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Comparison of medical research performance by thermodynamic and citation analysis methods

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Abstract
Beside citation metrics, in recent years, the thermodynamic indicators have been introduced. So, we want to compare citation metrics like *h*-index to thermodynamic indicators such as the exergy for determining the best indicator to rank the scientific agents effectively. This study is the bibliometric research and analyzes the scientific performance of the best countries, institutions, and universities in medical fields based on the citation metrics and the thermodynamic indicators upon extracted data from Scopus and Scimago databases. The Excel software version 2016 was used for analyzing the research performance of these medical agents and descriptive statistics were reported. Among countries, the United States had the best research performance based on the highest number of *P*, *C*, *h*, *X*. But, it had the lower impact than some countries like the United Kingdom and Italy. Iran is ranked 17th among the countries of the world in terms of studying indicators. About the world medical institutions, the National Institutes of Health Bethesda had the best research performance based on *h* and *X*, but the most qualitative institution was the American Cancer Society. Iranian medical universities compared to their world peers had the lower *P*, *C*, *i*, *h*, *X*. But Tehran University of Medical Sciences ranked first upon *h* and *X*. Mashhad University of Medical Sciences had the best quality of the scientific publication. Results showed that the exergy as the thermodynamic indicator and research performance metric can rank better the academic units based on the total number of papers and citations than the citation metrics such as *h*-index.

Keywords Academic Medical Centers · Thermodynamics · Bibliometrics · Academic performance

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Introduction

The citation analysis has been extensively used to evaluate scientific performance, detecting scholarly collaboration, planning of scientific disciplines, assessing the impact of research outputs, and observing knowledge transfer across domains. Papers and their citations have been used to form networks (Ding et al. 2014). The large bibliographic databases have recently used citations and other indicators based on citation numbers, as tools for the quantitative assessment of scientific research. Citations counts are often interpreted as proxies for the scientific influence of papers, journals, scholars, and institutions (Waltman 2016). So, many studies had done about this topic and used different indicators based on it. Beside citation count, other research performances are the number of papers. An important research performance that uses these two indicators to evaluate authors, journals, and institutions is *h*-index.

The *h*-index is a measure that it was designed to assess the quantity and significance of an individual's academic contributions and determines prolific authors with taking into account the relevance of their publications. The *h*-index was first described by Hirsch (2005). So, its measurement is very simple (Therattil et al. 2016). The *h*-index of an author is equal to the numbers of articles, *h*, that have been cited at least *h* times (Hirsch 2005). Hirsch said that *h*-index takes into account the number of papers published and the citations to those papers in a balanced way and thus, is useful to make comparisons between scientists (Hirsch and Buela-Casal 2014). *H*-index can be readily calculated by Scopus, Web of Science, and Google Scholar. The various databases seem to have a high degree of correlation between their *h*-index calculations (Lee et al. 2009). So, this measure can be used for evaluating researchers, getting research grants, and promoting them (Therattil et al. 2016). But, this indicator should be carefully used. The reasons include that an *h*-index in a field or subfield often is not comparable with *h*-indices in other fields or subfields. The *h*-index should never be used as the only factor to evaluate a researcher. Fashionable topics and collaboration can be increased *h*-index of scientists (Hirsch and Buela-Casal 2014). Another disadvantage of *h*-index is that it uses the *h*-value as a threshold for the cutoff of the tails of the distributions (Leydesdorff 2013).

Regarding to advantages and disadvantages of *h*-index as research performance and other scientometric indicators, in recent years, the thermodynamic indicators have been proposed for evaluating scientific performance. Sanee based on Prathap research in 2011 said that a thermodynamic general system has a total energy which can be in various modes (chemical, electrical, mechanical, thermal and so forth); but it is assumed that the system is closed and energy is not exchanged. Only a part of the energy can be converted to the work that is well known as Exergy or *X* (Sanee et al. 2016). Exergy is external energy (Sciubba and Wall 2007) and can be used in the other fields like bibliometrics, because it needs to determine quantity and quality for combining with each other and evaluating research performance (Prathap 2011). In the 3-D evaluating measurement of performance after computing quantity *P* and quality *i* parameters, it is possible to derive other indicators by following these sequences. $P = i^0P$ (zeroth-order indicator), $C = i^1P$ (first-order indicator), $X = i^2P = iC$ (second-order indicator), where $C = \Sigma cj$, $j = 1$ to *P*. *C* and *P* as performance indicators and quantity are total number of citations and papers respectively (Dwivedi 2017). The quantity part is represented by the number of papers, *P*, in the publication set (for a team or individual scientist), and the quality part is represented by the impact, $i = C/P$, where *C* is the total number of citations received by the *P* papers (Prathap 2014a). It may be true that *X* is the simplest construction of a composite indicator to measure performance. An indicator like h-index is a non-intuitive and heuristic construction (Prathap 2017a). So, exergy as the quantitative amount of research performance, which combines quantity and quality and ranks scientific agents such as researchers, journals, and organizations (Sanee et al. 2016). Beside exergy, there are other thermodynamic indicators such as energy, entropy (Prathap 2011), and zynergy (Prathap 2014b) that they have special features.

On the other hand, the scientometric indicators like thermodynamic ones can be used in different fields such as medical sciences. Medical research is heavily funded by governments, charities, and private companies, presumably because it can lead to improvements in lifespan and quality of life and because some medical discoveries, such as new drugs, equipment, and treatments, can be highly profitable. Medical research also seems to be frequently expensive due to the need to have high levels of confidence in the results if they may affect human health. Funders and managers sometimes need to assess the impact of research or conduct a cost–benefit analysis that their money is being spent effectively (Thelwall and Wilson 2016). Scientific performance of researchers in medicine seeking academic advancement, tenure, or funding is commonly assessed using bibliographic indices, such as mean citations per publication, total publications, journal impact factors, and the number of citations. All of these measures have some limitations. For example, total measure of publications productivity but don't indicate the importance or impact of an individual's work, whereas mean citations per paper might reward low productivity or fail to recognize high productivity (O'Leary and Crawford 2010).

So, we want to compare citation metrics like the total number of papers and citation, citation per papers, and h-index to thermodynamic indicators such as exergy for determining the best indicator to rank scientific agents effectively.

Data and methods

This study is the bibliometric research and analyzed scientific performance based on two methods that one of them was the citation metrics such as the total number of papers and citations, citation per papers, and h-index and other method was thermodynamic indicators such as exergy. So, data were extracted for the best ten countries and institutions in medical fields in the world based on Scimago journal and country rank (https://www.scimagojr.com/) and Scimago institutions ranking (https://www.scimagoir.com/) respectively upon Scopus database in 2017. Then, type one of the Iranian medical universities were chosen for comparing to the best countries and medical institutions in the worlds and both of the citation metrics and exergy were measured for them. The main data including P, C, h was extracted from Scopus in August of 2018 and then i and X were computed. The Excel software version 2016 was used for analyzing the research performance of these medical agents and descriptive statistics were reported.

Results

Upon the extracted data from Scopus database, the performance metrics including zero (P), first (C, i), and second (X) indicators along with h-index were measured for the world best ten countries and institutions in the medical fields, then type one of the Iranian medical universities were compared with the world peers. Based on the study objectives, Table 1 shows the United States has the most papers, citations received by papers, h-index, and exergy. But in comparison with the United Kingdom, Germany, Italy, Canada, France, and

Table 1 Citation metrics and thermodynamic indicators for the best ten countries in medical fields

Country	*P*	*C*	*i* = *C*/*P*	*H*-index	*X* = *iC*
United States	227,962	174,269	0.76	1407	132,444.4
United Kingdom	63,490	59,059	0.93	944	54,924.87
Germany	52,940	44,339	0.84	795	37,244.76
Italy	38,386	35,278	0.92	702	32,455.76
China	103,538	56,839	0.55	407	31,261.45
Canada	36,156	33,415	0.92	796	30,741.8
France	34,752	31,341	0.9	753	28,206.9
Australia	32,297	28,395	0.88	638	24,987.6
Japan	41,396	22,464	0.54	576	12,130.56
India	31,250	12,304	0.39	336	4798.56
Iran	14,852	6573	0.44	173	2892.12

Australia has the lower impact of papers based on $i(C/P)$ as a qualitative indicator. After the United States, China has the most scientific productions. Rankings based on h-index and exergy indicates that the United States had the most amounts of h and X; but for other countries these two indicators were different.

The best countries in medical fields were ranked based on exergy and it shows Iran is ranked 17th among the countries of the world in terms of studying indicators. But, Iran has the higher quality of scientific productions than India and the lowest P, C, h, and X (Fig. 1).

Based on the ranked health institutions in Scimago institutions rankings in 2018, the United States has 9 medical institutions and France has one institution among the best ten medical institutions. Inserm from France has the highest number of papers and citations. The best quality and impact of scientific researches related to American Cancer Society,

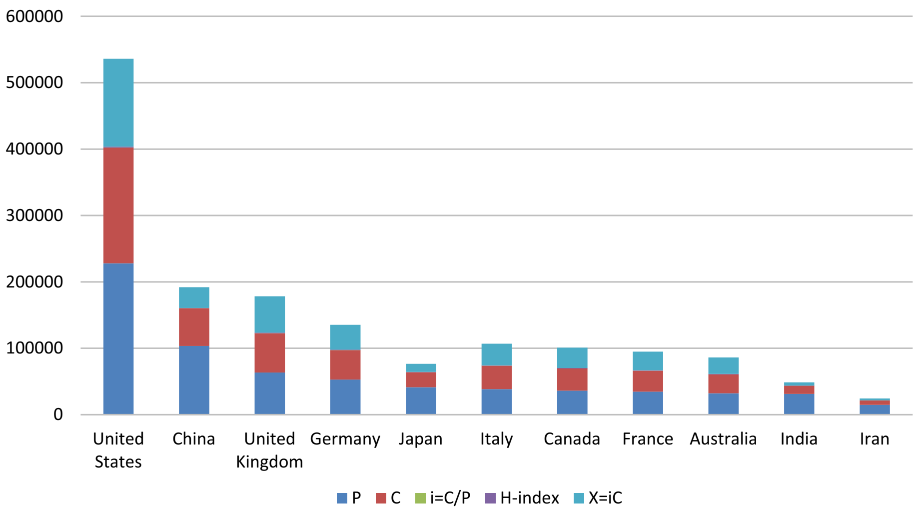

Fig. 1 Bar chart for the performing indicators. The best ten countries of the world in medical fields and compared to Iran

Table 2 The best ten medical institutions in the world based on Scimago institution ranking data and the amounts of *P*, *C*, *i*, *h*, *X* indicators for them in 2017

Institute	Country	*P*	*C*	*i* = *C*/*P*	*H*-index	*X* = *iC*
National Institutes of Health Bethesda	USA	10,094	47,337	4.68	60	221,537.2
Howard Hughes Medical Institute	USA	2396	21,569	9	50	194,121
Inserm	France	15,693	52,650	3.35	57	176,377.5
Massachusetts General Hospital	USA	7032	31,227	4.44	54	138,647.9
Brigham and Women's Hospital	USA	6300	29,243	4.64	54	135,687.5
Broad Institute	USA	1173	12,102	10.31	46	124,771.6
Department of Veterans Affairs	USA	11,718	34,840	2.97	42	103,474.8
American Cancer Society	USA	169	3589	21.23	17	76,194.47
Scripps Research Institute	USA	1013	6023	5.94	30	35,776.62
Whitehead Institute for Biomedical Research	USA	171	1795	10.49	18	18,829.55

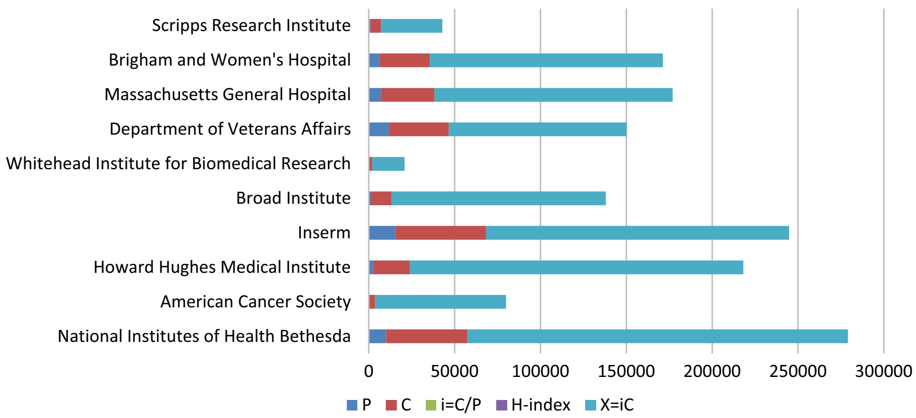

Fig. 2 Research performing the best ten health institutions in the world based on Scimago institution ranking in 2018

and National Institutes of Health Bethesda has the best research performance based on *h* and *X*. Whitehead Institute for Biomedical Research despite the small number of articles and citations than other institutions ranked second after American Cancer Society based on the quality indicator. This indicator has the direct effect on exergy amount (Table 2).

The bar chart of these medical institutions shows that the National Institutes of Health Bethesda has the best research performance based on exergy and Howard Hughes medical Institute ranked second. The lowest *X* related to Whitehead Institute for Biomedical Research (Fig. 2).

Iran has about 70 medical universities upon Iran ministry of health and medical education website (http://ird.behdasht.gov.ir/). These universities are divided into three types 1, 2, and 3. In terms of the various educational and researching standards, the highest ranking of these universities is type one medical universities. So, ten universities are of this type. Based on data extracted from Scopus in 2017, Tehran University of medical sciences has the best research performance upon *P*, *C*, *h*, *X*. It ranked first. After that, Shahid

Table 3 Research performance of Iranian Medical Universities based on Scopus data in 2017

Medical University of Iran	*P*	*C*	*C*/*P*	*H*-index	*X*
Tehran University of Medical Sciences	5201	9666	1.85	27	17,882.1
Shahid Behesti University of Medical Sciences	3258	5107	1.56	19	7966.92
Iran University of Medical Sciences	1886	3552	1.88	18	6677.76
Tabriz University of Medical Sciences	1549	3214	2.07	17	6652.98
Mashhad University of Medical Sciences	1500	3128	2.08	19	6506.24
Shiraz University of Medical Sciences	1505	2431	1.61	13	3913.91
Isfahan University of Medical Sciences	1313	1887	1.43	14	3453.21
Ahvaz Jundishapur University of Medical Sciences	796	1651	2.07	15	3417.57
Kerman University of Medical Sciences	625	1078	1.72	12	1854.16

Here, windows for *h*-index and *X* are the same

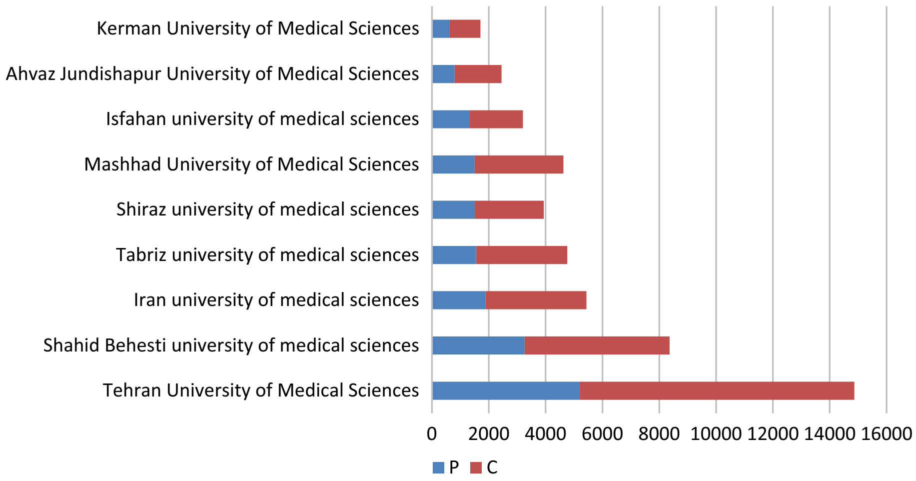

Fig. 3 *P* and *C* of Iranian medical sciences universities

Beheshti university of medical sciences ranked second based on these indicators. The good rank upon the impact of scientific researches related to Mashhad University of Medical Sciences. Ahvaz and Kerman despite the small number of articles have the good impact (Table 3).

Figure 3 shows Tehran has the most papers and citations to these articles than other medical universities. Based on research production and citation metric, Kerman gets the last position among their peers. The relation between *C* and *C*/*P* appears in Fig. 4. Where the number of citations is higher, the impact will increase. In other words, the high number of citations, despite the small number of articles, will increase the scientific quality of the university. Therefore, Ahwaz has a high scientific impact despite a small number of articles and Tehran, despite the high number of articles and citations, has a lower quality than Ahvaz (Fig. 3).

Figure 4 shows that the high amount of citation cause to the high amount impact of medical units. About the relationship between *h*-index and exergy, the high *h*-index doesn't indicate the high exergy and this causes different rankings based on these both indicators.

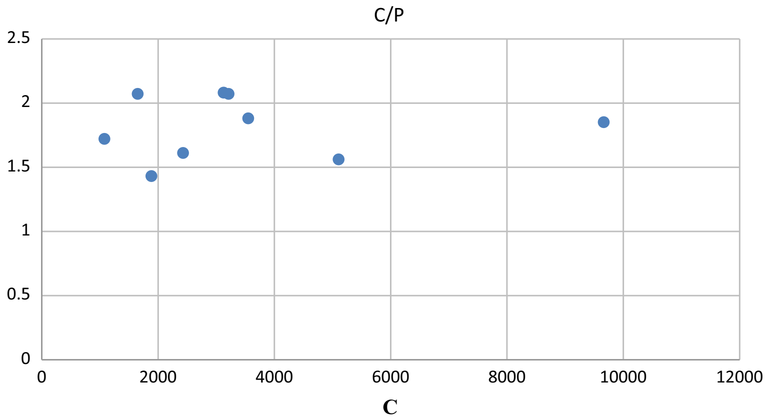

Fig. 4 The relationship between *C* and *C*/*P* as composite and quality indicators respectively

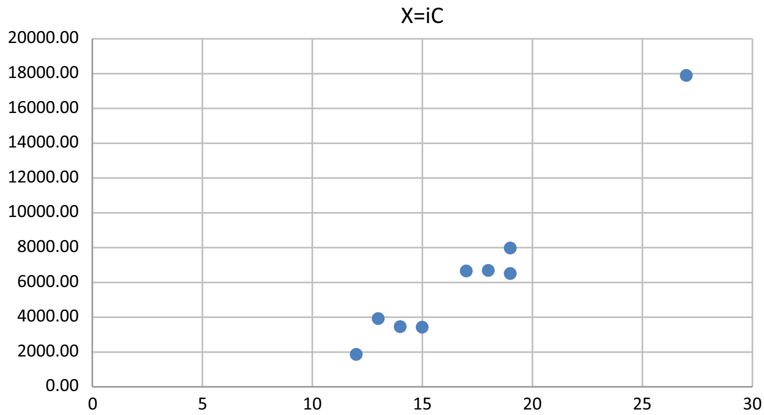

Fig. 5 The relationship between *H* and *X* as composite indicators

Tehran University of medical sciences has the highest *h* and *X*. Shahid Beheshti and Mashhad universities of medical sciences have *h*-index 19, but they have different exergy amounts. So that, Shahid Beheshti has the higher exergy than Mashhad and Iran University of Medical Sciences with *h*-index 18 ranked ahead of Mashhad based on exergy indicator (Fig. 5).

Conclusions and discussion

Major findings

Jorge Hirsch as the creator of *h*-index said that different disciplines have varying citation patterns and different *h*-index (Prathap 2017b). Thus, we can identify *h*-index for different fields including medicine. The *h*-index has already been tested and validated in several fields of medicine (Benway et al. 2009; Choi et al. 2009; DeLuca et al. 2013; Lee et al.

2009; O'Leary and Crawford 2010; Pagel and Hudetz 2011; Rad et al. 2012; Therattil et al. 2016). *H*-index has some good features like simplicity and determining prolific authors to allocate research funding and promotion of researchers to the higher positions (Therattil et al. 2016). So, our study demonstrated that countries, institutions, and universities in medical fields with the highest *h*-index have a good research performance. In this study, the United States as a country, National Institutes of Health Bethesda as a medical institution in the world, and Tehran University of medical sciences as a medical university in Iran had the best performance based on *h*-index. Also, they have the high number of articles and citations that both of them are important in determining *h*-index. Therattil et al. (2016) said that the number of articles positively correlated with increasing *h* number. Beside usages of *h*-index, it shouldn't be used to evaluate the scientific performance of academic researchers as the only factor because of limiting to the number of articles and citations (Hirsch and Buela-Casal 2014) and using the *h*-value as a threshold for the cutoff of the tails of the distributions (Leydesdorff 2013). So, in the recent years, Prathap introduced the thermodynamic indicators in the bibliometric evaluation of research aggregations such as countries, organizations, authors, and journals (Prathap 2011).

The important thermodynamic indicators that they have already been introduced and used including energy, entropy, exergy (Prathap 2011), Zynergy as a phantom indicator (Prathap 2014b), excellence based on exergy formula (Prathap 2017b), *p*-index as mock *h*-index (Prathap 2009), and impact ($i = C/P$) (Prathap 2011). In this research, we use exergy as a second order indicator of scientific performance and introduce the new ranking of countries, institutions, and universities in medical fields. Results showed that scientific unit with high *h*-index has nearly high exergy, but ranking based on both of them are different. Hereof, the United States had the highest *h* and exergy. After that, the United Kingdom had the same situation, but Canada compared to Germany was different, so that Canada had higher *h* than Germany; but Germany had the higher exergy. In the other words, the high *h*-index doesn't indicate high exergy surely. About the best medical institutions based on Scimago institution ranking data and medical universities of Iran, this was the same. The National Institutes of Health Bethesda from the USA had the high *h* and exergy, after that, Inserm had high *h* but it had lower exergy than the Howard Hughes Medical Institute. On the other hand, Tehran University of medical sciences from Iran had the highest *h* and *x* and Shahid Beheshti and Mashhad had the same *h*, but they had different exergy. Iran University of Medical Sciences ranked third after Shahid Beheshti based exergy method. This results can be because of *i* index as quality and first order indicator of research performance. Two important dimensions of *i* are *P* as the total number of papers and *C* as the total citations received by these articles that gains upon $i = C/P$. So, "*i*" is the impact of scientific units such as countries, authors, journals, and organizations. Results indicated that units had the most amounts of impact and *C*; they could have the highest exergy. These results are the same with Sanee et al. (2016) and Nishy et al. (2012). In this study, United Kingdom among the best ten countries in medicine, Whitehead Institute for Biomedical Research among the best ten health institutions, and Mashhad University of Medical Sciences from Iran had the most qualitative scientific productions. Among Iranian medical universities, Ahvaz Jundishapur University of medical sciences despite the small number of papers because of double citation than articles ranked after Mashhad based impact indicator. So, exergy affected by citation and impact indicators.

Conclusions

Results showed that there are different metrics for ranking scientific units such as countries, organization, authors, and journals. Among these indicators, many studies use *h*-index for ranking. But, this indicator can't be the perfect metric for acceptable ranking of different aggregations. Because it's affected by numbers of articles and low or high amount of citations haven't effect on it. Therefore, introducing thermodynamic indicators as exergy identified new ranking that it is some different from *h*-index. So, despite using *h*-index by citation databases such as Web of Science, Scopus, and Google Scholar, exergy doesn't use by these databases. Exergy is a composite indicator of quality and quantity indicators that it merges C as both quantity and quality indicator with $i = C/P$ as a quality indicator and gives the best ranking of scientific units. So, other thermodynamic indicators such as Energy, Entropy, Zynergy, and Excellence can be studied in different fields including the medical sciences and other fields.

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References

Benway, B. M., Kalidas, P., Cabello, J. M., & Bhayani, S. B. (2009). Does citation analysis reveal association between *h*-index and academic rank in urology? *Urology, 74*(1), 30–33.

Choi, M., Fuller, C. D., & Thomas, C. R., Jr. (2009). Estimation of citation-based scholarly activity among radiation oncology faculty at domestic residency-training institutions: 1996–2007. *International Journal of Radiation Oncology Biology Physics, 74*(1), 172–178.

DeLuca, L. A., Jr., St John, A., Stolz, U., Matheson, L., Simpson, A., & Denninghoff, K. R. (2013). The distribution of the *h*-index among academic emergency physicians in the United States. *Academic Emergency Medicine, 20*(10), 997–1003.

Ding, Y., Zhang, G., Chambers, T., Song, M., Wang, X., & Zhai, C. (2014). Content-based citation analysis: The next generation of citation analysis. *Journal of the Association for Information Science and Technology, 65*(9), 1820–1833.

Dwivedi, S. (2017). Publications of Banaras Hindu University during 1989–2016: A three-dimensional Bibliometric Study. *DESIDOC Journal of Library and Information Technology, 37*(6), 403.

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences, 102*(46), 16569–16572.

Hirsch, J. E., & Buela-Casal, G. (2014). The meaning of the *h*-index. *International Journal of Clinical and Health Psychology, 14*(2), 161–164.

Lee, J., Kraus, K. L., & Couldwell, W. T. (2009). Use of the *h* index in neurosurgery. *Journal of Neurosurgery, 111*(2), 387–392.

Leydesdorff, L. (2013). An evaluation of impacts in "Nanoscience and nanotechnology": Steps towards standards for citation analysis. *Scientometrics, 94*(1), 35–55.

Nishy, P., Panwar, Y., Prasad, S., Mandal, G., & Prathap, G. (2012). An impact-citations-exergy (iCX) trajectory analysis of leading research institutions in India. *Scientometrics, 91*(1), 245–251.

O'Leary, J. D., & Crawford, M. W. (2010). Bibliographic characteristics of the research output of pediatric anesthesiologists in Canada. *Canadian Journal of Anesthesia/Journal canadien d'anesthésie, 57*(6), 573–577.

Pagel, P., & Hudetz, J. (2011). H-index is a sensitive indicator of academic activity in highly productive anaesthesiologists: Results of a bibliometric analysis. *Acta Anaesthesiologica Scandinavica, 55*(9), 1085–1089.

Prathap, G. (2009). Is there a place for a mock *h*-index? *Scientometrics, 84*(1), 153–165.

Prathap, G. (2011). The energy–exergy–entropy (or EEE) sequences in bibliometric assessment. *Scientometrics, 87*(3), 515–524.

Prathap, G. (2014a). Quantity, quality, and consistency as bibliometric indicators. *Journal of the Association for Information Science and Technology, 65*(1), 214.

Prathap, G. (2014b). The zynergy-index and the formula for the *h*-index. *Journal of the Association for Information Science and Technology, 65*(2), 426–427.
Prathap, G. (2017a). Comparative end-to-end evaluation of research organizations. *Current Science, 113*(3), 455.
Prathap, G. (2017b). A three-dimensional bibliometric evaluation of recent research in India. *Scientometrics, 110*(3), 1085–1097.
Rad, A. E., Shahgholi, L., & Kallmes, D. (2012). Impact of self-citation on the *H* index in the field of academic radiology. *Academic Radiology, 19*(4), 455–457.
Sanee, N., Mohammadi, M., & Mirsaeid, J. G. (2016). Evaluation of scientific status of endocrine, diabetes, and metabolism research centers in Iran using exergy method. *Webology, 13*(2), 32.
Sciubba, E., & Wall, G. (2007). A brief commented history of exergy from the beginnings to 2004. *International Journal of Thermodynamics, 10*(1), 1–26.
Thelwall, M., & Wilson, P. (2016). M endeley readership altmetrics for medical articles: An analysis of 45 fields. *Journal of the Association for Information Science and Technology, 67*(8), 1962–1972.
Therattil, P. J., Hoppe, I. C., Granick, M. S., & Lee, E. S. (2016). Application of the *h*-index in academic plastic surgery. *Annals of Plastic Surgery, 76*(5), 545–549.
Waltman, L. (2016). *Conceptual difficulties in the use of statistical inference in citation analysis*. Preprint. arXiv:1612.03285.