RESEARCH ARTICLE

Future VIROLOGY

A bibliometric analysis of dengue-related publications in the Science Citation Index Expanded

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Dengue is a re-emerging infection that poses significant threat to about half of the world's population, but there was little information on the bibliometric trend and patterns of dengue research globally. The purpose of this research is to provide a bibliometric analysis of dengue research from 1991 to 2014, and to assess the relationship between the burden of dengue and scientific publications. Most papers were classified under the topics of tropical medicine, virology, infectious diseases, parasitology or immunology. India may soon surpass Thailand in the ranking. Overall, international collaboration appeared to play a significant role in dengue research. Regional specificity of dengue may also influence the bibiliometric profile of dengue research. Nevertheless, dengue research output appeared to be positively and significantly related to the level of dengue cases, an indication that the scientific community was responding well to the needs of the population.

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KEYWORDS
bibliometrics • burden of disease • dengue • research output

Background

Approximately half of the world's population is at risk for dengue virus infection [1]. The WHO estimates that dengue infects 50–100 million people annually [2]. However, other estimates put the number of total infections at 390 million, of which 96 million are symptomatic [3]. Dengue is composed of four serotypes (DEN1–4). The disease is transmitted primarily by the *Aedes aegypti* mosquito and secondarily by the *Aedes albopictus* mosquito. Symptoms include fever, headaches, retro-orbital pain, joint and muscle soreness, and rashes. While most dengue cases are asymptomatic or mild, serious cases can evolve into fatal dengue hemorrhagic fever and dengue shock syndrome. Patients can be infected by multiple serotypes, but immunity against one serotype does not result in life-long immunity against other serotypes. In fact, infections by multiple serotypes can increase the risk of severe dengue [1,4]. Most cases of dengue are clustered in Southeast Asia and Latin America, with fewer cases in Europe and Africa, some in the USA (Peurto Rico, Hawaii, Texas and Florida), and nearly none in Canada [3]. Dengue fever was nearly eradicated in Americas after a stringent vector control program by the Pan American Health Organization starting in 1940, but failure to sustain the program resulted in a resurgence of cases in the 1980s [5]. Additionally, factors such as urbanization, globalization, increases in population density, and poor sanitation and infrastructure are believed to play large roles in increasing the spread of dengue fever [6]. In 2015, the first dengue vaccine, Dengvaxia by Sanofi Pasteur, was licensed in Mexico. Brazil, El Salvador, Paraguay

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and The Philippines, have since also licensed the vaccine, and the WHO just recently endorsed the vaccine [7,8]. While these advancements are important to limiting dengue transmission, further efforts are needed as dengue continues to be a rapidly growing health problem today.

An overall assessment of the state of dengue research can be best completed using bibliometric profiling. Bibliometric profiles create a bird's-eye view of the research landscape, history and trends of a certain topic or field (Matcharashvili, Sborshchikovi, Tsveraidze & Matcharashvili, 2014; The University Library, 2014) [9,10]. The profiles include factors such as allocations of research funding, publication topics, publication authors and institutions, number of citations, shifts in popular research areas over time and the geographical spread of research and publications. Bibliometric profiles have been completed for a number of infectious diseases, such as HIV [11], malaria [12], pneumonia [13], norovirus [14] and Chagas disease [15]. Among others, these profiles have helped to identify the appearance of new terminology [16], note the differences in research contributions by geographical area [12] and assess research funding and publications to provide evidence for greater funding efforts [13]. For dengue in particular, only a few bibliometric profiles have been completed, and only for specific regions of the world. Previous studies have assessed research efforts in relation to disease burden in particular geographical locations, such as Latin America, India and China, and called for greater research efforts [17–19], and noted the leading role of the USA, India and Brazil in dengue virus research [20]. However, despite the global presence of dengue, the disease distribution is very uneven [21]. The regional specificity of dengue fever implies that its bibliometric profile might differ in diseases, such as cancer [22], stroke [23] and diabetes [24], which do not have regional specificities. Hence, the purpose of this research was to provide a bibliometric profile of scientific publications of dengue fever, to understand the influence of regional specificity on bibliometric characteristics and to assess the relationship between the burden of dengue fever and scientific publications. Such a comprehensive overview of the current state of dengue research is important to understanding, for both researchers and policy makers, where research is taking place, and its impact on disease burden.

Methodology

Publication data were obtained from the online version of the Science Citation Index Expanded (SCI-EXPANDED) databases from the Web of Science Core Collection by Thomson Reuters

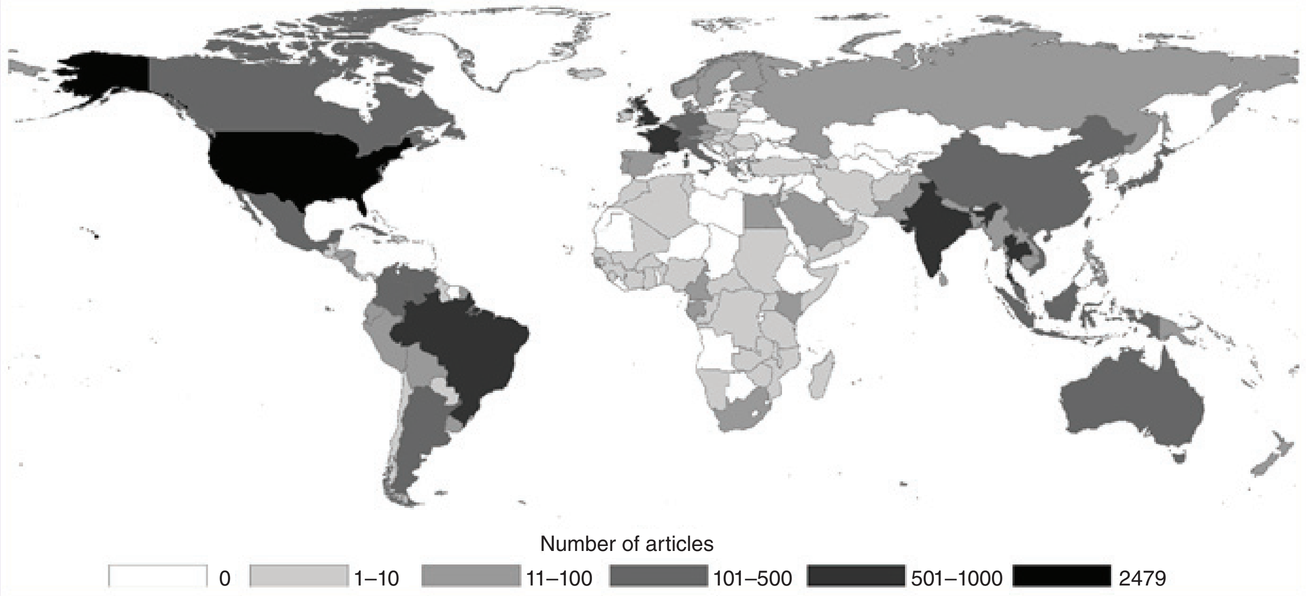

Figure 1. The global distribution of dengue-related articles.

Table 1. Bibliometric statistics of articles from 1991 to 2014.

Year	TP	AU	AU/TP	NR	NR/TP	PG	PG/TP
1991	62	251	4.0	1374	22	443	7.1
1992	56	240	4.3	1552	28	441	7.9
1993	73	312	4.3	1912	26	594	8.1
1994	70	287	4.1	2047	29	553	7.9
1995	72	294	4.1	1905	26	531	7.4
1996	97	405	4.2	2103	22	573	5.9
1997	97	441	4.5	2658	27	623	6.4
1998	129	652	5.1	3832	30	888	6.9
1999	140	734	5.2	3793	27	868	6.2
2000	147	764	5.2	4018	27	958	6.5
2001	149	896	6.0	4543	30	1144	7.7
2002	169	1060	6.3	5207	31	1244	7.4
2003	197	1194	6.1	5950	30	1451	7.4
2004	226	1269	5.6	7369	33	1808	8.0
2005	257	1530	6.0	7977	31	1974	7.7
2006	335	2048	6.1	10,767	32	2683	8.0
2007	377	2395	6.4	12,411	33	3006	8.0
2008	483	2928	6.1	16,177	33	3763	7.8
2009	559	3517	6.3	18,642	33	4377	7.8
2010	596	3925	6.6	21,047	35	4774	8.0
2011	671	4422	6.6	24,996	37	5607	8.4
2012	818	5441	6.7	30,615	37	6738	8.2
2013	966	6590	6.8	38,038	39	8677	9.0
2014	1000	6729	6.7	40,936	41	9249	9.2
Total	7746	48324		269,869		62,967	
Average			6.2		35		8.1

AU: Total number of authors; AU/TP: Average number of authors per article; NR: Number of references listed; NR/TP: Average number of references listed per article; PG: Total number of pages printed; PG/TP: Average number of pages printed per article; TP: Total number of articles.

(updated on 17 September 2015). The Web of Science Core Collection includes 8659 journals with citation references across 176 Web of Science categories in its science edition, according to Journal Citation Reports (JCR) of 2014. In this research, only original articles were considered among the various types of documents, since original articles have been peer-reviewed, and more likely had to have proposed novel concepts or presented substantive findings. Several steps were taken to identify dengue-related articles. First, the keyword 'dengue' was used to search for articles that were published from 1991 to 2014. The Web of Science database by Thomson Reuters allows on-line users to search for publications with topic keywords. Any article that has the word 'dengue' in the paper title, abstract, author keywords and *KeyWords Plus* were identified. In total, 9272 articles met the selection criteria. Bibliometric information for all articles was downloaded into Microsoft Excel 2013 [25]. However, *KeyWords Plus* supplies additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes in the ISI (now Thomson Reuters, NY, USA) database, and substantially augments title–word and author–keyword indexing [26]. Such a filter would likely include some articles that had little or no relevance to dengue fever research. Since the online version of the Web of Science by Thomson Reuters does not allow users to conduct a keyword search without including *KeyWords Plus*, another filter, the so-called 'front page' criteria was developed [27]. This method only identifies articles in which the word 'dengue' appears on the 'front page' – that is, the article title, abstract or author keywords. Articles that could only be searched using *KeyWords Plus* were excluded. The filtering process was carried out in Microsoft Excel 2013. Ultimately, the process yielded 7746 dengue-related articles for further bibliometric analysis.

Additional coding of downloaded records was manually performed [25]. Since author affiliation

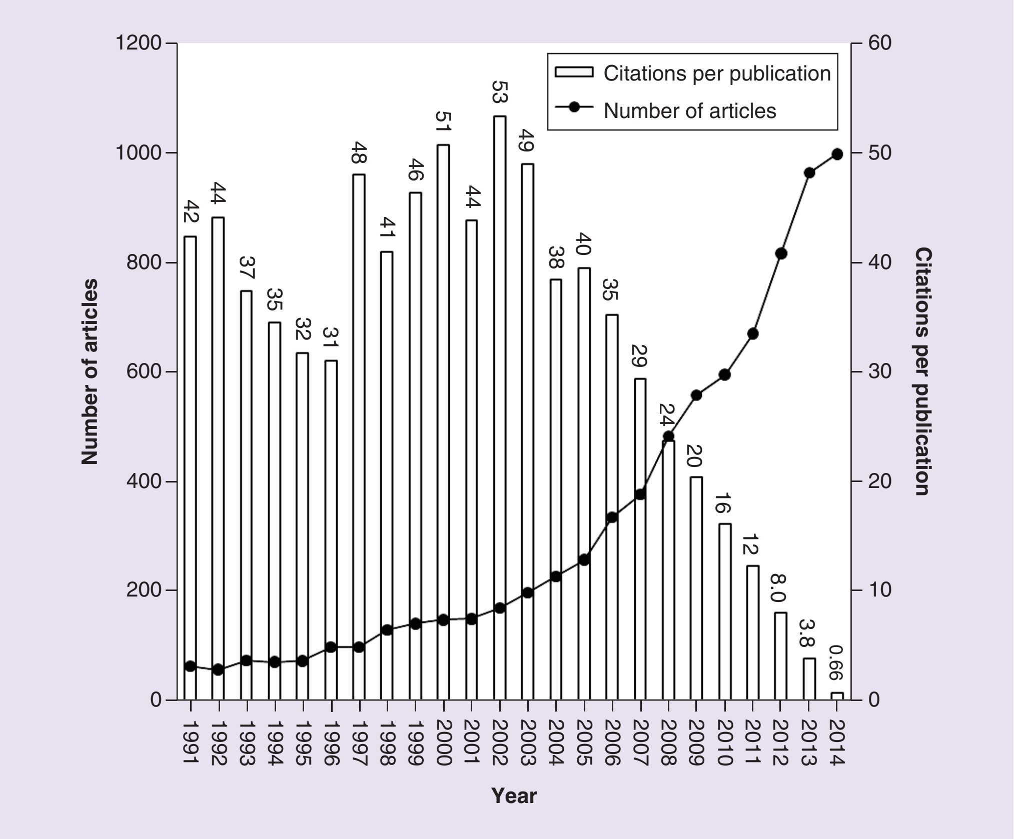

Figure 2. Number of articles and average citations per article by publication year.

information did not follow a standardized format, and some countries have changed names over the years, some affiliation information needed to be recategorized manually. Articles originating from England, Scotland, Northern Ireland and Wales were reclassified as being from the UK. Articles from Hong Kong were included under the heading of China [27]. Articles from Zaire were reclassified as being from the Democratic Republic of the Congo (Dem. Rep. Congo) [28]. Articles from the USSR were checked and reclassified as being from Russia [29]. Minist. Def. USSR was also reclassified as being the Ministry of Defense of the Russian Federation (Minist. Def. Russia). Impact factors (IFs) were taken from the JCR published in 2014 (IF_{2014}). Six bibliometric indicators were used to describe the bibliometric profile of institutions or countries: total articles, independent articles, collaborative articles, first-authored articles, corresponding-authored articles and single-authored articles [30]. Contribution of an institution or a country was defined by whether at least one author was affiliated with the institution or the country [30]. If a paper had authors from different institution or countries, it was classified as an institution- or country-collaborative article. If the researchers' addresses were from the same country or the same institution, the article was defined as a 'single-country article' or 'single-institution article.' The terms 'internationally collaborative article' and 'inter-institutionally collaborative article' were applied to articles that were respectively coauthored by researchers from multiple countries or multiple institutions [25].

Several citation indicators were used in this research. The total number of citations from the Web of Science Core Collection (TC) an article accumulated up to the end of 2014 (TC_{2014}) [31] was generated. Since information on TCs is updated frequently by the Web of Science database, the citation numbers varied from time to time. TC_{year} provides an invariant indicator and can be repeated by other researchers. The other indicator used was C_{year}, which was the number of times being cited from the Web of Science Core Collection in a particular year [29]. C_{2014} indicates the number of times an article was cited in the year 2014 only. The total number of citations from the Web of

Science Core Collection per year (TCPY) was also used [29].

Results & discussion

In total, 7746 dengue-related articles were found in the SCI-EXPANDED from 1991 to 2014. Ninety-six percent of all articles were published in English. Other languages and numbers of articles were Spanish (97 articles), French (96), Portuguese (82), German (23), Turkish (5), Malay (2), Polish (2), Chinese (2) and one for each of Czech, Italian, Korean and Russian. Figure 1 shows the global distribution of dengue-related articles by countries specified in the author affiliation. Countries in the Americas, Southeast Asia and Western Europe appeared to have a higher number of articles compared with others.

• Bibiliometric profile

Table 1 shows annual statistics of articles from 1991 to 2014. The average number of authors per article increased from 4.0 to 6.7, and the number of references cited by each article increased from 22 to 41. The number of dengue-related publications also grew exponentially over time. The total number of articles was 62 in 1991, and then the number doubled in about 7 years to 129 articles in 1998, then doubled again in 7 years to about 257 articles in 2005. Afterward, the growth rates increased again until 2012, but showed signs of slowing down in 2013 and 2014. Based on Figure 2 alone, we cannot tell whether the decline in the rate of growth was due to a real slow-time in research or a lag in publication time or indexing. No clear conclusion can be drawn. However, the data were downloaded on 17 September 2015. Even though more publication could be updated for the year 2013 and 2014, the number would probably be very small. Hence, the lag in indexing would likely not be the reason for the decline in growth rate. Overall, the statistics graphed in Figure 2 clearly demonstrate such a pattern of moderate growth, followed by rapid growth and a decline in growth. The significant increase in the number of publications after 2000 could have been due to an increase in funding. Notably, the Gates Foundation announced in 2003 that they were dedicating US$55 million to dengue-related research through the Grand Challenges Program [32]. Additionally, the National Institute of Allergy and Infectious Diseases increased funding for dengue research from US$5.2 million in 2000 to $30.1 million in 2005 (17 November 2011, retrieved from [33]). The influx of significant funding probably led to the increase in publications as well. Previous research indicated a positive association with

Table 2. Subject categories with at least 100 articles.

Web of Science category	TP	Percent (%)	Journals (n)
Tropical medicine	1580	20	19
Virology	1425	18	33
Infectious diseases	1386	18	78
Parasitology	861	11	36
Immunology	828	11	148
Microbiology	567	7.3	119
Entomology	504	6.5	92
Multidisciplinary sciences	470	6.1	56
Biochemistry and molecular biology	464	6.0	289
Biotechnology and applied microbiology	448	5.8	162
General and internal medicine	310	4.0	153
Research and experimental medicine	260	3.4	123
Biochemical research methods	219	2.8	79
Veterinary sciences	214	2.8	133
Pharmacology and pharmacy	174	2.2	254
Biophysics	129	1.7	73
Genetics and heredity	129	1.7	167
Pediatrics	126	1.6	119
Biology	114	1.5	85
Cell biology	100	1.3	184

TP: Total number of articles.

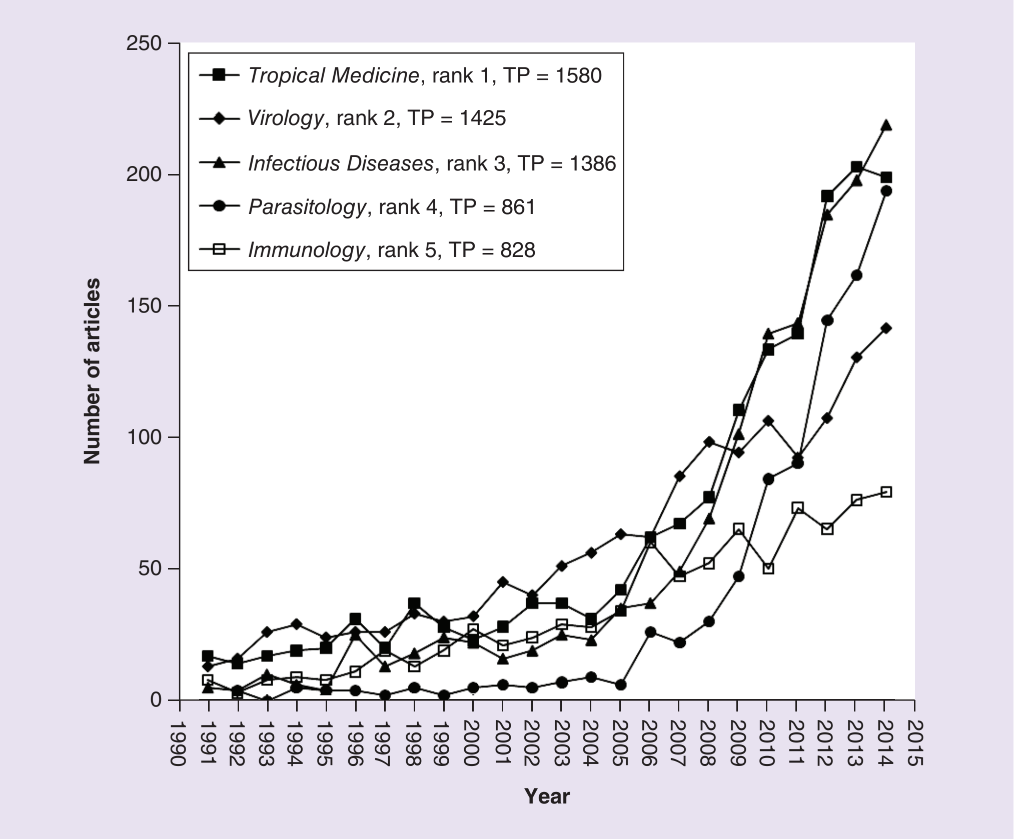

Figure 3. Growth trend of the number of articles in the five leading subject categories by publication year.
TP: Total number of articles.

funding and publication outputs in public health-related research [34].

Figure 2 also shows the average number of citations received per publication (CPP = TC_{2014}/total publication). The reason for using CPP as an indicator, rather than citations during the first year published, or the first 5 years published was that CPP is more stable, and it reflects the overall impact of articles. Citations during the first year or first 5 years published would likely to fluctuate more, since some articles did not start to accumulate citations until a few years after publication. Articles published in the period 1997–2003 had the highest CPP. This is not surprising, as it takes time to accumulate citations [35]. Articles published after 2005 showed a clear decreasing trend in CPP. More recent articles had shorter times to accumulate citations, and because of the high number of articles published per year, citations per article showed a clear decreasing trend, similar to what was observed in the field of science [36] and arts [37]. The average number of citations per article were similar for 1991, 1992 and 1997 but showing a definitive decreasing pattern from 1993 to 1996, despite of having sufficient time to accumulate citations. It is uncommon to see such a clear pattern as this, followed by a sudden and significant increase in citations in 1997. The article 'Rapid detection and typing of dengue viruses from clinical samples by using reverse transcriptase-polymerase chain reaction,' published in 1992, was the only high ranking article published before 1993. Hence, high-citation outliers before 1993 would likely not be the reason for the decreasing trend afterward. Although the increase of scientific journals online in the late 1990 may have an effect on the downward trend of citations, it was unlikely that it would have caused such a definitive downward trend for articles published in the early 1990.

Further examination showed that percentages of articles published in 1994, 1995 and 1996 that had a value of TCPY of <1 were 51, 51 and 56%, respectively. Such a pattern perhaps indicates a 'dark age' of dengue research when articles published during the period were not cited very often. By ‘dark age,’ we are comparing the TCPY of those years (1994–1996) with other years of dengue research publications. Reasons for this could be a lack of breakthrough findings during that period of time. The article ‘Dengue: the risk to developed and developing countries’ [38] was the only one published in 1993–1996 that made the top ten (TC_{2014} = 479).

Dengue-related articles were distributed in 130 of 176 subject categories in the JCR SCI-EXPANDED as of 2014. **Table 2** shows the top 20 Web of Science categories with at least 100 articles. The leading categories were tropical medicine with 1580 articles (20% of 7746 articles), followed by virology with 1425 (18%) articles, infectious diseases with 1386 (18%) articles, parasitology with 861 (11%) articles and immunology with 828 (11%) articles. There were only 19 journals listed in the category of tropical medicine, and a total of 289 journals in the category of biochemistry and molecular biology.

Figure 3 shows the number of publications per year from the top five categories with more than 800 articles. These patterns of growth of the five categories slightly differed. For instance, the number of publications in the immunology category showed steady growth with no period of rapid growth, while all the other categories showed a period of rapid growth. The parasitology category showed little growth at all before 2005, but entered a phase of rapid growth immediately after 2005. Based on **Figure 3**, the number of immunology publications may soon fall further behind the number of papers in other categories. The nature of immunology research is very different from parasitology and virology research. Namely, the tools for immunological research are fewer and less developed. Dengue is a human-specific disease, meaning it does not naturally infect other animals [39], even though there is transmission of sylvatic dengue among primates, but most nonhuman primates do not show symptoms of dengue disease [40].

This narrows the number of available research tools. Viruses can be propagated *in vitro,* and dengue-infected *A. aegypti* mosquitoes are readily available and can be dissected without ethical limitations. In contrast, there are many ethical limitations, as well as high costs, to human

Table 3. The 13 most productive journals (total number of articles >100) with the number of articles, impact factor in 2014 and category of journals during the period of 1991–2014.

Journal	TP (%)	IF_{2014}	Web of Science category
American Journal of Tropical Medicine and Hygiene	468 (6)	2.699	Public, environmental and occupational health Tropical medicine
PLoS Neglected Tropical Diseases	325 (4.2)	N/A	Infectious diseases Parasitology Tropical medicine
Journal of Virology	319 (4.1)	4.439	Virology
PLoS ONE	301 (3.9)	3.234	Multidisciplinary sciences
Virology	168 (2.2)	3.321	Virology
Journal of Medical Entomology	132 (1.7)	1.953	Entomology Veterinary sciences
Journal of General Virology	131 (1.7)	3.183	Biotechnology and applied microbiology Virology
Journal of the American Mosquito Control Association	120 (1.5)	0.948	Entomology
Vaccine	116 (1.5)	3.624	Immunology Research and experimental medicine
Journal of Virological Methods	114 (1.5)	1.781	Biochemical research methods Biotechnology and applied microbiology Virology
Memorias do Instituto Oswaldo Cruz	108 (1.4)	1.592	Parasitology Tropical medicine
Emerging Infectious Diseases	107 (1.4)	6.751	Immunology Infectious diseases
Tropical Medicine and International Health	106 (1.4)	2.329	Public, environmental and occupational health Tropical medicine

%: The percentage of articles of journals in total articles; IF_{2014}: Impact factor in 2014; N/A: Not available in 2014; TP: Total number of articles.

Table 4. The top 24 most productive countries (total number of articles >100).

Country	TP	TPR (%)	IPR (%)	CPR (%)	FPR (%)	RPR (%)	SPR (%)
USA	2479	1 (32)	1 (24)	1 (48)	1 (24)	1 (24)	1 (28)
Brazil	948	2 (12)	2 (13)	5 (12)	2 (11)	2 (11)	4 (6.2)
Thailand	659	3 (8.5)	5 (4.4)	3 (16)	5 (4.4)	5 (4.3)	9 (2.3)
India	635	4 (8.2)	3 (11)	17 (3.3)	3 (7.6)	3 (7.6)	7 (3.8)
France	580	5 (7.5)	8 (3.7)	4 (15)	4 (4.6)	4 (4.7)	2 (10)
UK	538	6 (7.0)	16 (1.5)	2 (18)	12 (2.7)	11 (2.7)	3 (7.7)
Australia	433	7 (5.6)	6 (4.1)	6 (8.5)	7 (4.2)	7 (4.2)	4 (6.2)
Singapore	422	8 (5.5)	7 (4.0)	7 (8.4)	8 (4.1)	8 (4.1)	18 (1.2)
Taiwan	369	9 (4.8)	4 (5.6)	20 (3.1)	6 (4.3)	6 (4.3)	30 (0.38)
Japan	287	10 (3.7)	12 (2.2)	9 (6.6)	11 (2.7)	10 (2.8)	13 (1.5)
China	281	11 (3.6)	9 (3.6)	16 (3.7)	9 (3.0)	9 (3.0)	13 (1.5)
Malaysia	279	12 (3.6)	10 (3.3)	13 (4.3)	10 (2.7)	12 (2.7)	18 (1.2)
Germany	255	13 (3.3)	14 (1.6)	10 (6.5)	14 (2.0)	14 (2.0)	6 (4.6)
Mexico	255	13 (3.3)	11 (2.5)	12 (4.8)	13 (2.3)	13 (2.4)	N/A
Vietnam	191	15 (2.5)	32 (0.24)	8 (6.8)	20 (1.0)	20 (0.91)	30 (0.38)
Cuba	159	16 (2.1)	15 (1.6)	21 (3.0)	15 (1.7)	15 (1.7)	10 (1.9)
The Netherlands	157	17 (2.0)	23 (0.45)	11 (5.1)	18 (1.2)	18 (1.2)	N/A
Argentina	132	18 (1.7)	13 (1.9)	34 (1.4)	16 (1.4)	16 (1.5)	23 (0.77)
Colombia	129	19 (1.7)	18 (1.2)	24 (2.7)	17 (1.2)	17 (1.2)	13 (1.5)
Canada	123	20 (1.6)	20 (0.79)	19 (3.2)	21 (0.78)	21 (0.84)	18 (1.2)
Switzerland	120	21 (1.6)	36 (0.20)	14 (4.2)	27 (0.49)	29 (0.47)	18 (1.2)
Indonesia	119	22 (1.5)	28 (0.33)	15 (3.9)	24 (0.64)	24 (0.55)	23 (0.77)
Venezuela	109	23 (1.4)	19 (0.85)	25 (2.5)	22 (0.75)	22 (0.75)	30 (0.38)
Italy	106	24 (1.4)	24 (0.43)	18 (3.2)	23 (0.66)	23 (0.64)	N/A

CPR (%): Rank and percentage of international collaborative articles; FPR (%): Rank and percentage of first-authored articles; IPR (%): Rank and percentage of independent articles; N/A: Not available; RPR (%): Rank and percentage of corresponding-authored articles; SPR: Rank and percentage of single-authored articles; TP: Total number of articles; TPR (%): Rank and percentage of total articles.

immunological research when using animal models, the leading method in immunological research [41]. The reliance on animal models for *in vivo* testing means that it may take longer to carry out immunological research than research in the other four categories.

Dengue-related articles were published in a total of 1106 journals. Of these, the 13 journals with the most dengue-related articles are listed in Table 3. Each of these contained more than 100 articles. The *American Journal of Tropical Medicine and Hygiene* had the greatest number of articles with 468 papers, while the *Journal of Virology* had the highest IF_{2014} of 4.439. Some of the leading journals did not belong to a leading subject category. Three of the top 13 journals did not belong to any of the top five subject categories: *PLoS ONE* (category of multidisciplinary science), *Journal of Medical Entomology* (both of entomology and veterinary sciences) and *Journal of the American Mosquito Control Association* (entomology).

Six indicators, including total publications, independent publications, collaborative publications, first-authored publications, corresponding-authored publications and single-authored publications (SPs), were previously used to evaluate publication outputs of countries and institutions [42,43]. The affiliation of the first- or corresponding-author indicated the institution that played a major role and contributed the most to the research [29,44–45]. Among the 7746 articles, there were only 32 with no affiliations in Web of Science. The remaining 7714 articles had author affiliations from 151 countries. Among them, 5082 (66% of 7714 articles) were single-country articles representing 85 countries and 2632 (34%) were internationally collaborative articles representing 145 countries. Table 4 lists the 24 countries with at least 100 articles. Among them, the USA led with 2479 articles. Interestingly, the leading countries that appear in Table 4 were quite different from the leading countries that appear in most bibliometric studies on biomedical-related topics. In biomedical-related research, G7 countries usually are among the top 10 [9,46]. This was not the case for dengue-related research. There were significantly more publications originating from countries in Southeast Asia (Thailand, India, Singapore and Taiwan) and South America (Brazil). These countries were rarely among leaders in research output in other fields, but were among the top ten publishers of original manuscripts in dengue research. Again, this could probably be related to the regional specificity of dengue research, since dengue fever has become a significant public health concern in the Asian-Pacific [47], Latin America and the Caribbean [48] regions in recent decades. We speculated that as the burden of disease increased, more efforts and resources were put into combating the disease, hence leading to greater research output. This could explain why there were more articles coming from Asia and South America.

Most of the top ten productive countries also ranked in the top ten for independent articles, with the exception of the UK and Japan. Since dengue fever is not endemic to the UK or Japan, and the countries only have a few hundred cases of dengue fever annually, they most likely need to collaborate with other countries on dengue research. The ability to conduct independent research may be limited by the availability of study subjects or infected mosquitoes, or access to the dengue virus. Hence, it is more likely for the UK and Japan to engage in international collaborations for dengue research, and thus they had fewer country-independent articles.

Figure 4 shows trends of the annual number of articles for the six leading countries (TP > 500). The growth trend was similar before 2000, but began to diverge afterward. Brazil showed a much steeper growth pattern, while Thailand showed a slower growth pattern than the other countries. India also began to show strong growth after 2010. Thailand is currently ranked third in total articles, but showed signs of leveling off. A closer look at Thailand revealed that it relied heavily on international collaborations, compared with Brazil and India. International collaboration may boost research output within a relatively short period of time [49,50], but overreliance on international collaboration may hamper the growth in research capacity for the country that does not establish its own independent research. The level of international collaboration

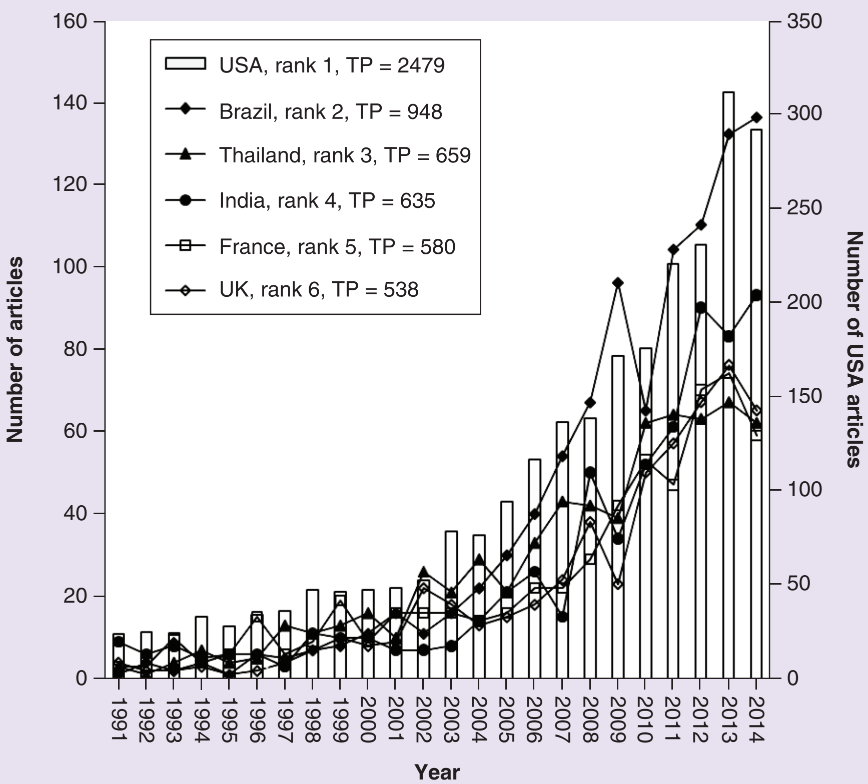

Figure 4. Annual publication of the top six countries during 1991–2014 (TP > 500).
TP: Total number of articles.

may change quickly depending on funding and international politics, and hence may fluctuate quickly, and probably should not be relied upon as a long-term solution for boosting research output. Although no previous research has pointed this out, we speculated that over-reliance on collaboration would occur more frequently in a research topic with regional specificity, such as in dengue research, than in a research topic without regional specificity. Countries with a high research capacity but a low caseload would collaborate with countries with a high caseload, in order to complement each other. This international collaboration phenomenon was also reported in the case of severe acute respiratory syndrome related research [51].

There were 17 institutions with at least 100 articles in dengue-related research, as indicated in Table 5. Mahidol University of Thailand topped the list with 352 articles. The US had the greatest number of institutions (seven), followed by Brazil (three) and Thailand (two). France, the UK, Singapore, Malaysia and Australia each had one institution with at least 100 articles. As in the case of Mahidol University, which published 352 of 659 articles (53%) from Thailand, that of the University of Oxford, which published 166 of 538 articles (31%) from the UK, and that of the Institut Pasteur, which published 189 of 580 articles (33%) from France, a clearly dominant institution was observed in a country. It is uncommon to see one institution dominate research to such an extent, publishing more than 30% of articles from a country, particularly a county with as many institutions as the UK or France. In other medical bioresearch topics, the top institution published lower percentages of articles in its country, such as 15% of

Table 5. Institutions with a total number of articles >100.

Institution	TP	TPR (%)	SIPR (%)	ICPR (%)	NCPR (%)	FPR (%)	RPR (%)	SPR (%)	SP (%)	ICP (%)	NCP (%)
Mahidol University, Thailand	352	1 (4.6)	1 (2.9)	1 (7.9)	2 (2.7)	1 (2.3)	1 (2.4)	N/A	70 (20)	209 (59)	73 (21)
Centers for Disease Control and Prevention, USA	258	2 (3.3)	3 (2.1)	4 (4.7)	1 (3.1)	2 (1.5)	2 (1.5)	2 (2.3)	50 (19)	125 (48)	83 (32)
Institut Pasteur, France	189	3 (2.5)	4 (2.0)	5 (4.3)	26 (1.0)	4 (1.4)	4 (1.3)	1 (3.5)	47 (25)	114 (60)	28 (15)
University of Oxford, UK	166	4 (2.2)	18 (0.63)	2 (5.2)	85 (0.48)	18 (0.57)	15 (0.61)	3 (1.9)	15 (9)	138 (83)	13 (7.8)
National University of Singapore, Singapore	162	5 (2.1)	6 (1.5)	13 (2.3)	4 (2.4)	8 (1.0)	8 (1.0)	N/A	36 (22)	61 (38)	65 (40)
University of Massachusetts, USA	153	6 (2.0)	11 (1.1)	6 (3.7)	26 (1.0)	6 (1.2)	7 (1.0)	19 (0.77)	27 (18)	98 (64)	28 (18)
University of Malaya, Malaysia	151	7 (2.0)	2 (2.7)	18 (1.9)	17 (1.3)	3 (1.4)	3 (1.4)	19 (0.77)	65 (43)	51 (34)	35 (23)
University of Sao Paulo, Brazil	151	7 (2.0)	7 (1.4)	21 (1.7)	2 (2.7)	5 (1.2)	6 (1.2)	N/A	33 (22)	45 (30)	73 (48)
Armed Forces Research Institute of Medical Sciences, Thailand	142	9 (1.8)	150 (0.13)	3 (5.1)	205 (0.19)	62 (0.25)	91 (0.18)	N/A	3 (2.1)	134 (94)	5 (3.5)
Walter Reed Army Institute of Research, USA	139	10 (1.8)	47 (0.33)	8 (3.2)	10 (1.7)	16 (0.6)	17 (0.58)	8 (1.2)	8 (5.8)	84 (60)	47 (34)
Fiocruz Ministry of Health, Brazil	131	11 (1.7)	11 (1.1)	19 (1.8)	5 (2.1)	7 (1.2)	5 (1.2)	N/A	27 (21)	47 (36)	57 (44)
University of Queensland, Australia	123	12 (1.6)	17 (0.67)	14 (2.2)	7 (1.8)	12 (0.75)	12 (0.75)	19 (0.77)	16 (13)	58 (47)	49 (40)
National Institute of Allergy and Infectious Diseases, USA	118	13 (1.5)	5 (1.7)	51 (1.0)	6 (1.9)	9 (0.91)	11 (0.84)	N/A	40 (34)	26 (22)	52 (44)
University of California at Berkeley, USA	112	14 (1.5)	13 (0.92)	10 (2.6)	40 (0.82)	11 (0.87)	10 (0.87)	N/A	22 (20)	68 (61)	22 (20)
University of California at Davis, USA	110	15 (1.4)	74 (0.25)	7 (3.2)	48 (0.71)	26 (0.47)	26 (0.47)	42 (0.38)	6 (5.5)	85 (77)	19 (17)
Colorado State University, USA	108	16 (1.4)	8 (1.3)	21 (1.7)	19 (1.2)	10 (0.88)	9 (0.92)	N/A	30 (28)	45 (42)	33 (31)
Fundação Oswaldo Cruz, Brazil	105	17 (1.4)	32 (0.5)	21 (1.7)	9 (1.8)	23 (0.49)	20 (0.53)	N/A	12 (11)	45 (43)	48 (46)

FPR (%): Rank and percentage of first-author articles; ICP (%): Number and the percentage of internationally collaborative articles in total articles within each institution; ICPR (%): Rank and percentage of internationally collaborative articles; N/A: Not available; NCP (%): Number and percentage of nationally collaborative articles in total articles within each institution; NCPR (%): Rank and percentage of nationally collaborative articles; RPR (%): Rank and percentage of corresponding-authored articles; SIPR (%): Rank and percentage of single-institution articles; SP (%): Number and percentage of single-institution articles in total articles within each institution; SPR (%): Rank and percentage of single-author articles; TP: Total number of articles; TPR (%): Rank and percentage of total articles.

Table 6. The most frequently cited papers in 2014 with a number of citations in 2014 greater than 60.

Rank (C_{2014})	Rank (C_0)	Rank (TC_{2014})	Rank (TCPY)	Title	Ref.
1 (357)	1 (85)	9 (442)	1 (221)	The global distribution and burden of dengue	[3]
2 (108)	475 (2)	53 (203)	2 (68)	Protective efficacy of the recombinant, live-attenuated, CYD tetravalent dengue vaccine in Thai schoolchildren: a randomized, controlled Phase IIb trial	[64]
3 (83)	2165 (0)	17 (337)	4 (56)	The IFITM proteins mediate cellular resistance to influenza A H1N1 virus, west Nile virus and dengue virus	[65]
4 (81)	2165 (0)	21 (297)	7 (50)	A *Wolbachia* symbiont in *Aedes aegypti* limits infection with dengue, chikungunya and *Plasmodium*	[66]
5 (79)	73 (6)	2 (645)	12 (43)	Dengue viremia titer, antibody response pattern and virus serotype correlate with disease severity	[67]
5 (79)	54 (7)	39 (223)	4 (56)	Successful establishment of *Wolbachia* in *Aedes* populations to suppress dengue transmission	[68]
7 (73)	54 (7)	27 (258)	12 (43)	Composition and 3D architecture of the dengue virus replication and assembly sites	[69]
8 (64)	73 (6)	73 (175)	10 (44)	The *w*Mel *Wolbachia* strain blocks dengue and invades caged *Aedes aegypti* populations	[70]
9 (63)	25 (9)	8 (446)	4 (56)	Genome sequence of *Aedes aegypti*, a major arbovirus vector	[71]
10 (62)	2165 (0)	1 (707)	20 (31)	Rapid detection and typing of dengue viruses from clinical samples by using reverse transcriptase-polymerase chain reaction	[60]
10 (62)	19 (10)	3 (580)	9 (45)	Structure of dengue virus: implications for flavivirus organization, maturation and fusion	[72]
12 (60)	260 (3)	25 (262)	18 (33)	Spread of the tiger: global risk of invasion by the mosquito *Aedes albopictus*	[73]

C_{2014}: Number of citations in 2014; C_0: Number of citations in the publication year; TC_{2014}: Number of citations since its publication to the end of 2014; TCPY: TC_{2014} per year.

Helicobacter pylori research in France [52], 25% of human papillomavirus studies in France, and 11% in the UK [53], 20% of pluripotent stem cell research in the UK [54], and 18% of proteomic research in France [46]. While no previous research has indicated such a pattern, we speculated that the regional specificity of dengue fever may have contributed to domination by single institutions. The regional specificity of dengue fever poses a significantly higher barrier for institutions in the UK or in France to enter this field of research. Research partners have to be sought out and an international collaborative pattern has to be established. Hence, it is more difficult for any institutions to begin research on this topic. Consequently, the leading institutions in the UK and France tended to publish a high percentage of dengue articles through international collaborations. Sixty percent of all articles produced by the Institut Pasteur, and 83% of all articles produced by the University of Oxford were through international collaborations. In addition, the Department of Zoology of the University of Oxford published the most articles (86 articles, 52% of 166 University of Oxford articles) at this university. Again, due to the regional nature of dengue fever, some leading institutions would need to rely heavily on collaboration with countries in the Asian-Pacific and American-Caribbean regions to gain access to biological materials.

Among the top five countries listed in **Table 4**, India was the only leading country that did not have an institution with at least 100 publications, indicating perhaps that its dengue research was not concentrated in a few institutions but was more dispersed. Interestingly, India has overtaken Thailand in the annual number of research papers, despite being still behind in the total number of articles. Research capacity is positively related to the number of institutions and researchers involved [55]. Rather than relying heavily on a single institution, India may have greatly multiplied its research potential and rapidly increased its number of articles in recent years. India produced more country-independent articles than Thailand, despite having fewer total articles. It is projected that in the near future, India will likely overtake Thailand to become the third leading country in dengue research.

A high citation count for an article could imply a high impact or visibility in the research field [56]. It also provides insights into which authors and topics are influencing a research discipline over time [57]. But, the rapid increase

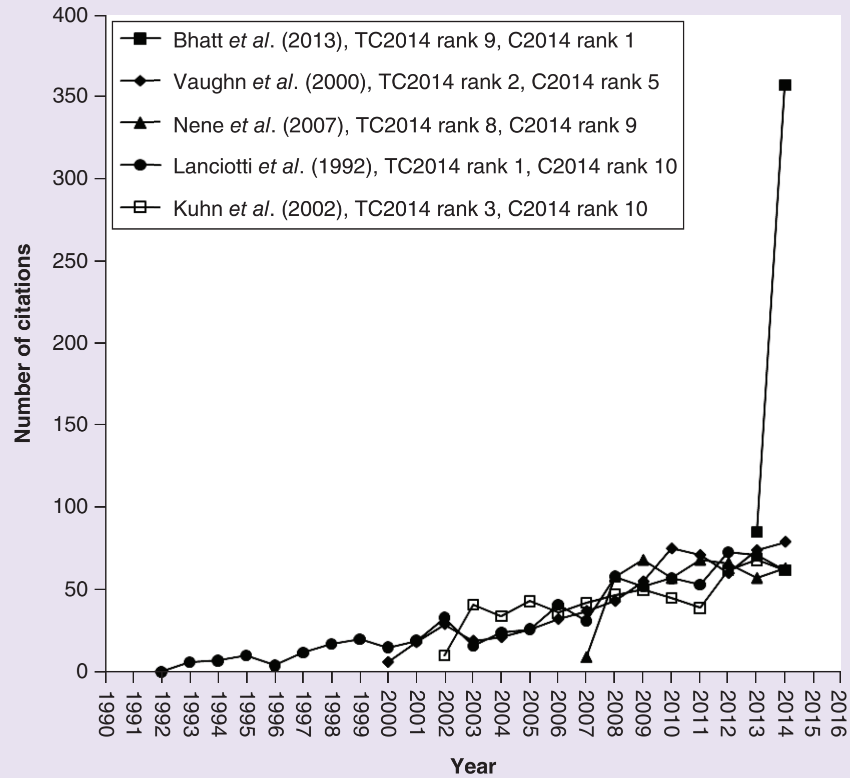

Figure 5. Article lives of the five articles ranked in the top ten of both the number of citations since its publication to the end of 2014 and number of citations in 2014.

in the volume of scientific activity has made it nearly impossible to identify research 'stars' using only the total number of citations, the standard bibliometric tool [58]. The use of another indicator, the number of citations in the last year (C_{year}) of an article could provide some indication of top articles [29]. It was found that the 'total citations' (TC_{year}) and 'citations in the last year' (C_{year}) when used together can reveal new insights in identifying leaders of a research topic [29,55,59]. **Table 6** shows the 12 most frequently cited articles in 2014. The most-often cited article in 2014 was 'The global distribution and burden of dengue' [3], published in *Nature* by Bhatt *et al.* in 2013. It was cited 357-times in 2014 (C_{2014} = 357). The article with the highest all-time citations (TC_{2014} = 707-times) was 'Rapid detection and typing of dengue viruses from clinical samples by using reverse transcriptase-polymerase chain reaction' [60], published in the *Journal of Clinical Microbiology* by Lanciotti *et al.* in 1992. Ten of the 12 articles received fewer than ten citations in the year of its publication, but did pick up momentum to become leading articles by 2014, indicating many leading articles in dengue research were not recognized in the beginning. **Table 6** also shows that some of the leading articles in total citations might soon fall behind in rankings. Among the 12 most highly cited articles in 2014, five articles were already ranked among the top 12 in terms of total citations (TC_{2014}). **Figure 5** shows the article life of those five articles that were ranked among the top 12 in both C_{2014} and TC_{2014}. With the exception of the article by Bhatt *et al.*, the other four articles showed steady growth over the years, and will probably continue to receive high citations, similar to other 'star' articles identified in various fields of research [61–63]. The Bhatt *et al.* article was published in 2013, and more time will be needed to determine the pattern of its article life.

• Burden of disease & publications

Previous research identified a correlation between research output for a disease and other macro-level indicators, such as health expenditures [74], gross domestic product (GDP) [75], the number of cases [51] and the mortality rate [76]. In this research, we used countries listed in **Table 4**, and downloaded their dengue case and dengue death data to assess if such correlations existed between research output and disease burden. Depending on the location of the country, dengue case and death data were retrieved from the websites of Pan American Health Organization [77], WHO in the Western Pacific Region [78] or European Center for Disease Prevention and Control [79]. Countries were further grouped into regions for comparisons. For the purposes of a regional analysis, Asia and Australia were combined because Australia falls under the same WHO region as some Southeast Asian countries.

Figure 6 shows the relationship between research output and the number of reported cases, while **Figure 7** shows the relationship between research output and the number of reported deaths. For Europe, the number of articles increased while the number of cases or death remained steady over the years. This was expected because of the low prevalence of dengue fever in Europe. There was little correlation between research output and the burden of dengue fever. For Asia/Australia, research output, case numbers and deaths increased together until around 2010. For Asia/Australia, the Spearman correlation coefficients for research output and cases were 0.585 ($p < 0.01$) for cases and 0.432 ($p > 0.05$) for deaths. In other words, the relationship between research output and cases was statistically significant, while that between research output and deaths was not. For the Americas, there were correlation coefficients of 0.735 ($p < 0.01$) for cases and 0.750 ($p < 0.01$) for deaths. A closer look at two specific countries, Brazil and Singapore, showed a similar relationship between the burden of disease and research. **Figure 8** showed the relationship between dengue cases and publication for Singapore, while **Figure 9** showed the relationship for Brazil. These two countries were chosen because they contained the most comprehensive data in terms of numbers of dengue cases and deaths, and produced a high number of dengue-related publications, as well. Correlations between research output and dengue cases were 0.698 ($p < 0.01$) for Brazil and 0.600 ($p < 0.01$)

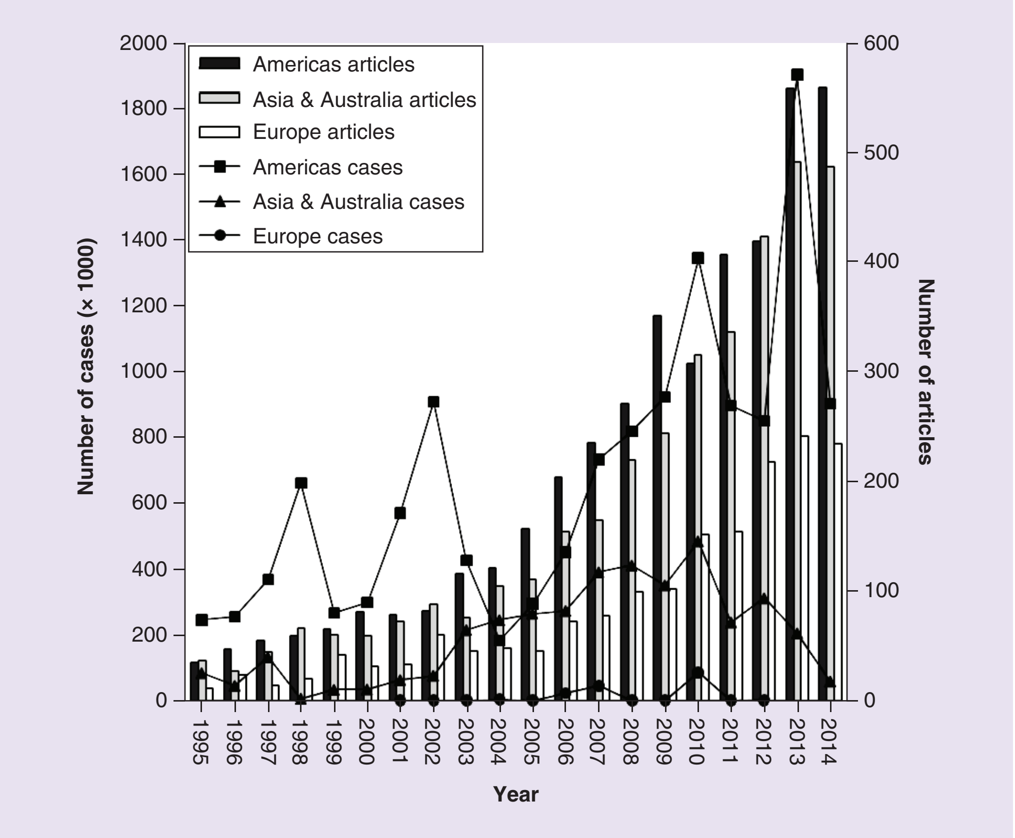

Figure 6. Trends of dengue cases and publications by region.

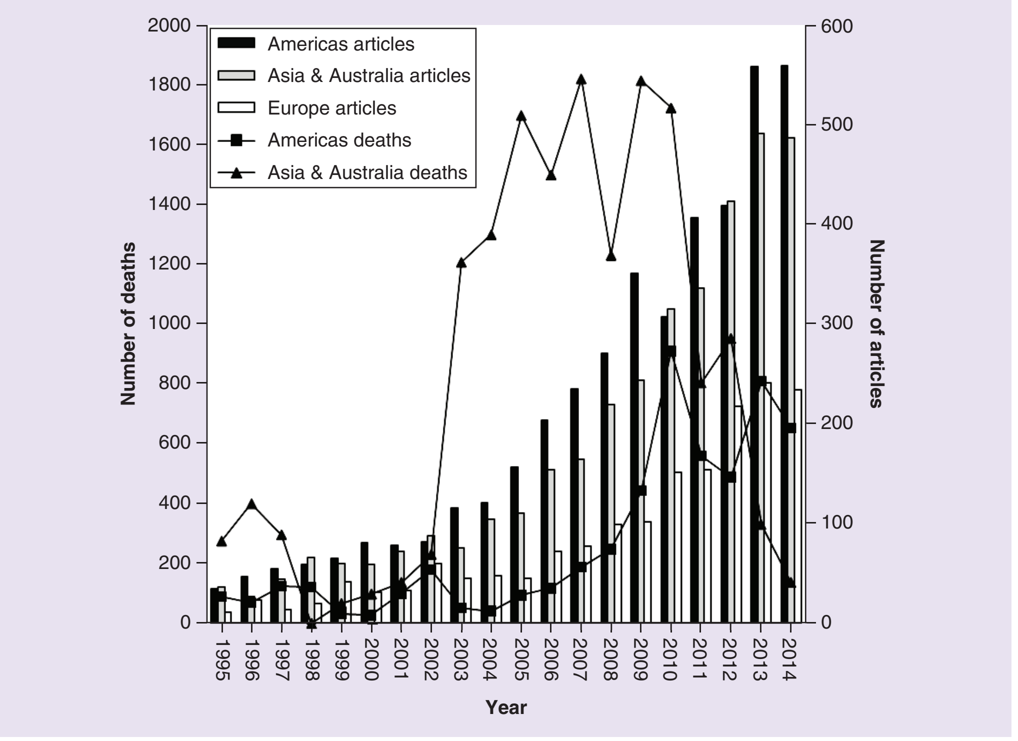

Figure 7. Trends of dengue death and publications by region.

for Singapore. To sum up, Europe's publication growth curve followed a similar trajectory as those of the Americas and Asia/Australia, but did not increase as quickly as those of the two other regions. Additionally, Europe's number of publications appeared to be independent of the

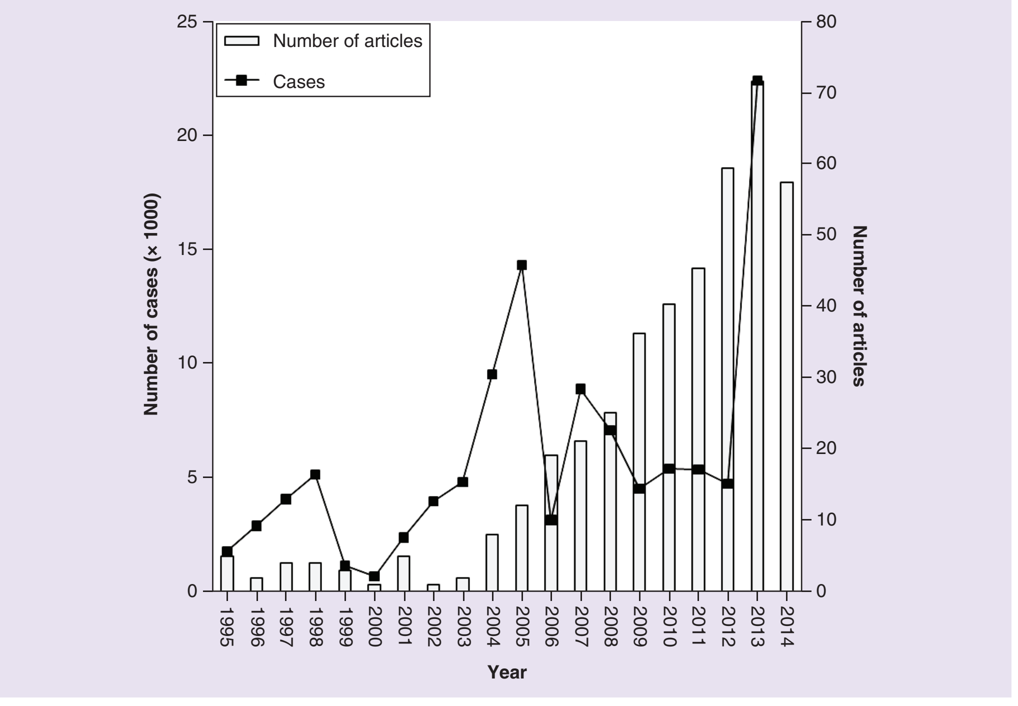

Figure 8. Singapore dengue cases and publications.

burden of disease, probably due to the regional specificity of dengue fever. The association between research output and disease burden was evident in the Americas and Asia/Australia.

Conclusion

This research used a vigorous 'front page' screening methodology, excluding articles that would had little or no relevance to dengue research, to download dengue related research articles from the SCI-EXPANDED database. Dengue research flourished after 2000, showing exponential growth. Compared with other topics of research, Dengue research appeared to be region-specific. Many developing countries and institutions from developing countries were among the leaders in research output. Countries such as Brazil, Thailand, India, Singapore and Taiwan were among the leaders. Because of the regional specificity of dengue fever, the level of international collaborations was high. Moreover, for some countries, there was a tendency to have an institution that dominated research output. The specific bibliometric characteristics of dengue research may be related to its regional specificity. However, as the prevalence of dengue fever changes, European countries may become more involved in dengue fever research, and conduct more independent research. An initial exploration showed that research output and the disease burden were significantly associated in regions with a high number of dengue cases. However, the lack of consistent data reporting from all countries may have biased the results. Thus far, only the Americas, through the Pan American Health Organization, had the most consistent reporting data from 1995 to 2014. To assess the relationship between research and the disease burden, an accurate and consistent method of reporting should be established before more research on the relationship between output and burden can be conducted.

Future perspective

Dengue fever is likely to continue to pose a major public health concern globally in the near future. Dengue-related research will also continue to increase, as indicated by the upward trend from 1991 to 2015. International collaborations between the USA, UK, France

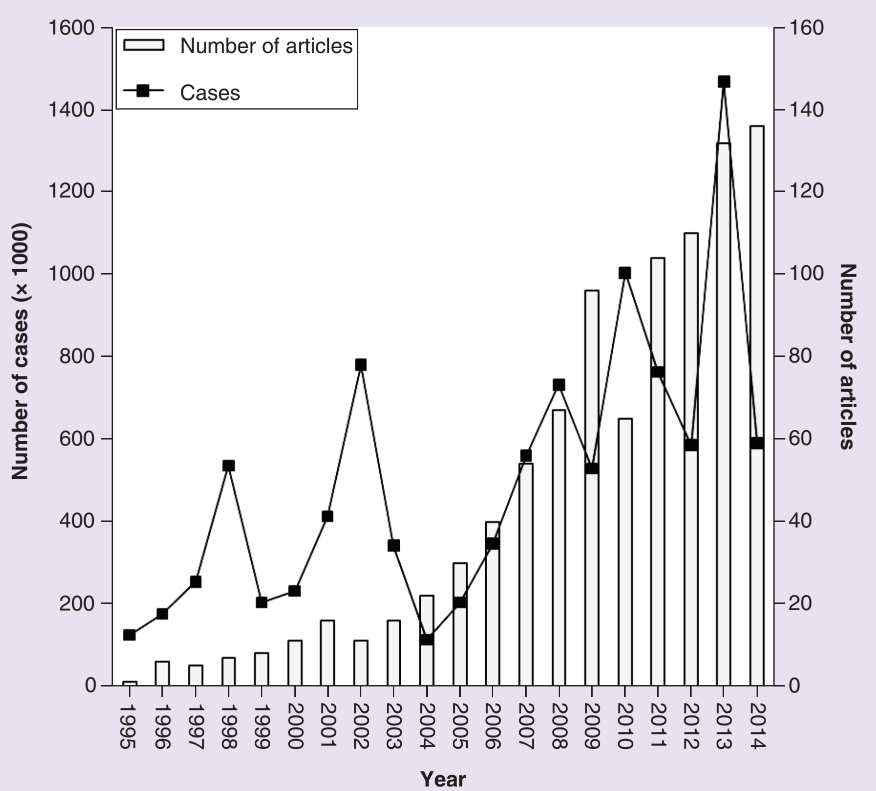

Figure 9. Brazil dengue cases and publications.

and other countries with high dengue burden, such as Thailand, Brazil and India, will likely to continue. The past trend indicated that India might soon overtake Thailand to become the third leading country in dengue research publications. The framework for reporting cases and deaths of dengue ought to be established in order to study the relationship between dengue research publication, disease burden and funding.

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The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

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EXECUTIVE SUMMARY

Background

- Dengue poses significant public health concern globally, but only few studies have used bibliometric tools to assess the current state of dengue research.
- The bibliometric profile of dengue research can have significant implications for policy makers and researchers.

Methods

- This research download dengue related research articles from the Science Citation Index Expanded database, and then used a 'front page' screening methodology to exclude articles that had little or no relevance to dengue research, but were downloaded with the standard keyword search.

Results/discussion

- Dengue-related research articles have been increasing exponentially after year 2000.
- The top five leading countries were the USA, Brazil, Thailand, India and France.
- The top five leading institutions were Mahidol University, Center for Disease Control and Prevention, Institute Pasteur, University of Oxford and National University of Singapore.
- Among articles published before 2014, the article 'Rapid detection and typing of dengue viruses from clinical samples by using reverse transcriptase-polymerase chain reaction' by Lanciotti *et al.*, have the highest citations.
- There is a high level of international collaboration in dengue research.
- Dengue research publication was positively related to the burden of disease in Asia/Australia and Americas regions.

Conclusion

- Accurate and consistent method for reporting cases and deaths among countries ought to be established in order for more meaningful analysis regarding the relationship between disease burden, research publication and funding.

References

Papers of special note have been highlighted as:
• of interest

1 WHO. Dengue and Severe Dengue. *Media Centre* (2016). www.who.int

2 WHO. Dengue. *Dengue Control* (2016). www.who.int/denguecontrol/en/

3 Bhatt S, Gething PW, Brady OJ *et al.* The global distribution and burden of dengue. *Nature* 496(7446), 504–507 (2013).

• **Provides a basic background on the global burden of dengue by regions.**

4 Simmons, CP, Farrar JJ, Nguyen VVC *et al.* Dengue. *N. Engl. J. Med.* 366(15), 1423–1432 (2012).

5 Gubler DJ. Dengue Viruses: their evolution, history, and emergence as a global public health problem. In: *Dengue and Dengue Hemorrhagic Fever (2nd Edition)*. DJ Gubler, EE Ooi, S Vasudevan, JJ Farrar (Eds). CABI, Oxfordshire, UK, 15–16 (2014).

• **Provides a comprehensive view on the history of dengue from a global perspective.**

6 Kyle JL, Harris E. Global spread and persistence of dengue. *Annu. Rev. Microbiol.* 62, 71–92 (2008).

7 Andersen T. WHO Approves World's First Ever Dengue Vaccine (2016). http://time.com

8 Hadinegoro SR, Arredondo-Garcia JL, Capeding MR *et al.* Efficacy and long-term safety of a dengue vaccine in regions of endemic disease. *N. Engl. J. Med.* 373(13), 1195–1206 (2015).

9 Li LL, Ding GH, Feng N *et al.* Global stem cell research trend: bibliometric analysis as a tool for mapping of trends from 1991 to 2006. *Scientometrics* 80(1), 39–58 (2009).

10 Fu HZ, Ho YS. A bibliometric analysis of the *Journal of Membrane Science* (1976–2010). *Electron. Libr.* 33(4), 698–713 (2015).

11 Rosas SR, Kagan JM, Schouten JT, Slack PA, Trochim WMK. Evaluating research and impact: a bibliometric analysis of research by the NIH/NIAID HIV/AIDS clinical trials networks. *PLoS ONE* 6(3), e17428 (2011).

12 Munoz-Urbano M, Lopez-Isaza AF, Hurtado-Hurtado N *et al.* Scientific research in malaria: bibliometric assessment of the Latin-American contributions. *Recent Pat. Anti-Infect. Drug Discov.* 9(3), 209–215 (2014).

13 Head MG, Fitchett JR, Newell ML *et al.* Mapping pneumonia research: a systematic analysis of UK investments and published outputs 1997–2013. *EBioMedicine* 2(9), 1193–1199 (2015).

14 Head MG, Fitchett JR, Lichtman AB *et al.* Mapping investments and published outputs in norovirus research: A systematic analysis of research funded in the United States and United Kingdom during 1997–2013. *J. Infect. Dis.* 213, S3–S7 (2016).

15 Delgado-Osorio N, Vera-Polania F, Lopez-Isaza AF *et al.* Bibliometric assessment of the contributions of literature on Chagas disease in Latin America and the Caribbean. *Recent Pat. Anti-Infect. Drug Discov.* 9(3), 202–208 (2014).

16 Bierbaum EG, Brooks TA. The literature of acquired immunodeficiency syndrome (AIDS): continuing changes in publication patterns and subject access. *J. Am. Soc. Inform. Sci.* 46(7), 530–536 (1995).

17 Bhardwaj RK. Dengue fever: a bibiliometric analysis of India's contributions to the research literature of this dangerous tropical disease. *Sci. Technol. Libr.* 33(3), 289–301 (2014).

18 Vellaichamy V, Jeyshankar R. Dengue research in India and China: a comparative study using bibliometrics. *IJLSIM* 1(1), 1–9 (2015).

19 Vera-Polania F, Perilla-Gonzalez Y, Martinez-Pulgarin DF *et al.* Bibliometric assessment of the Latin-American contributions in dengue. *Recent Pat. Anti-Infect. Drug Discov.* 9(3), 195–201 (2014).

20 Zyoud SH. Dengue research: a bibliometric analysis of worldwide and Arab publications during 1872–2015. *Virol. J.* 13, 78 (2016).

21 Gubler DJ. Dengue and dengue hemorrhagic fever. *Clin. Microbiol. Rev.* 11(3), 480–496 (1998).

22 Ugolini D, Puntoni R, Perera FP *et al.* A bibliometric analysis of scientific production in cancer molecular epidemiology. *Carcinogenesis* 28(8), 1774–1779 (2007).

23 Asplund K, Eriksson M, Persson O. Country comparisons of human stroke research since 2001: a bibliometric study. *Stroke* 43(3), 830–837 (2012).

24 Somogyi A, Schubert A. Correlation between national bibliometric and health indicators: the case of diabetes. *Scientometrics* 62(2), 285–292 (2005).

25 Li Z, Ho YS. Use of citation per publication as an indicator to evaluate contingent valuation research. *Scientometrics* 75(1), 97–110 (2008).

26 Garfield E. *KeyWords Plus*: ISI's breakthrough retrieval method. Part 1. Expanding your searching power on Current Contents on Diskette. *Curr. Contents* 32, 42499 (1990).

27 Fu HZ, Wang MH, Ho YS. The most frequently cited adsorption research articles in the Science Citation Index (Expanded). *J. Colloid Interface Sci.* 379(1), 148–156 (2012).

- **Provides the concept of 'front page' to improve bibliometric technique.**

28 Pouris A, Ho YS. Research emphasis and collaboration in Africa. *Scientometrics* 98(3), 2169–2184 (2014).

29 Ho YS. Top-cited articles in chemical engineering in Science Citation Index Expanded: a bibliometric analysis. *Chin. J. Chem. Eng.* 20(3), 478–488 (2012).

30 Xie SD, Zhang J, Ho YS. Assessment of world aerosol research trends by bibliometric analysis. *Scientometrics* 77(1), 113–130 (2008).

31 Wang MH, Yu TC, Ho YS. A bibliometric analysis of the performance of Water Research. *Scientometrics* 84(3), 813–820 (2010).

32 Edelman R. Dengue vaccines approach the finish line. *Clin. Infect. Dis.* 45(1), S56–S60 (2007).

33 NIAID.
www.niaid.nih.gov

34 Lewison G, Rippon I, de Francisco A *et al.* Outputs and expenditures on health research in eight disease areas using a bibliometric approach, 1996–2001. *Res. Evaluat.* 13(3), 181–188 (2004).

35 Chuang KY, Ho YS. An evaluation based on highly cited publications in Taiwan. *Curr. Sci.* 108(5), 933–941 (2015).

36 Monge-Nájera J, Ho YS. Bibliometry of Panama publications in the Science Citation Index Expanded: publication type, language, fields, authors and institutions. *Rev. Biol. Trop.* 63(4), 1255–1266 (2015).

37 Ho HC, Ho YS. Publications in dance field in Arts & Humanities Citation Index: a bibliometric analysis. *Scientometrics* 105(2), 1031–1040 (2015).

38 Monath TP. Dengue: the risk to developed and developing countries. *Proc. Natl Acad. Sci. USA* 91(7), 2395–2400 (1994).

39 Zompi S, Harris E. Animal models of dengue virus infection. *Viruses* 4(1), 62–82 (2012).

40 Vasilakis N, Cardosa J, Hanley KA *et al.* Fever from the forest: prospects for the continued emergence of sylvatic dengue virus and its impact on public health. *Nat. Rev. Microbiol.* 9(7), 532–541 (2011).

41 Frias-Staheli N, Dorner M, Marukian S *et al.* Utility of humanized BLT mice for analysis of dengue virus infection and antiviral drug testing. *J. Virol.* 88(4), 2205–2218 (2014).

42 Ho YS, Kahn M. A bibliometric study of highly cited reviews in the Science Citation Index Expanded™. *J. Assoc. Inf. Sci. Technol.* 65(2), 372–385 (2014).

43 Ho YS, Satoh H, Lin SY. Japanese lung cancer research trends and performance in Science Citation Index. *Intern. Med.* 49(20), 2219–2228 (2010).

- **Provides an example of bibliometric technique that can be used for medical research.**

44 Burman KD. 'Hanging from the masthead': reflections on authorship. *Ann. Intern. Med.* 97(4), 602–605 (1982).

45 Riesenberg D, Lundberg GD. The order of authorship: who's on first. *JAMA* 264(14), 1857 (1990).

46 Tan J, Fu HZ, Ho YS. A bibliometric analysis of research on proteomics in Science Citation Index Expanded. *Scientometrics* 98(2), 1473–1490 (2014).

47 Sly PD. Health impacts of climate change and biosecurity in the Asian Pacific region. *Rev. Environ. Health* 26(1), 42563 (2011).

48 Pinheiro FP, Corber SJ. Global situation of dengue and dengue haemorrhagic fever, and its emergence in the Americas. *World Health Stat. Q.* 50(3–4), 161–169 (1997).

49 Basu A, Aggarwal R. International collaboration in science in India and its impact on institutional performance. *Scientometrics* 52(3), 379–394 (2001).

50 He ZL, Geng XS, Campbell-Hunt C. Research collaboration and research output: a longitudinal study of 65 biomedical scientists in a New Zealand university. *Res. Policy* 38(2), 306–317 (2009).

51 Chiu WT, Huang JS, Ho YS. Bibliometric analysis of severe acute respiratory syndrome-related research in the beginning stage. *Scientometrics* 61(1), 69–77 (2004).

52 Suk FM, Lien GS, Yu TC *et al.* Global trends in *Helicobacter pylori* research from 1991 to 2008 analyzed with the Science Citation Index Expanded. *Eur. J. Gastroenterol. Hepatol.* 23(4), 295–301 (2011).

53 Lin HW, Yu TC, Ho YS. A systemic review of the human papillomavirus studies: global publication comparison and research trend analyses from 1993 to 2008. *Eur. J. Gynaecol. Oncol.* 32(2), 133–140 (2011).

54 Lin CL, Ho YS. A bibliometric analysis of publications on pluripotent stem cell research. *Cell J.* 17(1), 59–70 (2015).

55 Chen HQ, Ho YS. Highly cited articles in biomass research: a bibliometric analysis. *Renew. Sust. Energ. Rev.* 49, 42724 (2015).

56 Wohlin C. Most cited journal articles in software engineering. *Inf. Softw. Technol.* 47(15), 955 (2005).

57 Smith DR. Citation indexing and highly cited articles in the *Australian Veterinary Journal*. *Aust. Vet. J.* 86(9), 337–339 (2008).

58 Gingras Y, Wallace ML. Why it has become more difficult to predict Nobel Prize winners: a bibliometric analysis of nominees and winners of the chemistry and physics prizes (1901–2007). *Scientometrics* 82(2), 401–412 (2010).

59 Ho YS. A bibliometric analysis of highly cited articles in materials science. *Curr. Sci.* 107(9), 1565–1572 (2014).

60 Lanciotti RS, Calisher CH, Gubler DJ *et al.* Rapid detection and typing of dengue viruses from clinical samples by using reverse transcriptase-polymerase chain reaction. *J. Clin. Microbiol.* 30(3), 545–551 (1992).

- **It is the highest cited article in dengue-related research.**

61 Ho YS. Classic articles on social work field in Social Science Citation Index: a bibliometric analysis. *Scientometrics* 98(1), 137–155 (2014).

- **Provides a wide array of bibliometric indicators used in this analysis.**

62 Long X, Huang JZ, Ho YS. A historical review of classic articles in surgery field. *Am. J. Surg.* 208(5), 841–849 (2014).

63 Hsu YHE, Ho YS. Highly cited articles in health care sciences and services field in Science Citation Index Expanded: a bibliometric analysis for 1958–2012. *Methods Inf. Med.* 53(6), 446–458 (2014).

64 Sabchareon A, Wallace D, Sirivichayakul C *et al.* Protective efficacy of the recombinant, live-attenuated, CYD tetravalent dengue vaccine in Thai schoolchildren: a randomised, controlled Phase 2b trial. *Lancet* 380(9853), 1559–1567 (2012).

65 Brass AL, Huang IC, Benita Y *et al.* The IFITM proteins mediate cellular resistance to influenza A H1N1 virus, West Nile virus, and dengue virus. *Cell* 139(7), 1243–1254 (2009).

66 Moreira LA, Iturbe-Ormaetxe I, Jeffery JA *et al.* A *Wolbachia* symbiont in *Aedes aegypti* limits infection with dengue, chikungunya, and *Plasmodium*. *Cell* 139(7), 1268–1278 (2009).

67 Vaughn DW, Green S, Kalayanarooj S *et al.* Dengue viremia titer, antibody response pattern, and virus serotype correlate with disease severity. *J. Infect. Dis.* 181(1), 2–9 (2000).

- **It is the second highest cited article among dengue research.**

68 Hoffmann AA, Montgomery BL, Popovici J *et al.* Successful establishment of *Wolbachia* in *Aedes* populations to suppress dengue transmission. *Nature* 476(7361), 454–457 (2011).

69 Welsch S, Miller S, Romero-Brey I *et al.* Composition and three-dimensional architecture of the dengue virus replication and assembly sites. *Cell Host Microbe* 5(4), 365–375 (2009).

70 Walker T, Johnson PH, Moreira LA *et al.* The wMel *Wolbachia* strain blocks dengue and invades caged *Aedes aegypti* populations. *Nature* 476(7361), 450–453 (2011).

71 Nene V, Wortman JR, Lawson D *et al.* Genome sequence of *Aedes aegypti*, a major arbovirus vector. *Science* 316(5832), 1718–1723 (2007).

72 Kuhn RJ, Zhang W, Rossmann MG *et al.* Structure of dengue virus: implications for flavivirus organization, maturation, and fusion. *Cell* 108(5), 717–725 (2002).

- **It is the third highest cited article among dengue research.**

73 Benedict MQ, Levine RS, Hawley WA *et al.* Spread of the tiger: global risk of invasion by the mosquito *Aedes albopictus*. *Vector Borne Zoonotic Dis.* 7(1), 76–85 (2007).

74 Wiysonge CS, Uthman OA, Ndumbe PM *et al.* A bibliometric analysis of childhood immunization research productivity in Africa since the onset of the Expanded Program on Immunization in 1974. *BMC Med.* 11, 66 (2013).

75 Rousseau S, Rousseau R. Data envelopment analysis as a tool for constructing scientometric indicators. *Scientometrics* 40(1), 45–56 (1997).

76 Chuang KY, Huang YL, Ho YS. A bibliometric and citation analysis of stroke-related research in Taiwan. *Scientometrics* 72(2), 201–212 (2007).

77 Pan American Health Organization. www.paho.org

78 WHO. www.wpro.who.int

79 European Center for Disease Prevention and Control. http://ecdc.europa.eu