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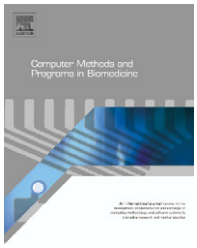

Scientific production of electronic health record research, 1991–2005

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ABSTRACT

Purpose: The increasing numbers of publications on electronic health record (EHR) indicate its increasing importance in the world. This study attempted to quantify the scientific production of EHR research articles, and how they have changed over time, in an effort to investigate changes in the trends cited in these critical evaluations.
Method: The articles were based on the science citation index (SCI) from 1991 to 2005. A descriptive study was performed using the 1803 documents published in the SCI from 39 countries in America, Europe, Africa, Asia, and Oceania. The evaluation was based on parameters including document type, language, first author's country of origin, number of citations and citations per publication.
Results: Of all publications, 1455 (80.7%) were articles, followed by meeting abstracts which represented about one-tenth of all types of EHR publications. Numbers of published articles have significantly increased when compared by each 5-year period. Most articles were published in English (98%) and were from the region of America (57%). The top 10 of the 374 journals accounted for 41% of the number of published articles. The US dominates publication production (57%) with a cumulative impact factor (IF) of 2227 and followed by the UK (8.5%, with a cumulative IF of 257.0) and the Netherlands (7.8%, with a cumulative IF of 211.1). An analysis of the number of articles related to population revealed a high publication output for relative small countries like Switzerland, the Netherlands, and Norway.
Conclusions: Research production in EHR showed a considerable increase during 1991–2005. The production was dominated by articles, those from the US, and those published in English. The production came from many countries, denoting the devotion to this field in different areas around the world.

1. Introduction

President Bush noted in his 2004 State of the Union Address: "By computerizing health records, we can avoid dangerous medical mistakes, reduce costs, and improve care." This statement recognized that electronic health record (EHRs) provide huge opportunity to enhance the quality of patient care and improve management of health systems. The Agency for

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Healthcare Research and Quality (AHRQ) [1] has funded organizations across the US that are implementing and evaluating electronic medical and health record systems, and is also systematically tabulating review evidence on the costs and benefits associated with use of health information technology. At the same time, the increasing numbers of publications on EHR indicate its increasing importance in the world. The first article in terms of a computerized medical record was written by Davis [2], entitled "Prototype for future computer medical records". Litzelman et al. [3] improved compliance with computer-generated reminders to perform fecal occult blood testing (FOBT), mammography, and cervical Papanicolaou (Pap) testing which has been cited most by other authors (107 times). In this study, we performed a bibliometric analysis on articles published concerning EHR research and attempted to discover any significant publication patterns. The bibliometric analysis was performed to assess quantitative trends of EHR research from articles encompassing the science citation index (SCI) distributed by the Institute of Scientific Information (ISI) [4] during the time span of 1991–2005. We wanted to quantify the scientific production of EHR research articles, and how it has changed over time, in an effort to investigate changes in the trends cited in these critical evaluations.

2. Methods

The articles were based on the SCI from 1991 to 2005. The following keywords were used to identify the computerized patient record-related research collected in the ISI database: computer* patient record*, computer* medical record*, electronic medical record*, electronic patient record*, electronic health record*, electronic health care record*, virtual EHR, digital medical record*, automated medical record*, provider-based patient medical record*, and computer-based patient record*. Among these keywords, "computer*" includes the words "computer" or "computerized", and "record*" includes the words "record" or "records". The evaluation was based on parameters including document type, language, first author's country of origin, number of citations, and number of citations per publication (CPP). Computer science journal titles were identified in the subject index of SCI journals in 2005, and the abbreviated title of each journal was entered as a search string. We found Artificial Intelligence, Cybernetics, Hardware & Architecture, Information Systems, Interdisciplinary Applications, Software Engineering, Theory & Methods, Information Science & Library Science and Medical Informatics were in this category. The cumulative impact factor for each nation was calculated by multiplying the number of articles from each country by the respective journal's impact factor (IF) for the year 2005. To assess the popularity of our discipline in each country, we also calculated a "national publication output", determined by the number of published articles per million inhabitants as estimated for 2005 by the world factbook web site [5].

3. Results

As to the type of published EHR documents, 1803 documents were published in SCI journals from 39 countries in America, Europe, Africa, Asia, and Oceania during 1991–2005. Table 1 shows that 1455 (80.7%) were articles, this number has significantly increased when compared by each 5-year period, followed by meeting abstracts which represented about one-tenth of all types of EHR publications. Of all numbers of EHR articles indexed by the SCI from 1991 to 2005, Fig. 1 shows an increasing trend during these 15 years. Particularly in 2005, we found the publication number was almost 57% higher than in 2004.

Of all published articles, Fig. 2 shows that the average number of articles on this topic in 1991–1995 was 32 (160/5 year), in 1996–2000 was 92 (462/5 year) and increased to 167 (833/5 year) in 2001–2005. There were 580 publications in computer science journals. The remaining 875 were published in non-computer science journals, mainly medical science journals. Thus, the ratio of the total number of EHR articles in computer science to non-computer science journals during these 15 years was 0.66. If we calculated the ratios of 1991–1995, 1996–2000, and 2001–2005, respectively, they were 0.63, 0.89 and 0.56. Therefore, the publication numbers of non-computer science journals were significantly higher than those of computer science journals, particularly in the 2001–2005 period. Table 2 shows that articles indexed by SCI were almost entirely published in English (97.6%), with no changes in this proportion over time. The region of EHR studies has not changed over time, either. America has dominated publication production (57%), followed by Europe (36%) and Asia (4.7%). During

Table 1 – Type of published electronic health record documents indexed by the science citation index from 1991 to 2005

Document type	1991–1995 (%)		1996–2000 (%)		2001–2005 (%)		Total (%)	
Article	160	(82.1)	462	(77.8)	833	(82.1)	1455	(80.7)
Meeting Abstract	3	(1.5)	75	(12.6)	99	(9.8)	177	(9.8)
Editorial Material	11	(5.6)	20	(3.4)	28	(2.8)	59	(3.3)
Review	7	(3.6)	16	(2.7)	31	(3.1)	54	(3.0)
Letter	6	(3.1)	16	(2.7)	9	(0.9)	31	(1.7)
News Item	0	(0)	4	(0.7)	9	(0.9)	13	(0.7)
Correction	0	(0)	1	(0.2)	4	(0.4)	5	(0.3)
Note	5	(2.6)	0	(0)	0	(0)	5	(0.3)
Software Review	3	(1.5)	0	(0)	0	(0)	3	(0.2)
Reprint	0	(0)	0	(0)	1	(0.1)	1	(0.1)
Total	195	(100.0)	594	(100.0)	1014	(100.0)	1803	(100.0)

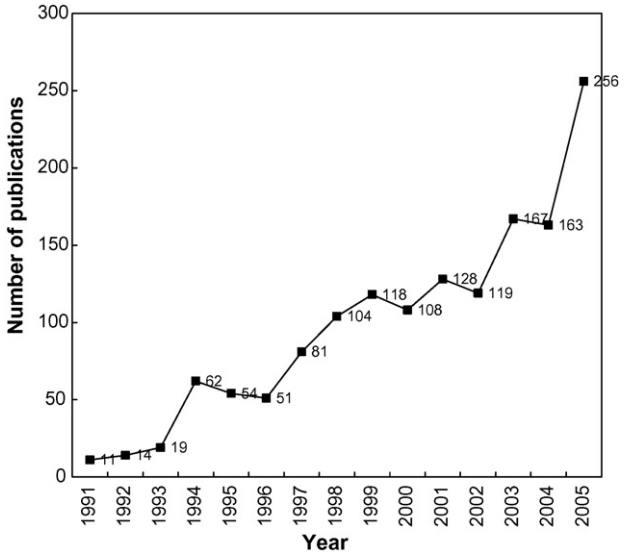

Fig. 1 – Numbers of published electronic health record articles indexed by the science citation index from 1991 to 2005.

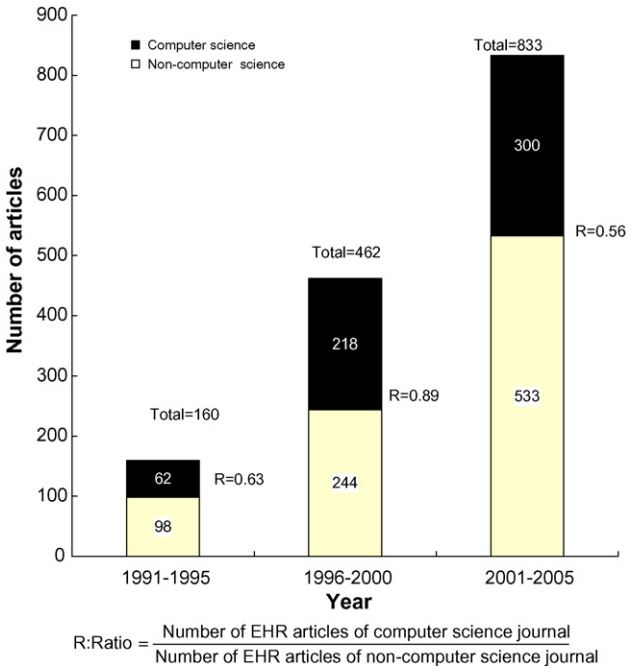

Fig. 2 – Numbers of published electronic health record articles of computer science journals and non-computer science journals indexed by the science citation index from 1991 to 2005.

these 15 years, we further analyzed 603 EHR articles (41%) from the top 10 of the 374 journals. These articles originated from different disciplines such as computer science, medical informatics, medicine or health sciences. Table 3 shows that the *Journal of the American Medical Informatics Association* contributed 200 articles (14%) with a citations per publication (CPP) of 6.4 followed by the *International Journal of Medical Informatics* (9.9%, CPP = 4.5) and *Methods of Information in Medicine* (7.2%, CPP = 9.4). Finally, results of the geographical distribution of articles in 22 countries are summarized in Table 4 except those countries with fewer than five publications. The USA has dominated publication production (54%) with a cumulative IF of 2227 followed by the UK (8.5%, cumulative IF = 257.0) and the Netherlands (7.8%, cumulative IF = 211.1). The ranking calculated according to the cumulative IF was fairly consistent with the ranking based on the absolute article count. However, the ranking of mean national IF significantly differed from the ranking based on the absolute numbers of articles due to those countries which had lower cumulative IF of articles. The analysis of the number of articles related to population also revealed a high publication output for relative small countries like Switzerland, the Netherlands, and Norway.

4. Discussion

To our knowledge, the present study represents the first published article using bibliometric techniques to quantify and evaluate scientific activity in the field of electronic health record. In this assessment, we covered articles based on the

Table 2 – Characteristics of published electronic health record articles indexed by the science citation index from 1991 to 2005

	1991–1995 (%)		1996–2000 (%)		2001–2005 (%)		Total (%)	
Language								
English	157	(98.1)	452	(97.8)	814	(97.7)	1423	(97.8)
Non-English	3	(1.9)	10	(2.2)	19	(2.3)	32	(2.2)
Total	160	(100.0)	462	(100.0)	833	(100.0)	1455	(100.0)
Region								
America	93	(60.0)	286	(63.0)	442	(53.6)	821	(57.3)
Europe	56	(36.1)	146	(32.2)	313	(38.0)	515	(35.9)
Oceania	5	(3.2)	8	(1.8)	15	(1.8)	28	(2.0)
Asia	1	(0.6)	14	(3.1)	52	(6.3)	67	(4.7)
Africa	0	(0)	0	(0)	2	(0.2)	2	(0.1)
Total	155	(100.0)	454	(100.0)	824	(100.0)	1433	(100.0)

Table 3 – Top 10 journals according to the number of articles published

Journal name	P (%)	C (%)	CPP
Journal of the American Medical Informatics Association	200 (14)	1286 (11)	6.4
International Journal of Medical Informatics	144 (9.9)	647 (5.7)	4.5
Methods of Information in Medicine	105 (7.20)	985 (8.7)	9.4
International Journal of Bio-Medical Computing	43 (3.0)	154 (1.4)	3.6
Journal of Digital Imaging	20 (1.4)	101 (0.89)	5.1
Journal of General Internal Medicine	19 (1.3)	408 (3.6)	21
MD Computing	19 (1.3)	190 (1.7)	10
Computer Methods and Programs in Biomedicine	19 (1.3)	131 (1.2)	6.9
British Medical Journal	18 (1.2)	305 (2.7)	17
Medical Informatics and the Internet in Medicine	16 (1.1)	11 (0.097)	0.69

P, publications; C, citations; CPP, citations per publication. The percentage for each category is shown in parentheses.

SCI in the ISI database since 1991. Although the electronic MEDLINE contains more articles and different types of publication, the authors selected journals based only on the SCI list in order to calculate the articles' citations after publication and the respective journal's impact factor. The present study documented a very significant increase in electronic health record publications in the health and computer science literature during the past 15 years compared by each 5-year period, especially in 2005.

The term electronic health record (EHR) may be described by computerized patient record (CPR), computer-based patient record, computerized medical record, electronic medical record (EMR), electronic patient record (EPR), electronic health care record (EHCR), virtual EHR, digital medical record (DMR), automated medical record, and provider-based patient medical record. These terms were all generated from the same vision more than 30 years ago. The Medical Records Institute's EHR trends and usage surveys [6,7] can help us understand their abundant similarities and differences. However, sufficient differences among them are more apparent now than even just a few years ago, reflecting the evolution of the concept [8,9]. According to the definition of the Institute of Medicine [10], EHR contains alerts, medication and order administration, integrated evidence-based medicine, seamless health information exchange between providers across the lifetime continuum of care (e.g., nursing homes, home health, rehabilitation, and assisted living), reporting diagnoses as a near real-time transaction to public health, and embedded clinical terminology to assist with documentation. A standard EHR and interoperable national health information infrastructure require the use of uniform health information standards, like HL7, DICOM, LOINC, and SNOMED. Therefore, standard

Table 4 – Number of articles from each country, percentage of world publications, cumulative and mean impact factors (IFs) of the publications, and number of publications per million inhabitants

Country	No. of articles	Percent of world	Cumulative IF	Mean national IF	Articles per million inhabitants
USA	773	54	2227 **(1)**	2.970 **(1)**	2.61 (5)
UK	122	8.5	257.0 (2)	2.274 (3)	2.02 (8)
Netherlands	112	7.8	211.1 (3)	1.885 (4)	6.83 (2)
Germany	83	5.8	101.8 (4)	1.226 (14)	1.01 (16)
Canada	41	2.9	101.3 (5)	2.533 (2)	1.25 (13)
Sweden	32	2.2	37.80 (6)	1.219 (15)	3.55 (4)
Australia	24	1.7	36.04 (7)	1.502 (9)	1.19 (14)
France	24	1.7	33.70 (9)	1.404 (11)	0.40 (18)
Switzerland	22	1.5	35.99 (8)	1.636 (6)	19.33 **(1)**
Norway	20	1.4	26.20 (11)	1.379 (13)	4.35 (3)
Japan	19	1.3	20.92 (13)	1.101 (17)	0.15 (21)
Italy	17	1.2	26.06 (12)	1.533 (9)	0.29 (20)
Israel	16	1.1	28.45 (10)	1.778 (5)	2.55 (6)
Austria	14	1.0	12.93 (16)	0.923 (21)	1.71 (10)
Belgium	14	1.0	14.23 (15)	1.016 (20)	1.35 (12)
Denmark	12	0.84	16.70 (14)	1.392 (12)	2.21 (7)
Finland	10	0.70	10.33 (19)	1.033 (19)	1.91 (9)
Greece	10	0.70	10.84 (18)	1.084 (18)	0.94 (17)
Hong Kong	8	0.56	12.37 (17)	1.546 (7)	1.16 (15)
Taiwan	7	0.49	8.370 (21)	1.196 (16)	0.31 (19)
Ireland	6	0.42	4.142 (22)	0.690 (22)	1.49 (11)
South Korea	6	0.42	9.267 (20)	1.545 (8)	0.14 (22)

The relative ranking for each category is shown in parentheses. The first ranking is marked in boldface.

clinical terminologies and classifications, with maps linking them, must be incorporated into EHR systems to achieve system interoperability and the benefits of a national health information infrastructure in the future [11].

From Fig. 2, we discovered that the ratio of the total number of EHR articles in computer science to non-computer science journals during our study period was 0.66. Due to the number of non-computer science journals are far more than computer science journals in SCI and EHR concepts and knowledge are highly used by medical science journals, so the volume of EHR articles may be more prevalent in non-computer science journals. This result also indicates that increasing numbers of health and medical studies are focusing on the topic of EHR. However, if we refer to Table 3: top 10 journals according to the number of articles published, only Journal of General Internal Medicine and British Medical Journal are belonged to non-computer science journals, and the others were computer science journals. From Melanie et al.'s systematic review on the effect of health information technology on health care [12], three major benefits for preventive health quality were demonstrated: increased adherence to guideline-based care, enhanced surveillance and monitoring, and decreased medication errors, but importance evidence related to financial costs and return on investment was not presented. Lacking key data on financial contexts, such as the degree of capitation, which has been suggested by a model for defining the business case for EHR [13], will significantly hamper the adoption of EHR by healthcare organizations. However, health information technologies are critical to transforming the healthcare industry [14,15]. Developing and implementing the EHR will be fundamental to healthcare delivery in the future [16].

We hypothesized that there was a close relationship between a country's economic status and its capacity to generate EHR articles. The relationship between scientific production and research and development (R&D) was significant [17]. Thus, if we had calculated the ratio between the total expenditure allocated to R&D and the EHR scientific production, we would have observed that the highly industrialized country of the United States (US) spends most on R&D followed by the UK. According to the National Science Foundation's data of estimated worldwide R&D expenditures: 1990–2003, US, European Union (EU); Organization for Economic Co-operation and Development (OECD) spent 161.41, 121.49 and 380.34 billions on R&D respectively in 1991, and these amounts increased to 284.58, 211.19 and 679.78 billions in 2003. It showed that just US's R&D expenditure was more than 15 EU countries. On the other hand, those non-OECD countries' R&D expenditures also increased from 32.45 to 130.46 billions in the same time periods. However, the total amount of non-OECD countries' expenditures was still far behind those highly industrialized countries. However, these data must be analyzed with caution since a country's R&D spending is one function of several factors, and this expenditure is basically on industrial activities [18]. We also found some countries' citation of each publication was not as good as their cumulative IF. For example, the rank of German and Sweden's cumulative IF were on the top 4 and 6 on the list, but their mean national IF were dropped to 14 and 15. Thus, when evaluate the countries' production of EHR, the volume and citation of articles both should be examined. Finally, although the US has dominated EHR publication in the world (Table 4), comparing the relationship between scientific production and population size, we found that the top three countries' populations were less than 10 million with the exception of the Netherlands. It was also interesting to discover that these three countries are not English-speaking countries.

5. Conclusions

The research production in EHR has considerably increased during 1991–2005. The production was dominated by articles, those published in the US, and those published in English. The production came from many countries, denoting the devotion to this field in different areas around the world.

6. Limitations

This study has a number of limitations. Due to the citations based on the SCI journals from 1991 to 2005 which represent only a portion of the published literature. The trends seen in the citations with abstracts might not be generalized to all EHR studies. Data were collected on 2 July 2006.

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