The Status and Trends of Mitochondrial Dynamics Research: A Global Bibliometric and Visualized Analysis

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Research

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Abstract

Objectives: Mitochondria are remarkably dynamic organelles encapsulated by bilayer membranes. The dynamic properties of mitochondria are critical for energy production. Our study aims to investigate the global status and trends of mitochondrial dynamics research.

Method: Publications related to the studies of mitochondrial dynamics from 2000 to 2019 were retrieved from Web of Science database. A total of 2999 publications were included. Bibliometric analysis was conducted by visualization of similarities viewer and GraphPadPrism 5 software.

Results: There is an increasing trend of mitochondrial dynamics research during the last 20 years. The cumulative number of publications about mitochondrial dynamics research followed the logistic growth model Ob . The USA made the highest contributions to the global research. The journal *Biochimica et Biophysica Acta (BBA) - Molecular Basis of Disease* had the largest publication numbers. The Johns Hopkins University is the most contributive institution. The main research orientation and funding agency were cell biology and NIH. All keywords related studies could be divided into three clusters: “Related disease research”, “Mechanism research” and “Cell metabolism research”.

Conclusion: Attention should be drawn to the latest popular research and more efforts will be put into mechanistic research, which may inspire new clinical treatments for the associated diseases.

Introduction

Mitochondria, considered as the “powerhouse” of eukaryotes, generate energy required for cell metabolism by oxidative phosphorylation (OXPHOS)[1, 2]. Mitochondria are remarkably dynamic organelles encapsulated by bilayer membranes, and the dynamic characteristics include mitochondrial fusion, mitochondrial fission and mitophagy[3]. Various physiological processes and metabolic regulations of cell are associated with mitochondrial dynamics[4], such as autophagy, programmed celldeath, redox signaling, calcium homeostasis, innate immunity and stem cells reprogramming[5, 6]. Mitochondrial fusion is the amalgamation of multiple mitochondria into one. Mitofusion1 (Mfn1) and mitofusion2 (Mfn2) mediate the fusion of the outer membrane and Optic Atrophy 1 (OPA1) mediates the fusion of the inner membrane[7, 8]. In contrast, mitochondrial fission is the division of a mitochondria into two or more seperated ones. Dynamin-related protein 1 (Drp1) and the classical dynamin 2 (Dnm2) are the major mediators of mitochondrial fission[9, 10](Fig. 1). The balance of mitochondrial fusion and fission is critical for the normal physiological function of cells, which contribute to regulation of mitochondrial morphology[11, 12], exchange of content[13, 14], maintenance of mitochondrial DNA (mtDNA) [9, 15] and clearance of damaged mitochondria[16, 17]. Defect and damage in mitochondrial dynamics have resulted in numerous human diseases, such as Charcot–Marie–Tooth disease type 2A (CMT2A)[18, 19], Multiple symmetric lipomatosis[20, 21], Dominant optic atrophy[22], Microcephaly and Optic atrophy[23]. Therefore, the mechanistic study of mitochondrial dynamics is gaining more and more attention in recent years, and treatments through mitochondrial pathway for related diseases are going to be a new clinical

strategy. However, studies on qualitative and quantitative characteristics of global research of mitochondrial dynamics are limited. Evaluation of the current status and trends of mitochondrial dynamics research and predicting promising popular topics and directions in the field are more essential.

Publication, as a central part of scientific research, is a significant indicator for research contribution. Bibliometrics combined with visualized mapping has been recognized as an effective means of assessing scientific progress[24, 25]. Information from online literature databases and metrology characteristics were analyzed via bibliometric analysis, which can be used to quantitatively and qualitatively evaluate the trends in the research community over time[26]. Comparison among the contributions of scholars, journals, institutions and countries could be shown through the bibliometric analysis[27]. Bibliometric analysis is also applied to policy making and clinical guidelines[28]. Moreover, efficient analysis has been applied successfully to make studies more intuitional, including exosomes[29], retina regeneration[30], stem cells for osteoarthritis[31], curcumin[32] and infect diseases[33]. The aim of our study is to assess the status and trends of mitochondrial dynamics research globally and discover the popular topics in the field.

Materials And Methods

Date source

Comprehensive bibliometric data and the SCI-EXPANDED, SSCI, A&HCI and ESCI citation index database were retrieved from the Web of Science (WOS) Core Collection, which is considered as the optimum database for bibliometrics[34] .

Search Strategy

The dataset from January 2000 to December 2019 was obtained from the WOS Core Collection. Theme words for searching were referred to MESH terms from PubMed, and the search term was as follows: ((TS="Mitochondrial Dynamics") OR (TS="Mitochondrial Dynamic") OR (TS="Dynamic of Mitochondria") OR (TS="Mitochondrial Fission and Fusion") OR (TS="Mitochondrial Fusion and Fission")) AND (Language = English) AND (Document type = Articles OR Reviews). The information about publications including research orientation, institutions, and funding were ameliorated by the data in the WOS.

Data Collection

The titles, years of publication, names of authors, nationalities, affiliations, keywords, names of publishing journals, abstracts of each record and citations within the publications downloaded from WOS, were saved as TXT files and imported into Microsoft Excel 2017. Any problem had been solved by consulting experts to reach a consensus.

Bibliometric And Visualized Analysis

Bibliometric analysis takes the advantage of bibliometric theory to analyze pertinent literatures through the use of mathematical and statistical approaches, which has become an important tool for global analysis and investigation in various scientific areas[35]. Basic characteristics of eligible publications, which were mentioned previously, were described through the intrinsic function of WOS. The H-index was regarded as an optimum measurement to evaluate the impact of scientific research and was proposed as an alternative to other bibliometric indicators[36]. The index of H means that H of a scientist's or a country's publications have been cited in other publications at least H times each[37], which reflects both the number of publications and the number of citations per publication[38]. Impact factors (IF) of all journals were obtained from the Journal Citation Reports of 2018.

Analytical Methods

The logistic growth model $\mathrm{f}(x) = \mathrm{a}/\left[1 + e^{b-cx}\right]$ was used to model the cumulative volume of documentation because of its great fitness and ability to predict the future trends[39, 40], where x represents the year and f(x) is the cumulative volume of papers by year. GraphPadPrism 5 (GraphPad Software Inc., CA, USA) was used to analyze the data including the time trend of the number of publications, the number of publications from different countries, institutions, funding agencies, research orientations, total citation frequency, average citation frequency and H-index. VOS viewer (Leiden University, Leiden, Netherlands) is a software tool for the visualized analysis of the publications[41], which was used for bibliographic coupling, co-authorship, co-citation and co-occurrence analysis.

Results

Analysis of global publications. Variations in the quantity of academic papers on a certain research field is a significant indicator for the development trend. Plotting the quantity of publications over time and conducting multivariate statistical analysis contribute to understanding the research level and future trend. A total of 2999 publications from 2000 to 2019 were derived from WOS database according to the search criteria. Most research was published in the last 10 years (2010–2019, 2,830, 94.36%). An increasing trend of global publications during the last 20 years was found, which shows the relative research of mitochondrial dynamics will be more and more concerned (Fig. 2c). Furthermore, Fig. 2d showed the logistic regression model fitting curves $\mathrm{f}(x) = 653.8847/\left[1 + e^{649.3359-0.3221x}\right]$ of the number of publications on mitochondrial dynamics research in the future per year. According to publications, the top 20 productive countries were listed in the Fig. 2b. USA (1184,38.542%) with the most number was the most contributor, followed by China (699，23.0%), Germany (235，7.65%), Italy (204，6.641%) and Canada (182，5.924%), the top 25 countries that had made the greatest contributions in mitochondrial dynamics research were shown in Fig. 2a, the darker the color, the more the number of publications. As expected, these productive countries are either economically developed or in a rapid development stage,

which attach great importance to scientific research. When it comes to the most contributive institutions, research orientations and funding, the ranking from WOS database were as followed respectively (Fig. 3): The Johns Hopkins University (59□1.921□), Chinese Academy of Sciences (53□1.725□) and Universitat de Barcelona (50□1.628□) and were listed in the top 3, and Cell Biology (930□30.273□), Biochemistry Molecular Biology (879□28.613□) and Neurosciences Neurology (505□16.439□) were listed in the top 3, and NIH (853□27.767□), HHS (853□27.767□) and NSFC (452□14.714□) were listed in the top 3.

Quality of publications of different countries. In regards to WOS database analysis, we tallied the total citations, average citations and H-index of each country (Fig. 4). Papers from USA had the highest number of citations (65,447), followed by Germany (1,1653), China (1,1569). At the same time, Papers from USA had the highest H-index (125). Germany ranked second in H-index (55), followed by China (52), Canada (49) and Italy (49). While the top 5 countries in average citation frequency were Israel (63.54), Switzerland (59.33), USA (55.28), Germany (49.59) and Canada (48.13).

Bibliographic coupling analysis. Bibliographic coupling analysis aims to find the relatedness of items based on the number of references they share and generate the knowledge domain map (KDM) of main research journals, institutions and countries in order to demonstrate the collaboration network among them in mitochondrial dynamics research. In Fig. 5, each sphere represents a journal, an institution and a country, and the sphere size represents the power of total link strength (TLS). The links between sphere represent the associations where the greater width of the link (namely link strength) means the closer correlation, which is also applied to co-authorship analysis, co-citation analysis and co-occurrence analysis. Sixty-six journals were shown in Fig. 5a in accordance with total link strength (TLS) and the size of sphere representing the power of journal in the research field of subchondral bone. The top 5 journals with the greatest total link strength were as follows: *Biochimica et Biophysica Acta (BBA) - Molecular Basis of Disease* (Impact Factor, IF = 4.328, 2018, TLS = 102,519 times), *Antioxidants & Redox Signaling* (IF = 5.828, 2018, TLS = 79,934 times), *PLoS ONE* (IF = 2.776, 2018, TLS = 71,751 times), *Mitochondrion* (IF = 3.449, 2018, TLS = 71,751 times) and *Journal of Biological Chemistry* (IF = 4.106, 2018, TLS = 60,878 times). There were 151 institutions shown in Fig. 5b based on papers with the minimum number of documents of an organization more than 10. Universitat de Barcelona (TLS = 172,099 times) ranked the first, followed by Case Western Reserve University (TLS = 169,681 times), The Johns Hopkins University (TLS = 142,157 times), Caltech (TLS = 155,568 times) and The University California, San Diego (TLS = 137,743 times). The top 5 countries based on papers with the minimum number of documents of a country more than 5 were shown in Fig. 5c, including USA (TLS = 2,625,487times), China (TLS = 943,403 times), Germany (TLS = 724,311 times), Italy (TLS = 603,911 times) and England (TLS = 550,749 times).

Co-authorship analysis. Co-authorship analysis aims to find the relatedness of items based on their number of co-authored documents and generate the knowledge domain map of main research authors, institutions and countries in order to demonstrate the collaboration network among them in mitochondrial dynamics research. Creating and analyzing the KDM of co-authorship network of productive authors, institutions and countries can provide valuable information for individual researchers to seek cooperation partners, for research organizations to develop cooperation groups, and for countries

to achieve the goal of academic exchanges. Authors, institutions and countries were analyzed via VOS viewer and 67 authors, 150 institutions and 45 countries were shown in Fig. 6. Zhu, XW (TLS = 52 times), Wang, XL (TLS = 52 times), Perry, G (TLS = 44 times), Reddy, PH (TLS = 38 times) and Chattipakorn, N (TLS = 38 times) were considered as the top 5 authors with the largest TLS. By the same way, the top 5 institutions with the TLS were as follows: The Johns Hopkins University (TLS = 54 times), McGill University (TLS = 48 times), Centre National de la Recherche Scientifique (TLS = 46 times), Universitat de Barcelona (TLS = 45 times) and Baylor College of Medicine (TLS = 44 times). Both authors and institutions were based on papers with the minimum number of documents of an author or organization more than 10. The top 5 countries with largest TLS based on papers with the minimum number of documents of a country more than 5 were USA (TLS = 614 times), England (TLS = 216 times), Germany (TLS = 210 times), China (TLS = 205 times) and Italy (TLS = 167 times).

Co-citation analysis. Co-citation analysis is purposed to determine the relatedness of items based on the number of times they are cited together. Through co-citation analysis, the important knowledge bases of the research field can be found efficiently and conveniently from the mass of cited references. Furthermore, the relevance of publications can also be analyzed and excavated. Papers with the minimum number of citations of a cited reference more than 50 were analyzed using VOS viewer and 336 references were shown in Fig. 7a. The top 5 were as follows: *The Journal of Cell Biology*. 2003. 160(2): 189–200[42].(TLS = 14,056 times), *The EMBO Journal*. 2008. 27(2): 433 – 46[43].(TLS = 12,836 times), *Molecular biology of the cell*. 2001. 12(8): 2245-56[44].(TLS = 10,612 times), *Developmental cell*. 2001. 1(4): 515 – 25[45].(TLS = 10,325 times) and *Nature genetics*. 2000. 26(2): 207 – 10[46].(TLS = 9,976 times). Journals with at least 50 citations were analyzed through VOS viewer and there were 480 journals shown in Fig. 7b. The top 5 journals with the largest total link strength were following: *The Journal of Biological Chemistry* (TLS = 1,102,933 times), *Proceedings of The National Academy of Sciences of The United States of America* (TLS = 900,746 times), *Journal of Cell Biology* (TLS = 807,056 times), *Cell* (TLS = 581,151 times) and *Nature* (TLS = 557,495 times). Papers with the minimum number of citations of an author more than 50 were identified and analyzed via VOS viewer and 468 authors were shown in Fig. 7c. The top 5 authors with the greatest total link strength were as follows: Chen HC (TLS = 67,672 times), Ishihara N (TLS = 35,069 times), Karbowski M (TLS = 34,765 times), Twig G (TLS = 31,575 times) and Wang, XL (TLS = 24,143 times).

Co-occurrence analysis. Co-occurrence analysis purposes to determine the relatedness of items based on the number of documents in which they occur together. Through the analysis, popular topics and directions were identified, which contribute to monitor and follow up the development of science research and programs[47, 48]. Keywords with the minimum number of occurrences more than 80 in all included publications were analyzed via VOS viewer. As shown in Fig. 8a, 62 identified keywords were classified into the 3 clusters: “Related disease research”, “Mechanism research” and “Cell metabolism research”. The results demonstrated that the most prominent fields of mitochondrial dynamics included the above 3 directions. For the “Related disease research” cluster, the primary keywords were Alpha-Synuclein, Amyloid-Beta, Alzheimer-disease, Parkinsons-disease, mitochondrial dysfunction and oxidative stress. For

the cluster of “Mechanism research”, frequently used keywords were Apoptosis, Cytochrome-c, Drp1, OPA1, Dynamin-related protein, Mitofusin 2, Mitochondrial fusion or fission. In the “Cell metabolism research” cluster, the main keywords were Activation, Autophagy, Metabolism, Mutation, Gene-expression and Degradation.

20,279Keywords were color coded by VOS viewer based on the average time they appeared in the total of 2999 publications (Fig. 8b). The blue color means the keywords appeared early and red colored keywords appeared later. Before 2012, most studies focused on “Saccharomyces-cerevisiae”, “Cytochrome-c release” and “Morphology”. The latest trends showed that “Mitofusin 2”, “Dynamin-related protein 1”, “Mitophagy”, “Biogenesis” and “Mechanism” would be concerned more widely in the future.

Papers with the minimum number of occurrences of a keyword more than 80 were identified and analyzed via VOS viewer. Density visualization map (Fig. 8c) was exported by VOS viewer. The times of occurrence of a key word was defined as the color of the area. The larger the tines, the warmer the color is. Blue corresponds with the lowest item density and red corresponds with the highest item density. “Fission”, “Fusion”, “Mitochondria”, “Oxidative stress” and “Apoptosis” were the most relevant keywords related to mitochondrial dynamics in general.

Discussion

1. **1. Trends in publications of mitochondrial dynamics research.** The present study purposes to assess mitochondrial dynamics research with visualized and bibliometric analysis, which can be applied to present the current status and make predictions in a certain research field. Dramatic progress in mitochondrial dynamics research especially in the last decade was analyzed in our study. The analysis witnessed significant annual increase in the total number of publications. As shown in our study, 68 countries and regions published articles and reviews in the field and the number of publications in the next few years could be predicted based on the current data. The results of our study also provide potential popularities in the field, which need further high-quality researches. Moreover, there will be more and more in-depth studies of mitochondrial dynamics and related articles will be published in the coming years.
2. **2. Status and quality of global publications.** Based on the results of the analysis about contributions of countries, USA was the most contributor to publications. In terms of publication number, the Johns Hopkins University, Cell Biology and NIH ranked first in institutions, research orientations and funding agency, respectively. In terms of total number of publications, total citation frequency and H-index, USA made the highest contributions to the research globally and could be regarded as the pioneer and the leading country in the field of mitochondrial dynamics research. However, Israel had the highest average number of citations and ranked 17th in H-index, which demonstrated that Israel was also an excellent contributor in mitochondrial dynamics research. As a result of the number of related publications, there was a mismatch between H-index and average number of citations, both were used for representing the quality of publications and the academic impact of a country. China ranked second in total number of publications, but was 18th in average citation frequency. The

reason why there was a discrepancy between the quantity and quality of publications may be because the Chinese academic evaluation system tends to focus on the quantity of publications instead of quality[49]. This policy prones researchers and doctors to publish articles more quickly, thereby the quality of studies was ignored. With the gradual increase in funding for research in China, the quality of studies will be improved dramatically to keep in step with global publications in the field.

Bibliographic coupling occurs when two works contain citations of the third work in their bibliographies. In our study, a similarity relationship among different publications was established by bibliographic coupling analysis in terms of journal, institution and country. *Biochimica et Biophysica Acta (BBA) - Molecular Basis of Disease*, *Antioxidants & Redox Signaling*, and *PLoS ONE* shown in Fig. 5a, may be the core journals of mitochondrial dynamics research. Latest research progress in this area are more likely to be reported by the aforementioned journals. Universitat de Barcelona with the most TLS was regarded as the leader institution in mitochondrial dynamics research. There were 4 institutions from USA in the top 5 list, which was consistent with the strength of USA in the field. This suggested that creating first-class research institutions played a significant and fundamental role in improving the academic level of a country. The authors, shown in Fig. 5c, may be the ones who contributed the most in the field and their further studies and latest publications should be closely monitored to obtain the latest advancement in mitochondrial dynamics research. The collaboration among different countries, institutions and authors were evaluated by co-authorship analysis and the top of results with higher total link strength showed that the authors/institutions/countries were willing to work with others. For example, Zhu, XW, The Johns Hopkins University and USA were the optimum choices for us to cooperate with. Co-citations analysis is utilized to assess the impact of a study by counting the number of times they were cited. The present results indicated that the mechanism studies about mitochondrial dynamics had the greatest total frequency of citation and many meaningful references were provided. *The Journal of Biological Chemistry* was the journal with the highest citation frequency in the field and the achievement of Chen HC, Karbowski M and Ishihara N were widely recognized.

1. **3. Focus of mitochondrial dynamics research.** According to the co-occurrence analysis, popular topics and latest research directions were identified. The map of a co-occurrence network was shown in Fig. 8a by analyzing the keywords appearing in title and abstract from all included studies. Three research directions were observed from the co-occurrence network map, including “Related disease research”, “Mechanism research” and “Cell metabolism research”. Our study could make a further clear for the trends of future research, even though the results were consistent with the common sense in the field. In the center of the co-occurrence map, in addition to “mitochondrial dynamics”, other keywords such as “Fission”, “Fusion”, “Mitochondria”, “Oxidative stress” and “Apoptosis” were shown with higher total link strength (Fig. 8c). The overlay visualization map (Fig. 8b) was the same as the co-occurrence map but in color. Different color stands for different years of the publications. Based on the results, “Mitofusin 2”, “Dynamin-related protein 1”, “Mitophagy”, “Biogenesis” and “Mechanism” may become the next popular subjects in mitochondrial dynamics research.

Meanwhile, the research in the mechanism of related diseases have been emerging widely in recent years. In addition, the mechanism of the treatment through mitochondrial pathway for related diseases may become a popular topic in the future.

2. **4. Strengths and limitations.** Publications on mitochondrial dynamics research in our study were retrieved from the Science Citation Index-Expanded Web of Science database, and the status and trends of mitochondrial dynamics research were assessed via bibliometric and visualized analysis, which was considered to be relatively objective and comprehensive. However, some limitations in our study have to be mentioned here. Publications in non-English were excluded, resulting in language bias. Additionally, studies published in 2020 were not included in this study and recently published high-quality articles might not be highlighted as a result of low citation frequency until now. Moreover, the document type was limited to articles and reviews. Therefore, further research should address the latest studies and other non-English publications, and include other types of documents as complete as possible.

Conclusion

The current study presented the global status and trends in mitochondrial dynamics research. The USA with the most contributions to the research plays a leading role in global research on mitochondrial dynamics. There was a discrepancy among the academic impact, the quality and the quantity of publications from China. *Biochimica et Biophysica Acta (BBA) - Molecular Basis of Disease* has the most publications related to the research. Notably, more and more studies about mitochondrial dynamics will be published in the coming years. The study of mechanism research and cell metabolism research will be concerned and scholars focusing on “Mitofusin 2”, “Dynamin-related protein 1” and “Mitophagy” are likely to be pioneers in this field and conduct the direction of future studies, which may contribute to a new clinical treatment for the related disease associated with the imbalance of mitochondrial dynamics.

Abbreviations

SCI-E = Science Citation Index-Expanded, WOS = Web of Science, oxidative phosphorylation (OXPHOS), IF = Impact factor, TLS = Total link strength, Mitofusion1 = Mfn1, Mitofusion2 = Mfn2, Optic Atrophy 1 = OPA1, Dynamin-related protein 1 = Drp1, Dynamin 2 = Dnm2, mitochondrial DNA = mtDNA, Charcot–Marie–Tooth disease type 2A = CMT2A, Knowledge domain map = KDM.

Declarations

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Authors' contributions

XM and CX conceived the research; XM and XL collected the data; XL and PF drafted the article and revised it carefully.

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Availability of data and materials

The data from the review are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Ethical approval of the study was not necessary.

Consent for publication

Not application.

Competing interests

The authors declared that there is no conflict of interest in this work.

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Figures

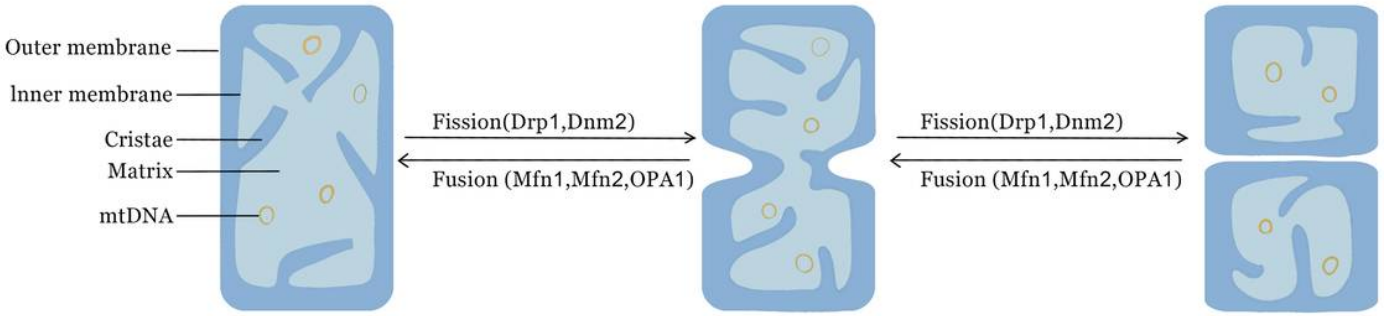

Figure 1

Schematic diagram of mitochondria and mitochondrial dynamics. Major components of mitochondria include outer membrane, inner membrane, cristae, matrix and mtDNA. Mitochondrial fusion is mediated by Mfn1, Mfn2 and OPA1. Mitochondrial fission is mediated by Drp1, Dnm2.

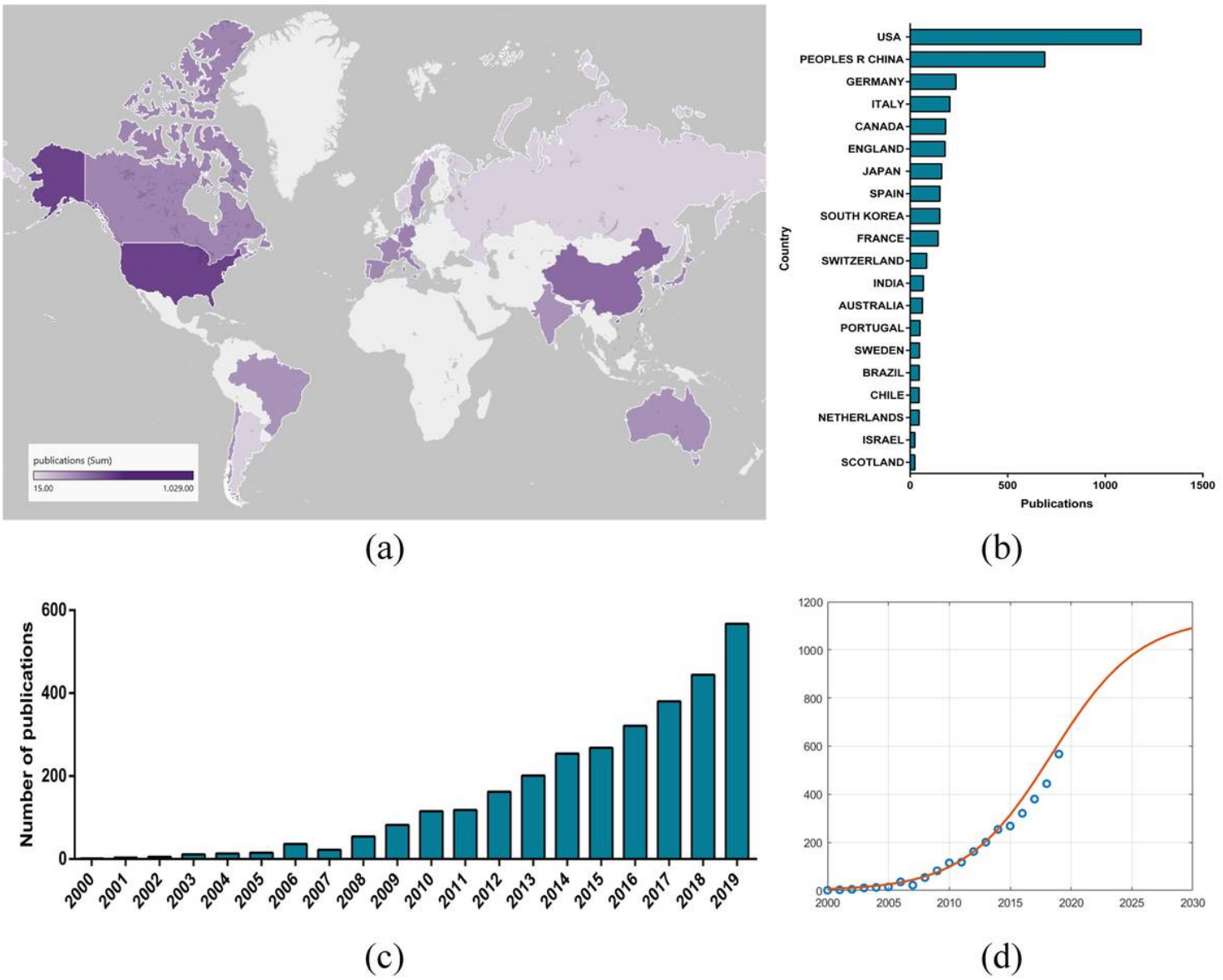

Figure 2

Global trends and contributed countries on mitochondrial dynamics research. (a) World map showing the distribution of mitochondrial dynamics research, in which the different color depths represent the different numbers of publications in different countries. (b) The sum of publications related to mitochondrial dynamics research from 20 countries or regions. (c) The annual number of publications related to mitochondrial dynamics research in the past 20 years. (d) Model fitting curves of growth trends of accumulated number of publications on mitochondrial dynamics research.

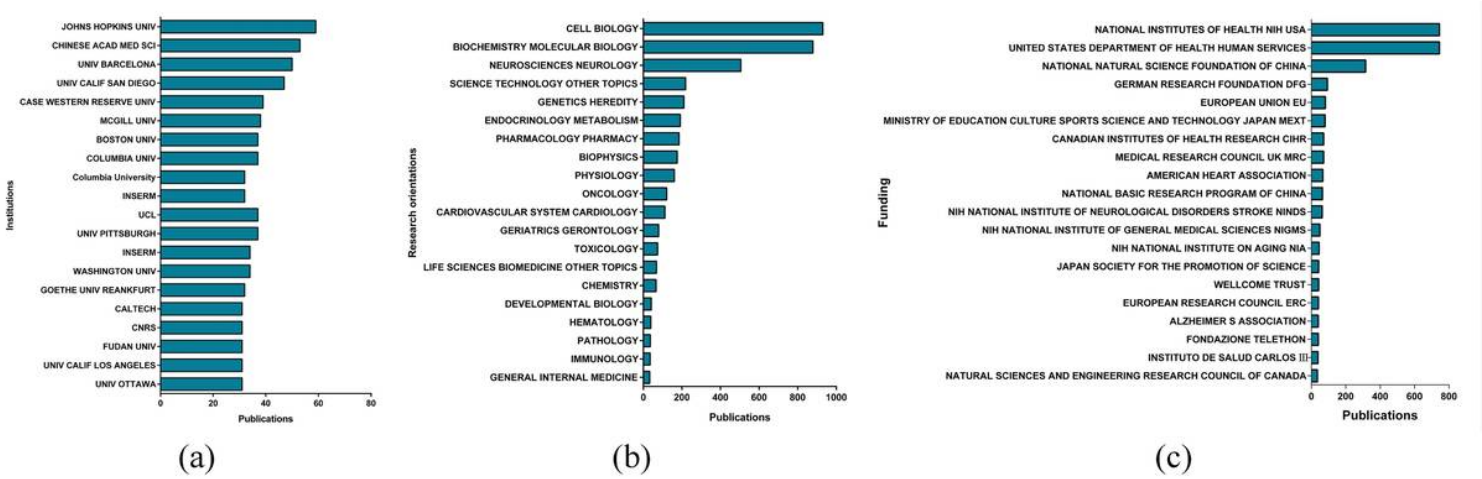

Figure 3

Institutions, research orientations and funding. (a) The most contributive institution with the most publications in mitochondrial dynamics research. (b) The most popular research orientation about mitochondrial dynamics. (c) The major contributive funds for mitochondrial dynamics.

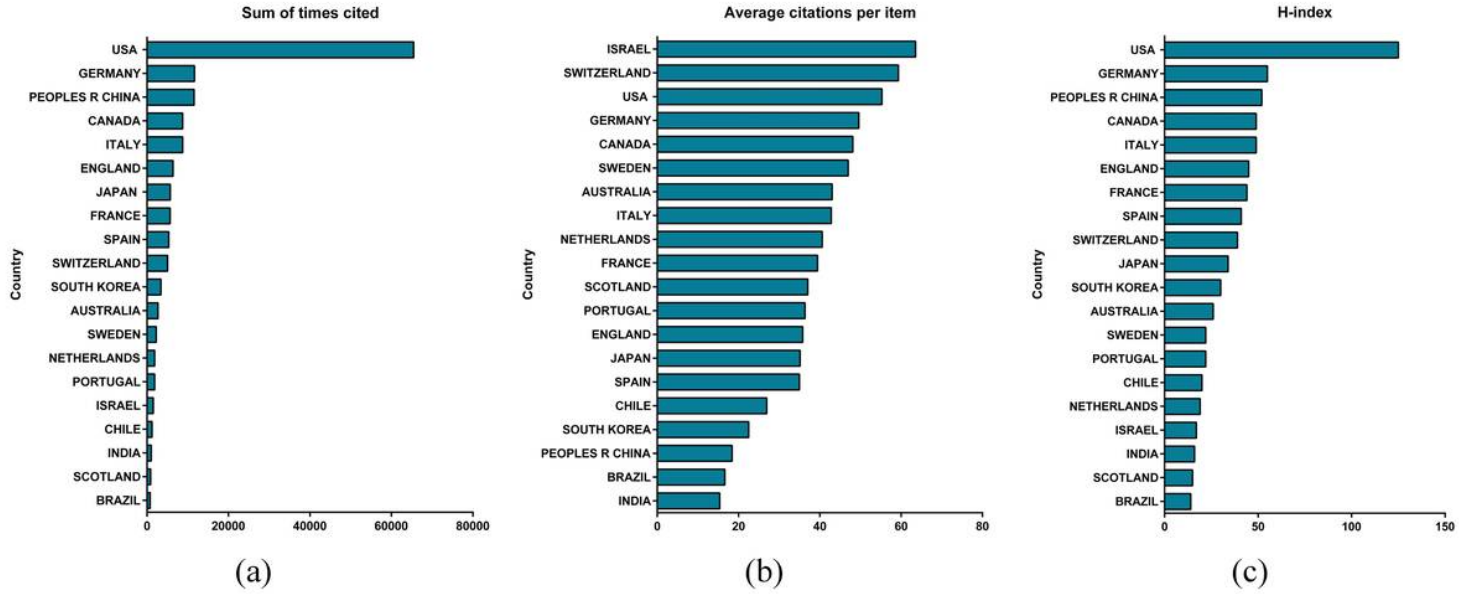

Figure 4

Citation frequency and H-index levels of different countries. (a) The total citations for mitochondrial dynamics research publications from different countries. (b) The average citations per paper for publications from the different countries. (c) The H-index of publications in the different countries.

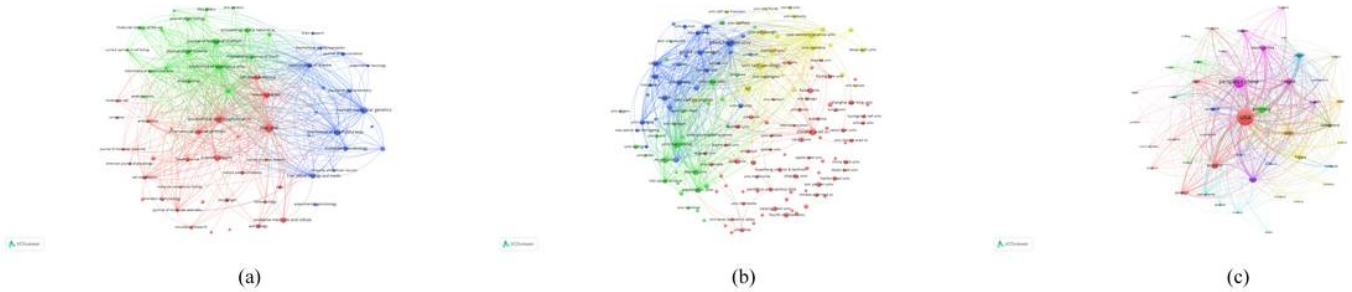

Figure 5

Bibliographic coupling analysis of global research about mitochondrial dynamics. (a) Mapping of the 63 identified journals on mitochondrial dynamics research. (b) Mapping of the 151 institutions on mitochondrial dynamics research. (c) Mapping of the 44 countries on mitochondrial dynamics research. The line between two points in the figure represents that two journals/institutions/countries had establish a similarity relationship. The thicker the line, the closer the link between the two journals/institutions/countries.

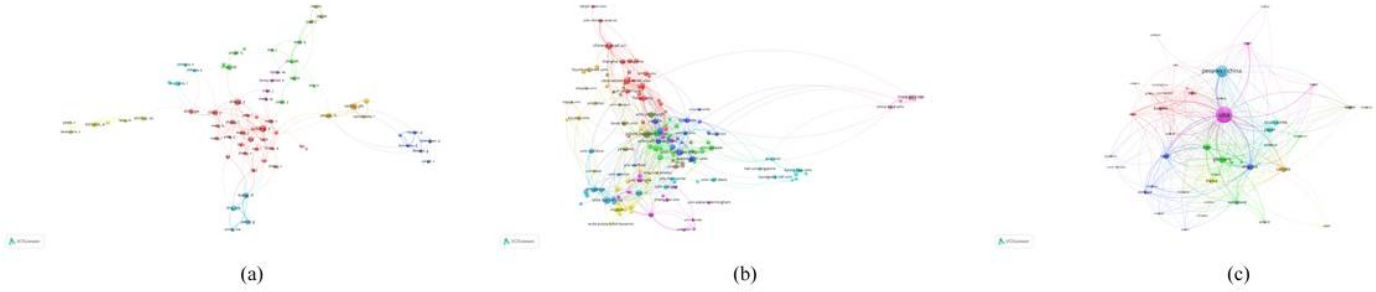

Figure 6

Co-authorship analysis of global research about mitochondrial dynamics. (a) Mapping of the 67 authors co-authorship analysis on mitochondrial dynamics research. (b) Mapping of the 150 institutions co-authorship analysis on mitochondrial dynamics research. (c) Mapping of the 45 countries co-authorship analysis on mitochondrial dynamics research. The size of the points represents the co-authorship frequency. The line between two points in the figure represents that two authors/institutions/countries had establish collaboration. The thicker the line, the closer the collaboration between the two authors/institutions/countries.

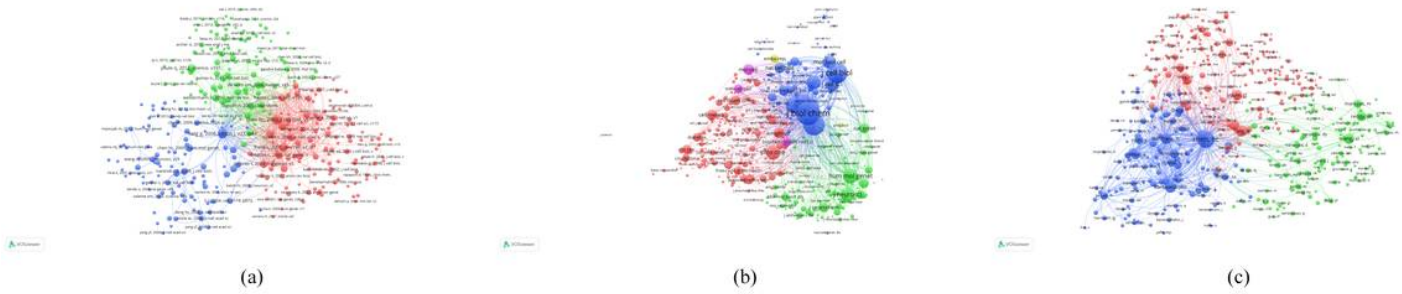

Figure 7

Co-citation analysis of global research about mitochondrial dynamics. (a) Mapping of co-cited references related to mitochondrial dynamics research. (b) Mapping of co-cited journals related to mitochondrial dynamics research. The points with different colors represent the cited references/journals. The size of the points represents the citation frequency. A line between two points means that both were cited in one paper/journal. A shorter line indicates a closer link between two papers/journals. (c) Mapping of the authors co-citation analysis on mitochondrial dynamics research. Points in the same color belong to the same research direction.

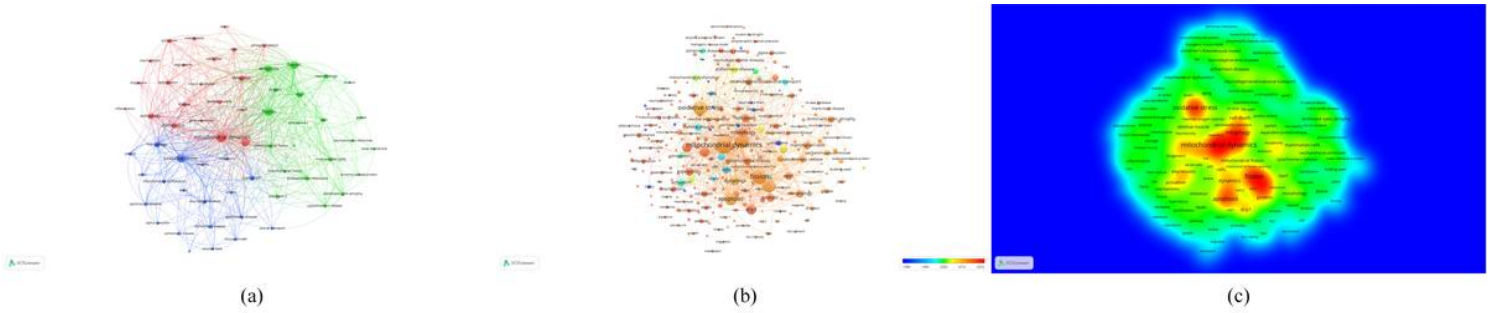

Figure 8

Co-occurrence analysis of global research about mitochondrial dynamics. (a) Mapping of keywords in the research on mitochondrial dynamics. The size of the points represents the frequency, and the keywords are divided into 3 clusters: “Related disease research” (upper in green), “Mechanism research” (right in blue) and “Cell metabolism research” (left in red). (b) Distribution of keywords according to the mean frequency of appearance. Keywords in blue appeared earlier than those in yellow and red colored keywords appeared later. (c) Density visualization map showed that “Fission”, “Fusion”, “Mitochondria”, “Oxidative stress” and “Apoptosis” were the most relevant keywords related to mitochondrial dynamics in general.

Supplementary Files

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