

Research on literature involving zirconia-based on Pubmed database: a bibliometric analysis

Huiyan Yu, Zhuangzhi Zhi, Chunxia Zhang and Huazhe Yang*

Zirconia is an important material for both medical science and chemical industry, and numerous studies on zirconia have been published. It is of great importance to summarize the study trend of zirconia for further studies. In the present paper, articles published during five years, i.e. from April 2009 to April 2014, were collected from the Pubmed database for statistical analysis, and the current situation and research advances of zirconia are summarized and analysed. It is found that an increasing number of articles concerning zirconia have been published every year especially in zirconia as dental materials. Authors are mainly from developed countries and regions, and a developing country such as China is playing an increasing role in this field.

Keywords: Bibliometrics, biomedicine, Pubmed, zirconia.

ZIRCONIA, a kind of non-metallic material with desirable biocompatibilities and corrosion resistance, has attracted significant interest among the researchers and doctors¹⁻¹⁵. Especially, its excellent mechanical properties (hardness, fracture toughness and strength) are useful compared to other ceramics, which enables manufacturers to apply zirconia widely in both medical science and chemical industry. Zirconia is widely used to prepare all ceramic crowns or hard tissue implants, bearings, refractories, etc. To date, numerous publications have appeared on zirconia, and it is of particular importance to summarize the hot issues and propose the developing trend of zirconia.

Bibliometric analysis is an imperative scientific tool to evaluate the impact of a certain research on scientific research as a whole. Further, it can reveal research advances and developing trends of a research field, which can provide valuable insights and inspiration for both researchers and the government to optimize their research focus for policy-making. It is therefore of prime importance to study zirconia by assessing various parameters of relative publications which can give us insight into research advances and focus of zirconia. Besides, it is also interesting to study the source of articles to clarify the participation and contribution of researchers worldwide, which may provide useful references to narrow the gap

between different countries or regions. To the best of our knowledge, there are no bibliometric studies on zirconia.

In the present study, statistical analysis was conducted based on publications involving zirconia in Pubmed databases¹⁶⁻²⁸, and information and data were extracted and analysed manually to avoid errors in statistical software. Research advances of zirconia have been summarized and analysed and the developing trends of zirconia proposed. Affiliations of authors were classified to evaluate the contributions of zirconia research from different countries and from different regions in China.

Materials and methods

Materials

Pubmed database was adopted to collect publications involving zirconia, and 4192 articles were searched from 1 January 2004 to 31 December 2014 by inputting keywords, i.e. zirconia, zirconium oxide or zirconium dioxide. In order to study the research advances of zirconia in detail in previous years, the time interval chosen was between April 2009 and April 2014, and 2149 articles could be searched.

Methods

Information and data were extracted manually from journal title, article title, authors, affiliations and abstract. Based on this information, statistical analysis was conducted to summarize and analyse the following parameters: time, journal titles, nationalities of authors, provinces of

Huiyan Yu and Huazhe Yang are in the Department of Biophysics, School of Fundamental Sciences, China Medical University, Shenyang 110001, China; Zhuangzhi Zhi is in the Department of Biomedical Engineering, School of Medical Devices, Shenyang Pharmaceutical University, Shenyang 110016, China and Chunxia Zhang is in the Department of Ophthalmology, Fuzhou General Hospital of Nanjing Military District, Fuzhou, Fujian 350025, China.

*For correspondence. (e-mail: hzyang@mail.cmu.edu.cn)

Chinese authors, international cooperation between Chinese and foreign authors and their area of interest. The classified statistics were then analysed to explore the research advances and development trends of zirconia.

Results and discussion

Number of articles published per year

The total number of articles involving zirconia was 4192 from 1 January 2004 to 31 December 2014, which was a steady increase over previous years (Figure 1). The number of articles was 142 in 2004 which rose to 668 in 2014. In addition, the slope of linear fitness from 2009 to 2014 was 61, which was higher than that from 2004 to 2009. Zirconia has thus played an increasing role in publications, and has gradually become a hot issue recently.

Distribution of articles in different journals

The number of articles involving zirconia was 2149 published in 328 journals between April 2009 and April 2014. Table 1 lists the journal titles with their abbreviations. Figure 2 shows the distribution of articles in different journals including 22 top-ranking journals which published more than 20 articles for each journal. The articles numbering 50.56% were published in the top 22 journals, indicating that these journals were important journals for zirconia studies. In addition, more than 200 articles involving zirconia were published in the journal

Table 1. Journal and abbreviation

Journal	Abbreviation
<i>Dent Mater.</i>	DM
<i>J. Prosthet. Dent.</i>	JPD
<i>J. Prosthodont.</i>	JP
<i>Clin. Oral. Implants Res.</i>	COIR
<i>J. Dent.</i>	JD
<i>Int. J. Oral Maxillofac. Implants.</i>	OMI
<i>Phys. Chem. Chem. Phys.</i>	PCCP
<i>J. Nanosci. Nanotechnol.</i>	JNN
<i>J. Biomed. Mater. Res. B Appl. Biomater.</i>	JBM
<i>Clin. Oral Investig.</i>	COI
<i>J. Mech. Behav. Biomed. Mater.</i>	JMBB
<i>J. Adv. Prosthodont.</i>	JAP
<i>J. Colloid Interface. Sci.</i>	JCIS
<i>J. Chromatogr. A</i>	JCA
<i>Acta. Odontol. Scand.</i>	AOS
<i>Acta. Biomater.</i>	AB
<i>Clin. Implant Dent. Relat. Res.</i>	CID
<i>ACS Appl. Mater. Interfaces</i>	ACS
<i>J. Adhes. Dent.</i>	JAD
<i>Quintessence Int.</i>	QI
<i>J. Hazard Mater.</i>	JHM
<i>Bioresour. Technol.</i>	BT
<i>Other Journals</i>	ELSE

Dent. Mater., followed by those published in *J. Prosthet. Dent.* (95 articles). This suggests that the dental application of zirconia is a hot issue.

Distribution of authors

All the publications were by authors from 64 different countries. The total statistical weight coefficient of each article was set as 1, containing the first author weight coefficient (0.7) and the rest co-authors' weight coefficient (0.3 in total and equally divided by the number of co-authors). Articles with no information on the nationality of authors were excluded and the number of remaining articles for statistical analysis was 2060. Figure 3 shows the distribution of 12 top-ranking nations with highest total weight coefficient. According to the calculation mentioned above, 341.54 articles were by Americans, 258.13 articles by Germans, 256.5 articles by Chinese, 161.12 articles by Japanese, 111.895 articles by Brazilians, 104.12 articles by Italians, 97.7 articles by South Koreans, 89.685 articles by Turks, 68 articles by Indians, 61.15 articles by Spanish, 57.175 articles by Swiss and 49.475 articles by British. The developed countries include United States, France, Britain, Japan, Germany, Canada, Italy, Sweden, Finland, Denmark, Norway,

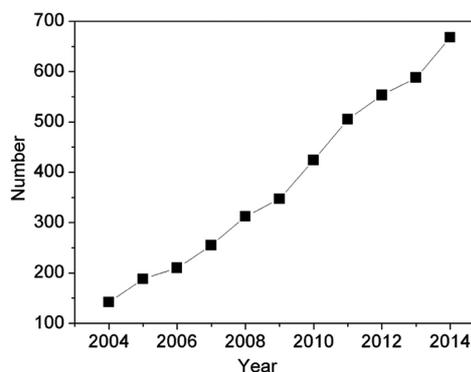


Figure 1. Total number of articles involving zirconia from 2004 to 2014.

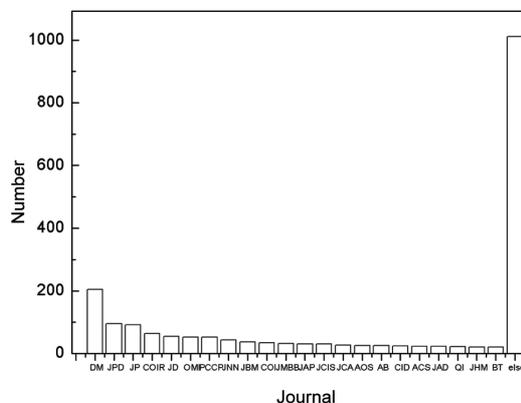


Figure 2. Distribution of articles involving zirconia in different journals.

the Netherlands, Belgium, Switzerland, Austria, Turkey, Australia, New Zealand, Greece, Iceland, Ireland, Luxembourg, Portugal and Spain. Therefore, the number of the publications for the 12 top-ranking developed countries was 1122.395, accounting for 54.49% of the overall publications. The United States, Germany and Japan accounted for 16.58%, 12.53% and 7.82% respectively of the total number, which shows that traditionally developed countries emphasized on basic research and applications of zirconia obtaining considerable research results. Further, among the 64 nations, all the developed countries published 1337.675 articles, accounting for about 64.94% of the total number. Accordingly, a small number of developed countries take a dominant role in studies on zirconia, and developing countries occupy a smaller proportion due to their relatively poor scientific and financial constraints. China, the largest developing country, ranked third in the number of publications (12.45% of the total percentage). Among the 256.5 articles by Chinese authors, 51 were in Chinese, which means the proportion of the literature in Chinese to English is 1 : 4.

Provinces distribution of Chinese authors

As shown in Figure 4, the Chinese authors were from 25 different provinces. The method to set statistical weight coefficient for province distribution was exactly similar

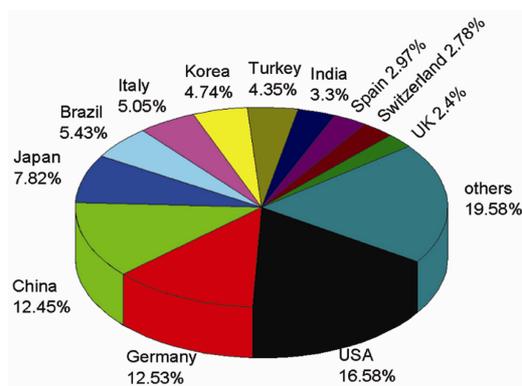


Figure 3. Distribution of nationalities of the authors.

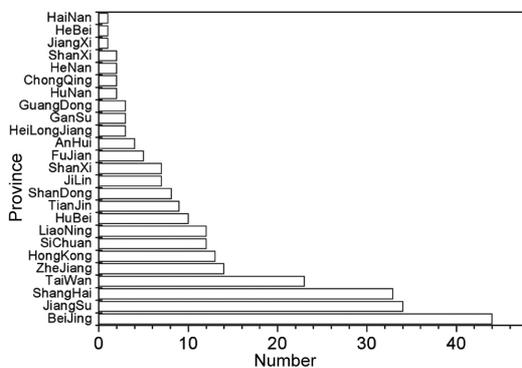


Figure 4. Distribution of articles in different provinces.

to that for other nations mentioned earlier. Results of statistical analysis on the distribution of number of articles in different provinces are as follows: 44 articles from Beijing, 34 from Jiangsu province, 32.9 from Shanghai, 23 from Taiwan, 14 from Zhejiang province, 13 from Hong Kong, 12 from Sichuan and Liaoning provinces for each, 10 from Hubei province, 9 from Tianjin, 8.1 from Shandong province, 7 each from Jilin and Shaanxi provinces, 5 from Fujian province, 4 from Anhui province, 3 each from Heilongjiang, Gansu and Guangdong provinces, 2 each from Hunan, Chongqing, Henan and Shanxi provinces and one article each from Jiangxi, Hebei and Hainan provinces. From the above data, it is seen that coastal provinces published 133 articles, accounting for 52.15% of the total. Four municipalities of China published 87.9 articles, accounting for 34.47% of the total. Most of the coastal provinces or municipalities are strong manufacturing regions possessing strong economic and scientific research. Thus, studies on zirconia are, to some extent, related to the economic development of a region. The developed regions pay high attention to basic research and practical applications of zirconia.

International co-authorship between Chinese and foreign researchers

Among the 2149 articles, only 2 were outcome of co-operation between China and foreign countries, i.e. the United States and Denmark. Besides, there was only one article written by researchers in mainland and Hong Kong. Therefore, as a developing country, China should strengthen international cooperation, which is the catalyst to narrow the gap between China and developed countries.

Area of interest of research

The focus of the overall 2149 articles was biomedical science and chemical industry (Figure 5). Among them, 1205 articles were related to biomedical science, accounting for more than 56% of the total publications. Especially, dental and orthopedic practices were of particular importance, covering 1136 articles and 69 articles respectively.

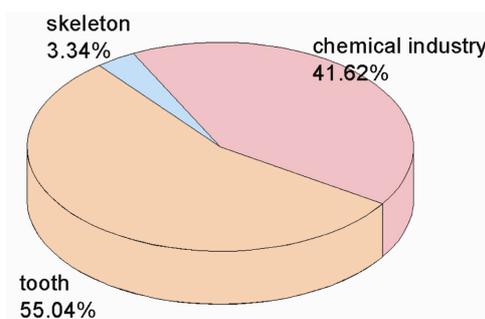


Figure 5. Area of interest of research.

In contrast, all branches of chemical industry field contributed to 41.62% of the total publications, which was lower than that for dental practice. In fact, various ceramics and organic materials have been widely applied in dentistry^{2,30}, and the dominant application of zirconia is based on dental restorations.

Conclusion

Published articles involving zirconia have dramatically increased. Developed countries especially America and Germany had the highest number of publications. China started paying more attention to zirconia, and 75% of zirconia articles of Chinese authors were in English, showing that the efforts of Chinese researchers had gradually been recognized by international peers. However, the number of high impact articles including international co-authorship articles was relatively small with a low overall research level. Therefore, international cooperation should be strengthened to improve the quality of research. In addition, according to statistics, the application of zirconia as dental materials has occupied a large proportion, which is consistent with the status that all-ceramic crown restorations have been widely applied in clinic. The development trend of this kind of material is likely to deal with clinical problems of zirconia-based all-ceramic crown restoration such as interfacial fracture of veneering porcelain/zirconia and low temperature degradation of zirconia crowns^{29,30}.

- Ren, Y. G. *et al.*, Kind and application of zirconia material. *China Ceram.*, 2008, **44**(4), 44.
- Ji, Y. *et al.*, Advances in zirconia bioceramics as all-ceramics crowns material: a review and outlook. *Rev. Adv. Mater. Sci.*, 2013, **34**, 72.
- Derek, W. J., Development of dental ceramics: an historical perspective. *Dent. Clin. North Am.*, 1985, **29**(4), 621.
- Rosenblum, M. A. and Schulman, A., A review of all-ceramic restorations. *J. Am. Dent. Assoc.*, 1997, **128**(3), 297.
- Roriz, V. M., *et al.*, Efficacy of a bioactive glass-ceramic (biosilicate) in the maintenance of alveolar ridges and in osseointegration of titanium implants. *Clin. Oral Implan. Res.*, 2010, **21**(2), 148.
- Marchi, J. *et al.*, Cell proliferation of human fibroblasts on alumina and hydroxyapatite-based ceramics with different surface treatments. *Int. J. Appl. Ceram. Technol.*, 2009, **7**(2), 139.
- Hisbergues, M., Vendeville, S. and Vendeville, P., Zirconia: established facts and perspectives for a biomaterial in dental implantology. *J. Biomed. Mater. Res. B: Appl. Biomater. B*, 2009, **88**, 519.
- Chevalier, J., What future for zirconia as a biomaterial. *Biomaterials*, 2006, **27**, 535.
- Özkurt, Z. and Kazazoglu, E., Zirconia dental implants: a literature review. *J. Oral Implantol.*, 2011, **37**(3), 367.
- Kern, M. and Wegner, S. M., Bonding to zirconia ceramic: adhesion methods and their durability. *Dent. Mater.*, 1998, **14**(1), 64.
- Kasuga, H. *et al.*, Surface characteristics of efficient-ground alumina and zirconia ceramics for dental applications. *Key Eng. Mater.*, 2009, **404**, 69.
- Shijo, Y. *et al.*, Studies on mechanical strength, thermal expansion of layering porcelains to alumina and zirconia ceramic core materials. *Dent Mater J.*, 2009, **28**(3), 352.
- Eric, A., Anne, P. and Thomas, H., Stiffness, elastic limit, and strength of newer types of endodontic posts. *J. Dent.*, 1999, **27**, 275.
- Sailer, I. *et al.*, Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. *Int. J. Prosthodont.*, 2009, **22**(6), 553.
- Brakel, R. V. *et al.*, Early bacterial colonization and soft tissue health around zirconia and titanium abutments: an *in vivo* study in man. *Clin. Oral Impl. Res.*, 2011, **22**, 571.
- Tholey, M. J., Swain, M. V. and Thiel, N., SEM observations of porcelain Y-TZP interface. *Dental Mater.*, 2009, **25**, 857.
- Denry, I. and Kelly, J. R., State of the art of zirconia for dental applications. *Dental Mater.*, 2008, **24**, 299.
- Zhao, J., Shen, Z., Si, W. and Wang, X., Bi-colored zirconia as dental restoration ceramics. *Ceram Int.*, 2013, **39**, 9277.
- Chintapalli, R. K., Mestra Rodriguez, A., Garcia Marro, F. and Anglada, M., Effect of sandblasting and residual stress on strength of zirconia for restorative dentistry applications. *J. Mech. Behav. Biomed.*, 2014, **29**, 126.
- Moradabadi, A., Roudsari, S. E. S., Yekta, B. E. and Rahbar, N., Effects of surface treatment on bond strength between dental resin agent and zirconia ceramic. *Mat. Sci. Eng. C-Mater.*, 2014, **34**, 311.
- Yoshida, H., Matsui, K. and Ikuhara, Y., Low-temperature superplasticity in nanocrystalline tetragonal zirconia polycrystal (TZP). *J. Am. Ceram. Soc.*, 2012, **95**(5), 1701.
- Koenig, V., Vanheusden, A. J., Le Goff, S. O. and Mainjot, A. K., Clinical risk factors related to failures with zirconia-based restorations: an up to 9-year retrospective study. *J. Dent.*, 2013, **41**, 1164.
- Guess, P. C., Att, W. and Strub, J. R., Zirconia in fixed implant prosthodontics. *Clin Implant Dent. R.*, 2012, **14**(5), 633.
- Pelaez, J., Cogolludo, P. G., Serrano, B., Lozano, J. F. L. and Suarez, M. J., A four-year prospective clinical evaluation of zirconia and metal-ceramic posterior fixed dental prostheses. *Int. J. Prosthodont.*, 2012, **25**(5), 451.
- Alhashim, A., Kamel, M. and Brackett, W. W., Four-year follow-up of the rehabilitation of a mandibular arch with a cementable zirconia-reinforced fixed dental prosthesis: a clinical report. *J. Prosthetic Dent.*, 2012, **108**(3), 138.
- Hallmann, L., Ulmer, P., Reusser, E., Louvel, M. and Hammerie, C. H. F., Effect of dopants and sintering temperature on microstructure and low temperature degradation of dental Y-TZP-zirconia. *J. Eur. Ceram. Soc.*, 2012, **32**(16), 4091.
- Mitov, G., Heintze, S. D., Walz, S., Woll, K., Muecklich, F. and Pospiech, P., Wear behavior of dental Y-TZP ceramic against natural enamel after different finishing procedures. *Dent. Mater.*, 2012, **28**(8), 909.
- Ambré, M. J., Aschan, F. and von Steyern, P. V., Fracture strength of yttria-stabilized zirconium-dioxide (Y-TZP) fixed dental prostheses (FDPs) with different abutment core thicknesses and connector dimensions. *J. Prosthodont.*, 2013, **22**, 377.
- Ji, Y. *et al.*, Influence of EDTA on demineralization rate of dentine: calcification treatment in root canal therapy. *J. Mater. Sci. Technol.*, 2014, **30**(7), 692-698.
- Yang, H. Z. and Ji, Y., Low-temperature degradation of zirconia-based all-ceramic crowns materials: a mini review and outlook. *J. Mater. Sci. Technol.*, 2016, **32**, 593-596.

ACKNOWLEDGEMENTS. The work was supported by the National Natural Science Foundation of China (No. 81500897), China Scholarship Council (No. 201408210385), Foundation of the Education Department of Liaoning Province (No. L2013285) and Science and Technology Planning Project of Shenyang City (No. F11-262-9-16).

Received 16 July 2016; accepted 28 October 2016

doi: 10.18520/cs/v112/i06/1134-1137