Classic articles published by American scientists (1900–2014): a bibliometric analysis

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The present study reports US independent classic articles published by American scientists from 1900 to 2014. We examined those articles that had been cited at least 1000 times since publication to the end of 2014 using the Science Citation Index Expanded in the Web of Science (WoS). We also applied a bibliometric indicator, the Y-index, to assess the contributions of the authors of these articles. The results showed that 4909 classic articles were published between 1916 and 2013, and that the most productive categories from the WoS were multidisciplinary sciences, biochemistry and molecular biology, and general and internal medicine. Science published most of these articles, and the three most productive institutions were Harvard University, Massachusetts Institute of Technology and Stanford University. The physicist, Edward Witten was the most prolific author and an article written by the biochemist, Marion Bradford at University of Georgia in 1976 had the highest number of citations. In addition, the article by Perdew, Burke and Ernzerhof at Tulane University had the highest number of citations in 2014.

Keywords: Classic articles, publication characteristics, scientometrics, *Y*-index.

RECENTLY, the scientific publications of a single country, for example, Panama[1], Serbia[2], the Czech Republic[3] and China[4] have been evaluated using bibliometric methods. Similarly, highly cited articles from a particular country[5–7] have been addressed using citations from the Web of Science Core Collection, from their publication date to the end of last year[8,9]. These studies show that different patterns of highly cited publications in *Web of Science* (*WoS)* categories and journals can be found in different countries. Furthermore, some highly cited articles can be published by extremely large groups. For example, one highly cited article[10] in *Physical Review Letters* with 106 citations from the Web of Science Core Collection (data last updated: 16 September 2016), was published by 5154 authors from 429 institutions in 78 countries with 128 funding. Another classic article[11] in *Physics Letters B* with 3531 citation from the Web of Science Core Collection (data last updated: 16 September 2016), was published by 2932 authors from 117 institutions in 29 countries with 70 funding. Other classic articles and reviews published in *Science Citation Index Expanded* (*SCI-EXPANDED*) have been studied[12,13]. The top 14 institutions for classic articles[12] and the top 12 institutions for classic reviews[13] are from USA. Classic articles have also been analysed in research fields such as surgery[14] and psychology[15].

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Generally speaking, researchers in USA have the highest number of scientific publications, and this is true for almost all scientific disciplines[12,13]. Today, citation counts and other bibliometric indicators such as the *g*-index[16], *h*-index[17], *A*-index[18], *R*-index[18] and *AR*-index[18] are used to characterize both the quantity and significance of a scientist's research publications. More recently, the *Y*-index has been developed to examine the number of first and corresponding author publications in different disciplines, institutions and countries[12,19,20].

In this study we analysed the US independent classic articles published in the *SCI-EXPANDED* with at least 1000 citations up to 2014 as follows: (i) in terms of their citation histories and (ii) by their *Y*-indices, in order to evaluate the publications of individual American authors.

Methodology

The publications reported in this study were retrieved from the on-line version of *SCI-EXPANDED*, the Thomson Reuters *WoS* database (updated on 27 August 2015). According to the Journal Citation Reports (JCR, 2014), *SCI-EXPANDED* indexes 8659 journals with citation references from 176 *WoS* categories in it. We retrieved these published articles for analysis using the following search strategies:

Search strategy 1 – We selected only those documents from 1900 to 2014 in *SCI-EXPANDED*.

Search strategy 2 – We located these documents in terms of the different states within USA.

Search strategy 3 – We considered only scientific articles and excluded abstracts, reviews, proceedings papers, letters, editorial materials, meeting abstracts, etc.

Search strategy 4 – We recorded the total number of times an article was cited from its date of publication to the end of 2014 under the heading TC_{2014} (refs 8, 9). We defined classic articles as $TC_{2014} \geq 1000$ and examined only those articles that included their author(s)' names and affiliations. The advantage of TC_{2014} compared to the usual measure of total citations in the Web of Science Core Collection lies in its invariance, for it is not updated over time. Similarly, C_{2014}, the total number of citations of an article in 2014 (ref. 9); and C_0, the total number of citations for an article in its publication year, were used to characterize the classic articles[13], and TCPY, the total number of citations per year (TC_{2014}/year)[21]. We downloaded all records and number of citations for each article for each year into spreadsheet software and manipulated them using Microsoft Excel 2013 (ref. 22).

In the *SCI-EXPANDED* database, the corresponding author is labelled as the reprint author. In the present study, this person is referred to as the corresponding author. In single-author articles, we classified the author as both the first and the corresponding author[19]. The corresponding author is most likely to appear first or last[23]. In multi-author articles where the authorship contribution was not specified, we classified the first author as the corresponding author[20]. We used the mailing address of at least one author to assess the contributions from different institutions.

Results and discussion

A total of 4909 US independent classic articles ($TC_{2014} \geq 1000$) were published in *SCI-EXPANDED* between 1916 and 2013. The average value of TC_{2014} was 2012 with the maximal value of 157,683. The only non-English classic article[24] had a TC_{2014} of 1051.

Effect of time on citation analysis

Figure 1 illustrates the distribution of 4909 US independent classic articles over time and their citations per publication (CPP = TC_{2014}/TP). The publication output in decades only changed slightly from the 1910s to the 1960s, but later, there was a sharply increasing trend, rising to a peak of 1798 articles in 1990s, and then dropping down again in last two decades.

Figure 1 also shows that the trend in CPP is different for the number of US independent classic articles across the decades, with the highest score occurring in the 1920s. During World War I, Irving Langmuir was the only author to publish a US independent classic article. He also published the earliest classic articles in 1916, 1917 and 1918 in the *Journal of the American Chemical Society*. The most highly cited article by Langmuir[25], with TC_{2014} of 5570, was widely applied in the field of adsorption[26]. Langmuir went on to win the Nobel Prize in Chemistry in 1932 for his discoveries and investigations in surface chemistry.

After World War II, from 1946 to 1966, there was only one US independent classic article with TC_{2014} of 1920 (ref. 27). The 1920s with 11 articles had a much higher CPP of 3697, which can be attributed to an article in 1925 by Fiske and Subbarow[28] with TC_{2014} of 22740. The eight most productive years were in the 1990s. The year with the most articles was 1998, which had 206 articles (4.2% of 4909 articles), followed by 1995 with 199 (4.1%), 1997 with 186 (3.8%), 1991 with 185 (3.8%), 1996 with 181 (3.7%), 1993 with 180 (3.7%), 1992 with 177 (3.6%), and 1999 with 177 (3.6%) articles. The latest classic article was published in *CA – A Cancer Journal for Clinicians*[29] with TC_{2014} of 3270. Indeed, all of these 'cancer statistics' articles, published from 1993 to 2013, were US independent classic articles. Chuang *et al.*[30] reported that these articles have dramatically increased cancer research in the last decade.

Journal and WoS category

In this context, 4909 classic articles were published in 697 journals across 151 *WoS* categories in *SCI-EXPANDED*. Among these, 351 (50% of 697 journals) contained only one classic article; 115 (16%) contained two, and 55 (7.9%) contained three articles. A total of 4708 articles were published in 590 journals with impact factor (IF) information in 2014 and 201 articles were published in 107 journals which had no IF_{2014}.

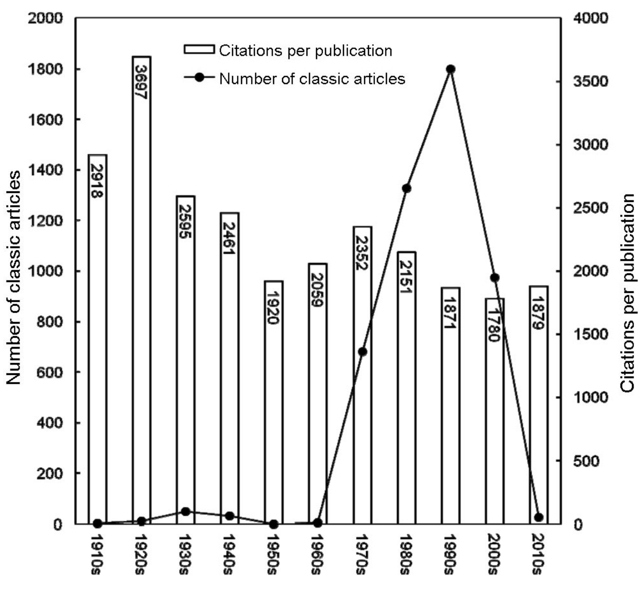

Figure 1. Number of US independent classic articles and citation per article by decades.

Figure 2 shows how these impact factors are distributed. Thirty-seven percentage of 4909 articles were published in 13 journals with IF higher than 30 ($IF_{2014} > 30$). Half of the US independent classic articles were published in 12 journals (Table 1). As can be seen from the table, *Science* ($IF_{2014} = 33.195$) published the most classic articles. The *New England Journal of Medicine* ($IF_{2014} = 55.192$) with 255 articles had the highest IF_{2014} whereas the *Journal of Chemical Physics* with 80 articles had the lowest IF_{2014} of 2.166. However, *CA – A Cancer Journal for Clinicians* with 21 articles about 'cancer statistics', had the highest IF_{2014} of 144.35.

Baltussen and Kindler[31] reported that the most frequently cited articles were published in journals with high IF. However, as shown in Figure 2, classic articles with $TC_{2014} > 1000$ can also be found in journals with lower IF[12,26], for example *American Mathematical Monthly* with $IF_{2014} = 0.170$, *Food Technology* with $IF_{2014} = 0.241$, *Communications in Soil Science and Plant Analysis* with $IF_{2014} = 0.353$, *Ferroelectrics* with $IF_{2014} = 0.431$ and *American Fern Journal* with $IF_{2014} = 0.436$. In addition, two of the three most high-impact articles in recent years ($C_{2014} > 6000$) were published in *Analytical Biochemistry* ($IF_{2014} = 2.121$) and *Methods* ($IF_{2014} = 3.600$).

Within the 151 *WoS* categories in *SCI-EXPANDED*, 54 (36% of 151 categories) generated 1–5 US independent classic articles, 29 (19%) generated 6–10 articles, 23 (15%) 11–30 articles, 32 (21%) 31–100 articles and 13 categories (8.6%) generated more than 100 articles. Table 2 shows the 30 *WoS* categories with at least 50 US independent classic articles. Multidisciplinary sciences with 56 journals published the most classic articles followed by biochemistry and molecular biology, general and internal medicine, cell biology and multidisciplinary physics. In total, 2630 articles (54% of 4909 articles) were published in these top five categories. Table 2 also shows number of journals in each category and cumulative percentages. *WoS* category of mathematics had the most journals (310). However, there were only 10 classic articles published in this category. It should be noted that journals can be classified in two or more categories in *WoS*; for example, *Cell* was listed in *WoS* categories of 'biochemistry and molecular biology' and 'cell biology', thus the cumulative percentage can sometimes be higher than 100%.

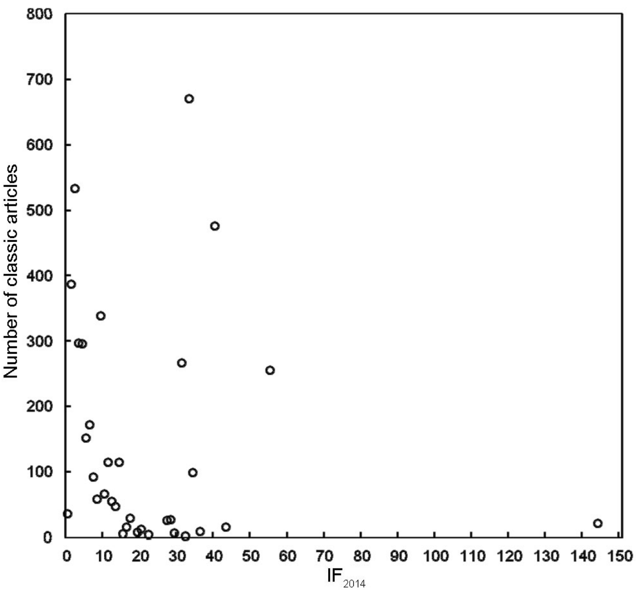

Figure 2. Relation between impact factor and number of articles published in journals with IF_{2014}.

Publication performance: authors

The number of authors involved in the 4909 US independent classic articles was 20276, among which 16772 (83% of 4909 articles) contributed only one article, 2273 (11%) contributed two articles, 651 (3.2%) contributed three articles, 266 (1.3%) contributed four articles and 314 (1.6%) contributed five or more. There were 4203 first authors (21% of 20276 authors), among which 3698 (88% of 4203 authors) contributed only one first article, and 380 (9.0%) contributed two articles. There were 4005 corresponding authors (20% of 20,276 authors), among which 3435 (86% of 4005 authors) contributed only one corresponding article and 394 authors (9.8%) contributed two articles.

In total 109 authors (0.54% of 20,276 authors) won a Nobel Prize, including 30 in Physiology or Medicine, 24 in Chemistry and 20 in Physics. Fifty-six Nobel laureates (1.3% of 4203 first authors) were first authors; 64 Nobel laureates (1.6% of 4005 corresponding authors) were corresponding authors and 33 Nobel laureates (4.7% of 703 single authors) were single authors.

Chuang and Ho[22] reported that the most single-authored classic articles were published in the US. Here 703 US independent classic articles were published by single authors, among which 562 authors (80% of 703 articles) contributed only one single-authored article and 41 (5.8%) contributed two articles. Edward Witten published 12 single-authored articles followed by Lars Onsager with 5, and J. Felenstein, F. D. M. Haldane and J. J. P. Stewart respectively, with 4 each. Onsager won the Nobel Prize in Chemistry in 1968 for his discovery of the reciprocal relations bearing his name, which are fundamental for the thermodynamics of irreversible processes. The article entitled 'Electric moments of molecules in liquids'[32] was Onsager's most highly cited with TC_{2014} of 4764.

The most prolific author was Edward Witten who published 30 US independent classic articles, followed by A. Jemal with 24 articles, C. M. Lieber with 24, P. M. Ridker with 23 and S. A. Rosenberg and H. J. Dai with 21 each. Witten and Lieber also published the most

Table 1. Characteristics of the top 12 journals with 50% of the US independent classic articles

Journal	TP (%)	IF_{2014}	*Web of Science* (*WoS*) category
Science	665 (14)	33.195	Multidisciplinary sciences
Nature	455 (9.3)	40.821	Multidisciplinary sciences
Cell	262 (5.3)	31.53	Biochemistry and molecular biology Cell biology
New England Journal of Medicine	255 (5.2)	55.192	General and internal medicine
Proceedings of the National Academy of Sciences of the United States of America	225 (4.6)	9.36	Multidisciplinary sciences
Physical Review Letters	146 (3.0)	6.9	Multidisciplinary physics
JAMA – Journal of the American Medical Association	99 (2.0)	34.446	General and internal medicine
Journal of the American Chemical Society	88 (1.8)	11.204	Multidisciplinary chemistry
Journal of Chemical Physics	80 (1.6)	2.166	Atomic, molecular and chemical physics
Journal of Biological Chemistry	60 (1.2)	4.288	Biochemistry and molecular biology
Physical Review B	54 (1.1)	2.564	Condensed matter physics
Physical Review D	42 (0.86)	2.967	Astronomy and astrophysics Particles and fields physics

TP: Total number of US independent classic articles; IF_{2014}: Impact factor in 2014.

Table 2. Top 30 *WoS* categories (TP ≥ 50)

WoS category	TP	%	Cumulative (%)	No. of journals
Multidisciplinary sciences	1353	28	28	56
Biochemistry and molecular biology	614	13	40	289
General and internal medicine	406	8.3	48	153
Cell biology	389	7.9	56	184
Multidisciplinary physics	201	4.1	60	78
Multidisciplinary chemistry	154	3.1	63	157
Genetics and heredity	148	3.0	67	167
Electrical and electronic engineering	147	3.0	70	249
Astronomy and astrophysics	123	2.5	72	60
Atomic, molecular and chemical physics	116	2.4	74	34
Neurosciences	114	2.3	77	252
Research and experimental medicine	107	2.2	79	123
Condensed matter physics	103	2.1	81	67
Physical chemistry	96	2.0	83	139
Applied physics	93	1.9	85	143
Statistics and probability	90	1.8	87	122
Immunology	89	1.8	88	148
Biochemical research methods	85	1.7	90	79
Oncology	84	1.7	92	211
Biology	80	1.6	94	85
Particles and fields physics	75	1.5	95	27
Multidisciplinary materials science	74	1.5	97	259
Biotechnology and applied microbiology	71	1.4	98	162
Psychiatry	71	1.4	99	140
Artificial intelligence computer science	61	1.2	101	123
Clinical neurology	59	1.2	102	192
Psychology	59	1.2	103	76
Cardiac and cardiovascular systems	56	1.1	104	123
Analytical chemistry	56	1.1	105	74
Peripheral vascular disease	50	1.0	106	60

TP, Total number of US independent classic articles.

first-authored articles and the most corresponding-authored articles (12 and 9 respectively). Witten's highest cited article, with TC_{2014} of 2412, was 'Dynamical breaking of super symmetry'[33]. However, it is important to note that with these data a potential bias in the analysis of authorship might occur when different authors have the same name, or the same authors use different names over time.

Equal credit for authorship, of course, cannot be given to all of the contributors. The most important authors are usually listed first or last. A non-alphabetical name order indicates that the first author has usually contributed the most[34]. However, the last author is often the key author in many disciplines[35,36]. The *Y*-index provides a single metric that identifies important characteristics related to

Table 3. Top 14 most productive institutions (TP > 100)

Institution	TP	TPR (%)	IPR (%)	CPR (%)	FPR (%)	RPR (%)	SPR (%)	SP/TP	SP_2/TP_2	SP_3/TP_3	SP_5/TP_5
Harvard University	532	1 (11)	1 (6.1)	1 (17)	1 (5.9)	1 (5.9)	1 (6.4)	45/532	10/117	4/50	1/16
Massachusetts Institute of Technology	251	2 (5.1)	3 (2.9)	2 (8.2)	3 (2.9)	3 (2.9)	4 (3.0)	21/251	6/56	3/22	2/10
Stanford University	232	3 (4.7)	2 (4.0)	3 (5.8)	2 (3.3)	2 (3.3)	2 (4.6)	32/232	10/64	6/31	3/11
Johns Hopkins University	156	4 (3.2)	6 (2.1)	5 (4.7)	6 (1.9)	6 (1.9)	35 (0.71)	5/156	2/41	1/18	0/7
University of California Berkeley	152	5 (3.1)	4 (2.6)	13 (3.8)	4 (2.2)	4 (2.2)	6 (2.4)	17/152	8/38	5/17	3/8
University of California San Diego	146	6 (3.0)	9 (1.8)	6 (4.7)	8 (1.7)	8 (1.7)	24 (1.0)	7/146	2/34	2/15	0/3
Yale University	146	6 (3.0)	5 (2.2)	9 (4.1)	5 (2.0)	5 (2.0)	6 (2.4)	17/146	4/31	4/15	0/2
National Cancer Institute	140	8 (2.9)	12 (1.6)	7 (4.6)	7 (1.8)	7 (1.8)	49 (0.43)	3/140	0/31	0/10	0/4
Washington University	135	9 (2.8)	7 (2.0)	12 (3.8)	9 (1.6)	9 (1.6)	8 (2.3)	16/135	3/40	3/17	2/3
University of California San Francisco	126	10 (2.6)	12 (1.6)	10 (3.9)	10 (1.5)	10 (1.5)	20 (1.1)	8/126	3/34	0/12	0/3
University of California Los Angeles	119	11 (2.4)	16 (1.3)	10 (3.9)	14 (1.3)	14 (1.2)	16 (1.3)	9/119	1/26	1/11	1/6
Brigham and Women's Hospital	109	12 (2.2)	143 (0.11)	4 (5.2)	24 (0.92)	24 (0.9)	49 (0.43)	3/109	0/13	0/3	0/0
Washington University	107	13 (2.2)	10 (1.7)	15 (2.8)	12 (1.5)	12 (1.5)	28 (0.85)	6/107	0/23	0/11	0/2
Cornell University	105	14 (2.1)	8 (1.8)	20 (2.6)	11 (1.5)	11 (1.5)	8 (2.3)	16/105	2/22	1/11	0/5

TP, Number of US independent classic articles ($TC_{2014} \geq 1000$); TPR (%), Rank of total US independent classic articles in the country and percentage of institution in all US independent classic articles; IPR (%), Rank of single-institution US independent classic articles in the country and percentage of institution in all single-institution US independent classic articles; CPR (%), Rank of inter-institutionally collaborative US independent classic articles and percentage of institution in all inter-institutionally collaborative US independent classic articles; FPR (%), Rank of first author US independent classic articles and percentage of institution in all first author US independent classic articles; RPR (%), Rank of corresponding author US independent classic articles and percentage of institution in all corresponding author US independent classic articles; SPR (%), Rank of number of single-author US independent classic articles ($TC_{2014} \geq 1000$) and percentage of institution in all number of single-author US independent classic articles; SP_2, Number of single-author US independent classic articles ($TC_{2014} \geq 2000$); TP_2, Number of US independent classic articles ($TC_{2014} \geq 2000$); SP_3, Number of single-author US independent classic articles ($TC_{2014} \geq 3000$); TP_3, Number of US independent classic articles ($TC_{2014} \geq 3000$); SP_5, Number of single-author US independent classic articles ($TC_{2014} \geq 5000$); TP_5, Number of US independent classic articles ($TC_{2014} \geq 5000$).

the first and corresponding authors that cannot be obtained by other traditional indicators[4].

Publication performances: institutions

Altogether, 4909 articles originated from 1536 institutions in USA, among which 971 (63%) contributed only one article and 174 (11%) contributed two articles. Only 253 institutions (16%) had single-authored US independent classic articles. The top 14 institutions with TP > 100 are listed in Table 3, with Harvard University, Massachusetts Institute of Technology and Stanford University heading the list. Harvard University published the most US independent classic articles (16) with $TC_{2014} \geq 5000$ (8.1% of 197 articles), 50 articles with $TC_{2014} \geq 3000$ (9.3% of 535 articles), 117 articles with $TC_{2014} \geq 2000$ (9.8% of 1197 articles) and 532 articles with $TC_{2014} \geq 1000$ (11% of 4909 articles). Stanford University, the University of California Berkeley and Princeton University published the most single-author articles, with three articles having $TC_{2014} \geq 5000$. Stanford University published six single-author articles with $TC_{2014} \geq 3000$ respectively. Stanford University and Harvard University published 10 single-author articles with $TC_{2014} \geq 2000$ respectively. Harvard University published 45 single-author articles with $TC_{2014} \geq 1000$ respectively. Finally, Harvard University dominated six indicators, including total US independent classic articles, single-institution articles, inter-institutionally collaborative articles, first author articles, corresponding author articles and single-author articles. These indicators were found to be about double those of Massachusetts Institute of Technology and Stanford University respectively. Furthermore, in Harvard University, C. M. Lieber published the most corresponding author articles (17 articles), while R. C. Kessler published the most first author articles (4 articles). Figure 3 shows the geographical distribution of the US independent classic articles. As expected, the highest publication rates came from the east and the west coast.

Publication quantity and the quality of the contribution: the Y-index

The *Y*-index is related to the order of author positions which is the number of first author publications (FP) and corresponding author publications (RP). The *Y*-index combines two parameters (j, h), to assess both the publication potential and characteristics of the contribution as a single index. The *Y*-index is defined as[19,20]

$$j = \mathrm{FP} + \mathrm{RP}, \tag{1}$$

$$h = \tan^{-1}\left(\frac{\mathrm{RP}}{\mathrm{FP}}\right), \tag{2}$$

where j is the publication potential which is a constant related to publication quantity, and h is publication characteristics which can describe the proportion of RP to FP.

The greater the value of j, more is the contribution of the first author and corresponding author publications. Different values of h represent different proportions of corresponding author publications from first author publications. $h > 0.7854$ indicates more corresponding author publications; $h = 0.7854$ indicates the same number of first author and corresponding author publications and $h < 0.7854$ indicates more first author publications. When $h = 0$, j is the number of first author publications, and $h = \pi/2$, j is the number of corresponding author publications.

Here we analysed 4909 US independent classic articles with both first and corresponding authors using the Y-index. Figure 4 shows the Y-index (j, h) distribution of the top 49 authors with $j \geq 8$. j is a publication intensity constant: an author with a high j has more articles as the first or corresponding author and takes the leadership role in more articles. Thus, for example, Edward Witten has 21 US independent classic articles, in 12 of which he is the single author and has the highest j of 24. Witten published these 21 articles when he was affiliated to Harvard University, Institute for Advanced Study and Princeton University during 1979–99. Next are Jemal ($j = 19$), Lieber ($j = 17$) and Ridker ($j = 11$). Witten also published the most first author articles (12) with Y-index (24, 0.7854), followed by Jemal with nine first author articles (19, 0.8380) and Ridker with eight first author articles (17, 0.8442). Lieber (17, $\pi/2$) published the most corresponding author articles with 17, followed by Witten (24, 0.7854) with 12 and Dai (12, 1.480) with 11. In addition, Mirkin (9, 1.446), Lander (9, 1.292), Young (9, 1.292), Peng (9, 1.107), Maniatis (9, 0.8961) and Kessler (9, 0.8961) had the same value of j. It is clear that all these authors are located on the same curve ($j = 9$) in Figure 4, indicating that they have the same publication potential but different publication characteristics. Mirkin ($h = 1.446$) has a higher ratio of corresponding author articles to first author articles, whereas Maniatis (h =0.8961) and Kessler ($h = 0.8961$) have a lower one. In Figure 4, Lieber is the only single-author who published 17 corresponding author articles, but no first author articles.

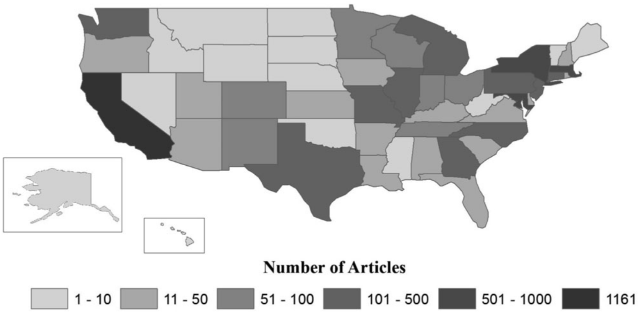

Figure 3. Global geographical distribution of US independent classic articles.

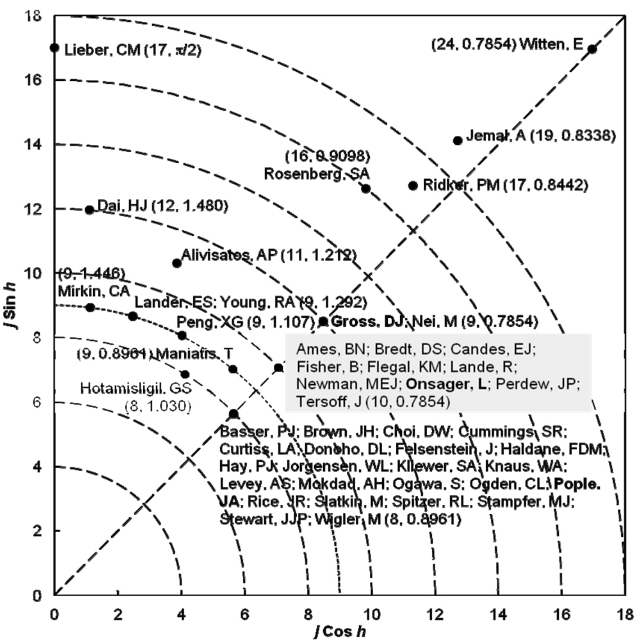

Figure 4. Top 49 authors with Y-index ($j \geq 8$).

An increase in the number of authors in a paper might lead to various unethical practices, including gift authorship[37,38]. Gift (or honorary) authorship is defined as the inclusion of an individual as an author who has not contributed adequately to the project[39,40]. Although honorary authorship or gift authorship is still regarded as a minor misdemeanour by many, it is unacceptable in *Lancet*[41]. In the present study, there were 3635 authors (18% of 20276 authors), who were first or corresponding authors of the US classic articles. Only 33 authors (0.91% of 3635 authors) published more first author articles than corresponding author articles ($h < 0.7854$). Corresponding authors are often senior researchers who have published classic articles and, typically, they supervise the planning and execution of the study and the writing of the paper[42].

A possible bias may occur when calculating the Y-index in that authors are sometimes listed in alphabetical order. In such a case, the first author may not be the major contributor to an article. Another bias is that in 1332 multi-author articles where the authorship contribution is not specified in the *WoS*, the first author may not be the corresponding author. Without making the authors' contributions to research articles explicit, readers may draw false conclusions about author credit and accountability[43].

The lifespan of the topmost cited classic articles: authors and institutions

According to Schwartz *et al.*[44], the authors of the most frequently cited papers appear to be pioneers, with papers

Table 4. Top 13 cited articles in 2014 (C_{2014} > 2000)

Rank				
C_{2014}	C_0	TC_{2014}	TCPY	References
1 (6324)	3486 (0)	5 (37,511)	5 (1974)	45
2 (6274)	3486 (0)	1 (157,683)	1 (4043)	55
3 (6003)	2745 (1)	9 (30,885)	2 (2206)	48
4 (4418)	2745 (1)	3 (48,044)	6 (1779)	46
5 (2859)	3486 (0)	7 (35,595)	14 (890)	57
6 (2610)	2 (660)	454 (3270)	7 (1635)	58
7 (2472)	3486 (0)	18 (17,966)	68 (461)	59
8 (2421)	879 (13)	6 (37,361)	4 (2076)	60
9 (2344)	1616 (5)	39 (11,735)	22 (733)	61
10 (2221)	3486 (0)	10 (29,352)	18 (753)	62
11 (2156)	2745 (1)	38 (11,862)	87 (409)	63
12 (2105)	2047 (3)	8 (30,954)	11 (1106)	64
13 (2084)	1812 (4)	23 (15,728)	84 (414)	47

C_{2014}, Total number of citations in 2014 from Web of Science Core Collection; TC_{2014}, Total number of citations from its date of publication to the end of 2014; C_0, Total number of citations in its publication year; TCPY, TC_{2014}/year.

departing significantly from what has come before and effective in encouraging further research. Table 4 lists the 13 top most cited US independent classic articles with $C_{2014} > 2000$ from the Web of Science Core Collection. Among these, five were published in the 1970s, three in the 1980s, three in the 1990s, one in the 2000s and one in the 2010s. Two of these articles were published by a single author, six by two authors, four by three authors, and one by seven authors. The article by Perdew *et al.*[45], Tulane University, had the highest C_{2014} of 6324. The University of North Carolina was the only institute that published two articles[46,47] with C_{2014} value of >2000. An article published in 1976 by Bradford[48] (University of Georgia) had the highest TC_{2014} of 157683 and TCPY of 4043. Other important publications came from research departments in industrial and national laboratories, including the American Cancer Society, Applied Biosystems in California, E. L. Du Pont de Nemours and Co. in Wilmington, the National Human Genome Research Institute in Bethesda, and the National Institutes of Health in Bethesda.

The most cited classic articles

The relationship between citations and year has been studied[49]. In general, it is accepted that articles published later are at a disadvantage in terms of citations compared to those published earlier[50]. Indeed, some articles, known as 'sleeping beauties', are not highly cited immediately after publication, but gain citations much later[51]. However, highly cited articles can be also found soon after publication[12,22]. In total, 1424 US independent classic articles (29% of 4909 articles) were not cited at all in their publication year ($C_0 = 0$), while 50 articles (1.0%) were cited more than 100 times ($C_0 > 100$), including five (10% of 50 articles) in 1987, and four (8.0%) in 2005 and 2009 respectively. Forty-eight percentage of the top 100 C_0 articles were published in the 2000s, 28% in the 1990s, 12% in the 1980s, 11% in the 2010s and one article in the 1970s. According to Ho and Kahn[13], articles with higher citations in their publication years (C_0) are likely to be cited in later years. These authors suggested that the increased number of journals in *SCI-EXPANDED* might be one of reasons for this. In addition, in the *SCI-EXPANDED* database, the number of articles increased from 676007 published in the 4962 journals in 1997 to 1282533 articles published in 8659 journals in 2014.

Figures 5–7 provide a history of the topmost US independent classic articles based on three indicators, C_0, TC_{2014} and C_{2014}. The US independent classic article by Wu *et al.*[52] had 758 citations in its publication year and 1174 citations in the next year after. Garfield[53] noted that a review with 350 citations within one year following publication had the highest citation recorded. Figure 5 shows the article life cycle for the top ten most cited classic articles reported in this paper in their publication year ($C_0 > 260$). Sharply decreasing trends can be generally found after their publication year or later years. Three top ten most cited classic articles were published in 1987, five in the 2000s and two were published in the 2010s. Seven of the top ten articles related to 'cancer statistics' were published in *CA – A Cancer Journal for Clinicians* by authors mainly from the American Cancer Society and from other institutions such as the Centers for Disease Control and the Prevention and National Cancer Institute. The other three articles were related to 'superconductivity' in *Physical Review Letters* by authors from University of Houston, University of Alabama, AT&T Bell Laboratories, and National Science Foundation.

Figure 6 shows the citation life cycles of the top ten US independent classic articles ($TC_{2014} > 29000$). Three of these articles were published in the 1970s, 1980s and 1990s respectively, and only one was published in the

2000s. The most frequently cited classic articles do not always have a high impact. The article by Chomczynski and Sacchi[54] had the sharpest increasing trend after publication to a very high peak, but sharply decreased to C_{2014} of 579 (rank 112th) thereafter. Similarly, the article, by Bradford[55] had a sharply increasing trend after publication in 1976, then reached a plateau, before descending steeply to a gorge in 2009, and then sharply increasing again to another plateau in 2011. This article was ranked first in the annual citations among single-author articles in *SCI-EXPANDED* from 2003 to 2007 (ref. 22).

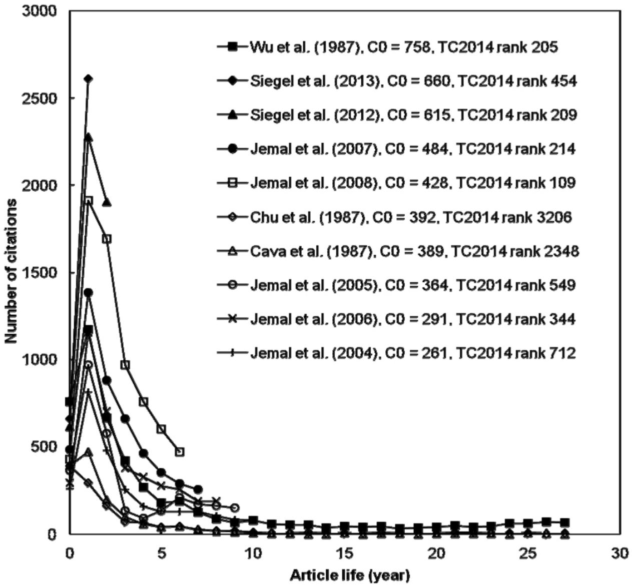

Figure 5. Life of the top ten most frequently cited articles in their publication year.

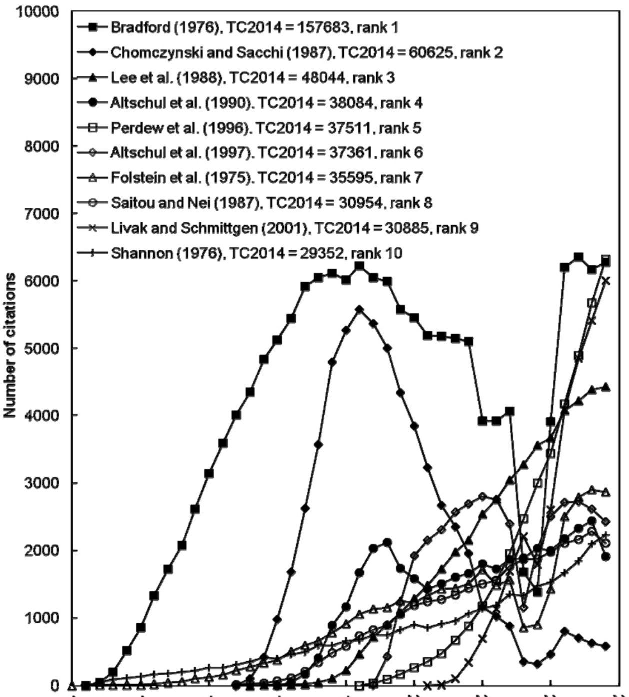

Figure 6. Life of the top ten most frequently cited articles.

In 2014, only 23 articles, 0.49% of 4909 US independent classic articles, had no citations and 7.5% articles had less than ten citations ($C_{2014} < 10$). Figure 7 shows the relationship between citations and year for the top ten articles ($C_{2014} > 2200$). There was a significant relationship between the top ten articles ranked by C_{2014} and TC_{2014}. Seven of the top ten articles can be found in both Figures 6 and 7. Similarly, a significant relationship between top cited articles with TC_{2014} and C_{2014} was reported in health care sciences and services field[56]. The most frequently cited article in 2014, with C_{2014} of 6324, was published in *Physical Review Letters*[45]. This article was also the second most frequently cited in 2010 in *SCI-EXPANDED*[12]. An article by Siegel *et al.*[29] has had high impact in recent years, ranked second in C_0 and sixth in C_{2014}, but ranked 454th in TC_{2014}.

Concluding summary

Thus, 4909 US independent classic articles published from 1916 to 2013 were found in *SCI-EXPANDED*. These articles were published in 697 journals listed in 151 *WoS* categories. Fourteen percentage of 4909 US independent classic articles were published in *Science*,

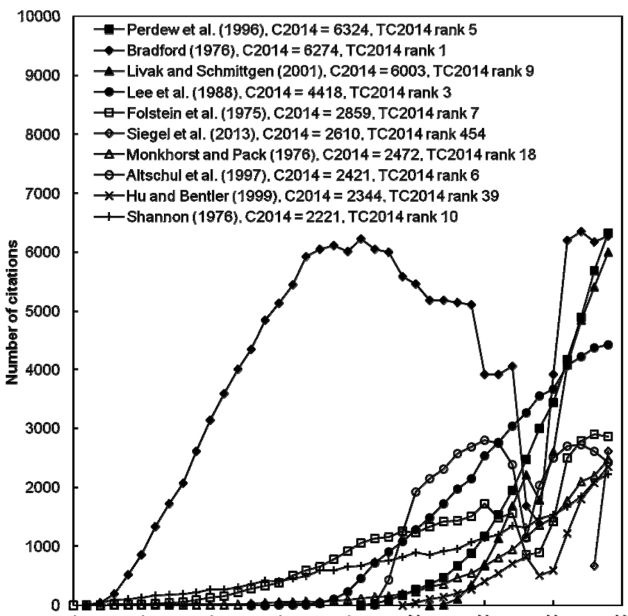

Figure 7. Life of the top ten most frequently cited articles in 2014.

followed by *Nature* with 9.3%. Articles with the most impact were published in *Analytical Biochemistry* in the categories of 'biochemical research methods', 'biochemistry and molecular biology' and 'analytical chemistry' respectively. Witten, an American theoretical physicist, published not only the most US independent classic articles but also the highest number of articles where he was the corresponding author and single-author respectively. Only 33% of the authors were first or held corresponding status. The article by Bradford had the highest number of citations since publication in 1976 to the end of 2014, while Perdew *et al.*[45] had the highest number of annual citations (6324 in 2014). Harvard University dominated the US independent classic articles and ranked top in single-institution articles, inter-institution collaborative articles, first author articles, corresponding author articles and single-author articles. Highly cited classic articles were also published by industries and national laboratories. The top classic articles with TC_{2014}, C_{2014} and C_0 were not the same. This means that it is not appropriate to use a single indicator to evaluate the impact of an article. We recommend that researchers pay more attention to the top articles with C_{2014} but not to those with TC_{2014}, because some top articles with TC_{2014} have not had a high impact in recent years.

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