field of cardiovascular research. By combining the Science Citation Index and Medline in this way, both databases were employed to best advantage.

### 4.2 The contribution of cardiovascular research to the biomedical field

From 1981 to 1991, 19% of the world's biomedical research output could be considered to have some relevance to cardiovascular biology or related areas. This may be a reflection of the multidisciplinary nature of the field. Alternatively, it may indicate the importance of cardiovascular disease as a major cause of death in the developed world.

### 4.3 International comparison of productivity

On an international level, the USA dominated the field during the 1980s. The UK share of world cardiovascular papers remained static during this decade, but Japan, Germany and France exhibited different patterns of publication. Japan was the only country to increase its share of world cardiovascular publications, while the German and French share declined during the first half of the 1980s. During the late 1980s, Germany showed a slight upturn in publication activity.

The five countries studied varied in the emphasis placed on cardiovascular research in relation to their overall national activity in biomedical research. Despite the dominance of the USA, its cardiovascular activity index suggested that by 1991, this area of research had less prominence within its national research portfolio. In France and the UK, cardiovascular research also had less prominence; activity indices declined over the period studied, unlike the indices for Japan and Germany. Thus, although the UK and USA publish large numbers of cardiovascular papers

each year, this field does not stand out in these countries as it does in Japan and Germany. It is possible, therefore, that the German and Japanese research communities are targeting cardiovascular science in a way that is not occurring in the UK or USA. The Japanese focus on cardiovascular research is perhaps unexpected, given the historically low incidence of cardiovascular disease in that country. It is possible that Japan is anticipating an increase in the incidence of cardiovascular disease. Alternatively, it may see export opportunities in this field for health care services in other countries.

### 4.4 Citation impact of cardiovascular papers

Citation analysis confirmed that productivity does not necessarily equate with impact. The relative citation index was used to compare the average number of citations per paper for a country to the world average. Values above 1.00 denote a citation impact higher than the world norm. Although Japan increased its share of cardiovascular research output between 1981 and 1986, this was not accompanied by an increase in its relative citation index. In contrast, both Germany and France experienced an increase in their relative citation index values over the period 1981–1986, despite a relative decline in their output.

### 4.5 Prominence of cardiovascular research

A comparison was made of the emphasis on different subfields in each of the countries. The variations in subfield activity may be an indication of different research priorities, but cultural factors and traditions may also play a part. Japan, with its lower incidence of heart disease, was relatively inactive in research on cardiovascular surgery. By contrast, this was the highest relative activity in the USA. The UK, with a strong tradition of pharmaceutical and basic research, concentrated mostly on research into cardiovascular agents and physiology; the least active subfields appear to have been diagnostic techniques and cardiovascular surgery. In Germany, the subfield with the highest relative activity was research on diagnostic techniques.

### 4.6 Co-authorship patterns

In this study, the intensity of collaboration with France and Germany was found to be higher than expected, given the number of papers produced and co-authored by these three countries internationally. The UK was more likely to collaborate with researchers from France or Germany than with researchers from the USA, despite having a common language with the latter. The analysis of co-authorship patterns confirmed those observed in another study of research collaboration, which found that the number of collaborations between groups decreased exponentially as a function of distance and that geographical proximity may be a factor for research institutions when choosing collaborators.[32]

### 4.7 Cardiovascular research activity in the UK

Globally, the UK is a major contributor to cardiovascular research, second only to the USA in terms of the impact of its cardiovascular publications and ahead of its European neighbours in terms of productivity. However, although cardiovascular research appeared to have some prominence in the national research portfolios of Japan and Germany, it did not stand out as a specially active field within the UK's national research portfolio.

Detailed analysis of the UK situation revealed that cardiovascular research activity and expertise was distributed throughout the country. Cambridge, Glasgow, Oxford and Nottingham were all active cardiovascular research centres. However, London-based institutions dominated the field, with 69 of the nation's most visible researchers (identified by the frequency of publication) working there. Within London, the largest centre was the Royal Postgraduate Medical School, followed by the National Heart and Lung Institute and St George's Medical School.

Although bibliometric analysis of any biomedical subject would identify London as a major area of research activity, this was particularly pronounced in cardiovascular research. The extent of cardiovascular research activity in London is likely to be a reflection of the clinical nature of the field and the concentration in the capital of the major teaching hospitals. However, in the wake of the Tomlinson report[33] health care provision for London is undergoing large-scale restructuring. The long-term implications are unclear but the effects of such profound changes are likely to be felt in all areas of clinical research.

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