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Brief Communication

The research landscape of oxidative stress in osteoarthritis from 1998 to 2021: a systematic bibliometric analysis

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Abstract: Objective: A substantial body of literature pertaining to oxidative stress in osteoarthritis (OA) has been published over the past few decades. However, a comprehensive systematic analysis in this field is currently lacking. The objective of this study was to perform a bibliometric analysis to visualize the current research hotspots and evolving trends associated with oxidative stress in OA, in order to contribute to a more comprehensive understanding of this field. Methods: The raw data pertaining to oxidative stress in OA, published between 1998 and 2021, were obtained from the Web of Science Core Collection database (WoSCC). In order to provide comprehensive results across multiple dimensions, various bibliometric software tools were employed to quantify and analyze the research focuses and trends regarding oxidative stress in OA. Results: A total of 1178 original articles and reviews on oxidative stress in OA were included, with China and the USA emerging as the primary driving forces in this research field. Notably, Wenzhou Medical University stood out as the most prolific institution in terms of publication volume. Blanco FJ was the most prolific author, and the journal with the most publications was *Osteoarthritis and Cartilage*. The analysis of keyword burst detection revealed that the investigation of chondrocyte senescence induced by oxidative stress was the most frequent. Conclusion: The burgeoning body of literature pertaining to oxidative stress in OA has experienced a consistent growth over the past few decades, and this field will garner widespread attention and in-depth investigation. The frontier of chondrocyte senescence, as revealed by bibliometric analyses, represents a special focus of this field, with potential as a vital therapeutic target for OA.

Keywords: Oxidative stress, osteoarthritis, bibliometric analysis, chondrocytes, senescence, CiteSpace, VOSviewer

Introduction

Osteoarthritis (OA) is the most prevalent chronic and age-related musculoskeletal disorder, characterized by chronic synovitis, progressive degeneration of articular cartilage, and secondary osteophyte formation [1]. Approximately 350 million individuals worldwide are grappling with OA, and the number of individuals impacted by this condition is projected to rise alongside the aging population [2]. OA, as a leading cause of disability and morbidity, has emerged as a significant global public health concern, imposing substantial economic burden on both individuals and society. Up to now, a multitude of strategies have been employed to manage OA, encompassing conservative treatment, conventional surgical interventions, and minimally invasive surgery [3]. Unfortunately, there is no definitive cure for OA, and current therapeutic approaches primarily aim to alleviate symptoms. Thus, investigating the underlying mechanisms is crucial to uncover novel therapeutic targets for OA, and advance academic research.

The imbalance between reactive species and antioxidants, manifested as oxidative stress, has been extensively associated with various pathologic conditions [4, 5]. Increasing evidence indicates that oxidative stress can perturb chondrocyte metabolism and physiological cell signals, thereby expediting chondrocyte senescence and death [6, 7]. The investigation of potential functions of oxidative stress in OA has garnered significant attention, with numer-

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ous articles being published annually. However, no bibliometric analysis has been conducted to date. This could aid researchers in identifying research trends within this field.

The bibliometric analysis employs a fusion of mathematical and statistical methods, and data visualization techniques to offer a comprehensive evaluation [8]. In contrast to a conventional review, systematic reviews, and meta-analyses, only through bibliometric analysis can scholars rapidly identify research hotspots, discern development trends, and present a comprehensive overview of the distribution of countries/regions, authors, and journals within the research field [9, 10]. CiteSpace, VOSviewer, Scimago Graphica, and R-bibliometrix are extensively employed across various disciplines, capable of converting vast amounts of valid data into knowledge maps for countries/regions, authors, and journals within the research domain [11]. In this study, we conducted a bibliometric analysis of the hotspots and frontier trends in "oxidative stress in OA" research, spanning from 1998 to 2021, using CiteSpace, VOSviewer, Scimago Graphica, and R-bibliometrix. These results may serve as a resource for future research.

Materials and methods

Data retrieval strategy

We selected the Science Citation Index Expanded (SCI-Expanded) from the WoSCC to obtain the raw data within a day on 30th September 2022. The search query was constructed as follows: [TS = (Oxidative Stress OR Antioxidative Stress) AND TS = (Osteoarthritis OR Osteoarthrosis)], with the temporal scope limited from 1998 to 2021. The language of the literature was confined to English, and the types of literature primarily consisted of articles and reviews. Following the exclusion of online publications from 2022, a total of 1178 publications were selected for further analysis.

Bibliometric analysis and visualization

We imported the obtained data into CiteSpace (version 5.8.R3), VOSviewer (version 1.6.17), and R-bibliometrix for subsequent visualization analysis. CiteSpace is a freely accessible Java-based application, initially developed by Prof. Chaomei Chen in 2004 [12]. In the present study, CiteSpace was employed to visualize the co-occurrence of institutions, the reference timeline, and keyword citation bursts. Developed by Leiden University, VOSviewer software enables the creation of visualizing and exploring knowledge maps derived from original data [13]. Thus, we leveraged VOSviewer to generate knowledge maps of countries, authors, journals, and keywords. In addition, the annual publications were meticulously analyzed and visually depicted using Microsoft Office Excel.

Results

Growth trend of publications

The output of research publications on oxidative stress in OA has demonstrated an escalating trend, spanning from the initial publication in 1998 up to 2021 (**Figure 1A**). The number of publications experienced a gradual increase until 2015, followed by a steeper rise. During the period from 2015 to 2021, research on oxidative stress in OA reached a zenith, resulting in the publication of 891 articles, which accounted for approximately 74.2% of the total articles.

Distribution of countries/regions and institutions

The top 10 countries/regions and institutions associated with oxidative stress in OA are presented in **Table 1**. China topped the list of most productive countries with 404 published articles, followed by the USA (211) and Italy (79). In **Figure 1B**, the top 10 countries/regions are represented by distinct colors. It is demonstrated that China debuted with the first article in 2006, and the number of articles has experienced an overall growth, particularly since 2015. The United States, which initially paid attention to this field in 1998, was early to investigate the topic. Nonetheless, the proportion of articles published by the USA has exhibited a declining trend post-2020, and its preeminent position in publication has been surmounted by China since 2015. **Figure 2A** depicts the collaborative network among the top 25 countries/regions, indicating that the United States demonstrates the highest level of collaboration with other nations. Furthermore, **Figure 2B** displays a global map delineating the geographical distribution of publications associated with the investigation of oxidative stress

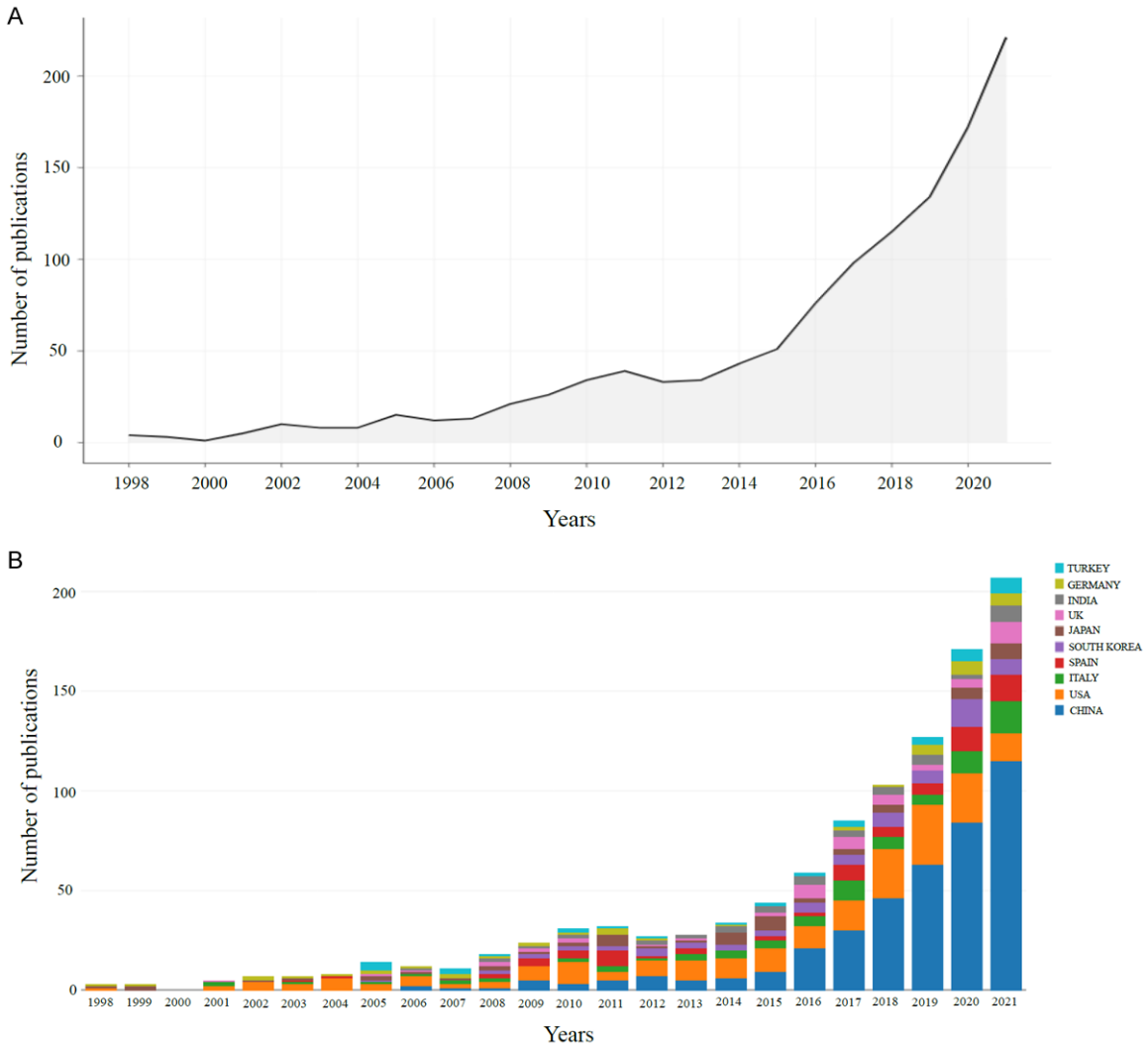

Figure 1. Trends in the number of publications (A) and the top 10 countries/regions (B) on oxidative stress in osteoarthritis research from 1998 to 2021.

in OA. The degree of blueness signifies the quantity of publications, while the thickness of the red line denotes the intensity of collaboration between countries/regions. The data suggests that the interaction between the United States and China is the most substantial. Interestingly, we observed that the volume of publications in Africa was significantly lower than in other regions, with many African countries even lacking any published works.

The top three institutions in terms of publication volume were Wenzhou Medical University (83), Xi'an Jiao Tong University (45), and Zhejiang University (38), all of which are based in China (**Table 1**). However, the top three institutions in terms of centrality rankings are Wenzhou Med University (0.08), Sun Yat-sen University (0.06), and Soochow University (0.06). The paucity of centrality and density in the institutional cooperation network (**Figure 2C**) suggests that research institutions exhibit dispersal and are deficient in persistent collaboration.

Visual analysis of authors and author partnership

As illustrated in **Table 1**, Blanco FJ, the most productive author, contributed 25 articles accounting for 2.12% of the total articles, followed by Loeser RF (18) and Zhang Y (15). The authors with the highest H-Index include Blanco FJ (15) and Loeser RF (15), emphasizing their

Table 1. Top 10 countries/regions, institutions, and authors that have contributed most to oxidative stress in osteoarthritis between 1998 and 2021

Rank	Country	Np	Institutions	Np	Centrality	Author	Np	H-index
1	China	418	Wenzhou Med Univ	83	0.08	Blanco FJ	25 (2.122)	15
2	USA	211	Xi'an Jiao Tong Univ	45	0.01	Loeser RF	18 (1.528)	15
3	Italy	79	Zhejiang Univ	38	0.04	Zhang Y	15 (1.273)	10
4	Spain	72	Nanjing Med Univ	32	0.01	Wang XY	13 (1.104)	8
5	South Korea	67	Iran Univ Med Sci	24	0.02	Alcaraz MJ	11 (0.934)	10
6	Japan	58	Taipei Med Univ	24	0.05	Haqqi TM	11 (0.934)	11
7	India	42	Univ Bologna	24	0.01	Wang J	11 (0.934)	7
8	Englan	42	China Med Univ	23	0	Benderdour M	10 (0.849)	9
9	Germany	41	Catholic Univ Korea	21	0	Borzi RM	10 (0.849)	9
10	Turkey	38	Guangxi Med Univ	21	0	Li X	10 (0.849)	8

Np, the numbers of publications.

invaluable contributions to the field. **Figure 2D** is partitioned into five clusters based on author collaborations, incorporating 32 nodes representing distinct authors. Loeser RF and Blanco FJ are situated at the core of the author partnership network.

Visual analysis of journals

The average year of all publications in a journal is presented **Figure 3A**. The rectangles depicting red color signify that the journals have been actively engaged in the research of oxidative stress in OA within recent times. Accordingly, journals such as *Antioxidants*, *Food & Function* and *International Journal of Molecular Sciences* were the most recent journals which concerned the research in this field. The mean frequency of citations for each related publication within the journal is depicted in **Figure 3B**. The color gradient from blue to red signifies journals that exhibit a higher average citation rate. The findings indicate that articles published in *Arthritis & Rheumatology*, *Nature Reviews Rheumatology*, *Biochemical Pharmacology*, and *Current Opinion in Rheumatology* are most frequently cited.

Visual analysis of co-cited references

The delineation of co-cited references through cluster analysis enables scholars to identify crucial focal points and the underlying knowledge base with greater efficiency. **Figure 3C** displays a temporal visualization of the clustering plot, effectively capturing the dynamic evolution of research hotspots over time. Obviously, Cluster #0 (cell senescence) exhibits the largest nodes along the timeline in 2016, and the recent clusters including Cluster #0 (cell senescence) and Cluster #3 (senescence), suggest that senescence constitutes the most prominent hotspot in the research on oxidative stress in OA.

Visual analysis of keywords and keywords burst

Figure 3D visualizes the co-occurring keywords, with items appearing more than 15 times being categorized into five clusters, namely pathogenesis, signaling pathways, molecular mechanisms, therapy, and biochemical characteristics. The top 25 keywords with the strongest citation burst are presented in **Figure 3E**, with their duration represented by the red-colored bar. The exploration of research themes can be categorized into two stages based on the keywords burst. The initial phase, spanning from 2002 to 2016, was primarily centered on the investigation of the oxidative stress mechanism in OA. The subsequent phase, covering the period from 2017 to 2021, was primarily focused on unraveling the senescence mechanism induced by oxidative stress in OA.

Discussion

The published literature demonstrates a comprehensive growth trend, with a sharp increase since 2015. This suggests that research in this field has commenced a rapid development phase, attracting numerous scholars to engage in this line of inquiry in recent years. Consequently, the research in this field will undoubtedly remain a focal point, with the output of lit-

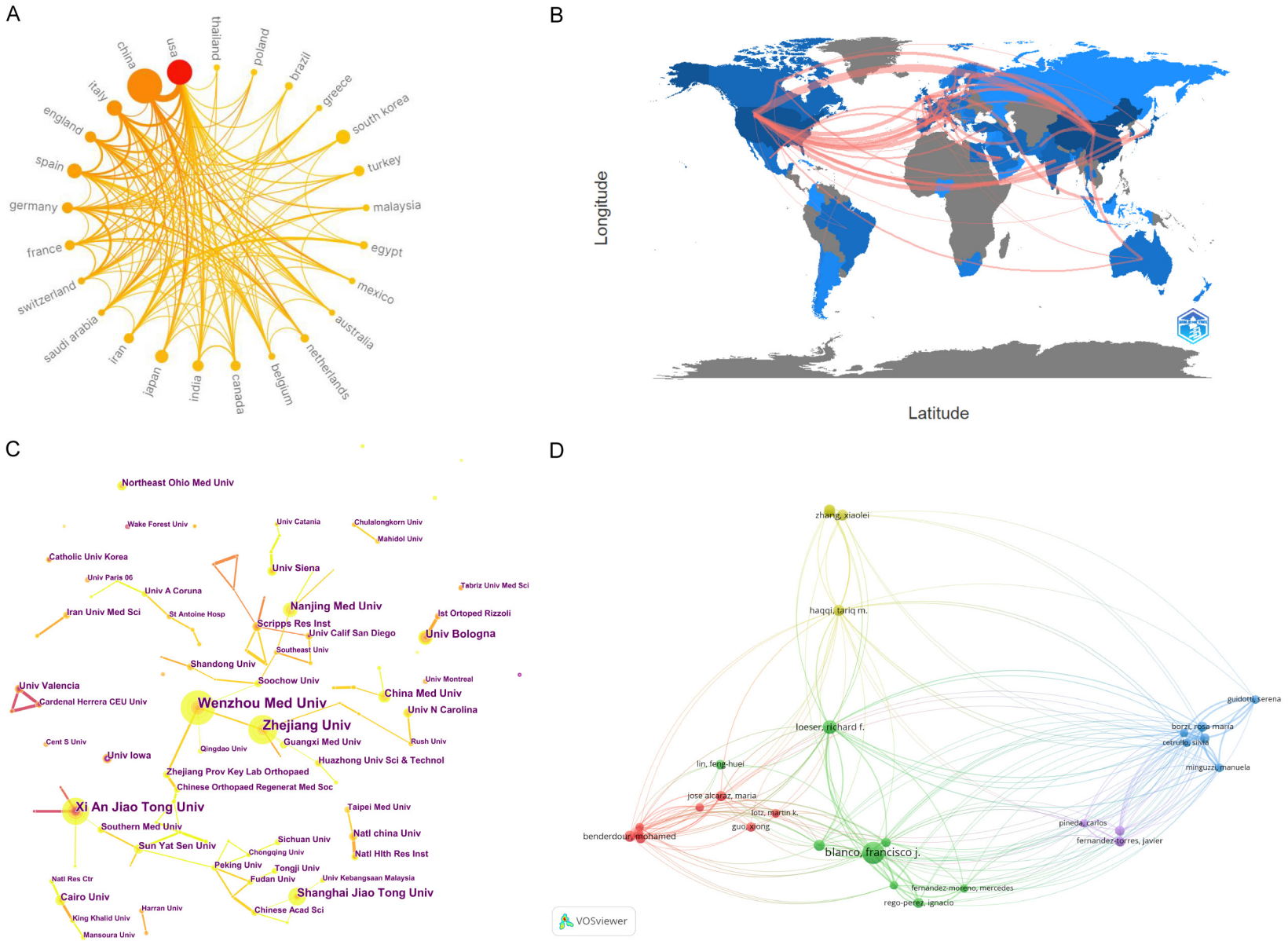
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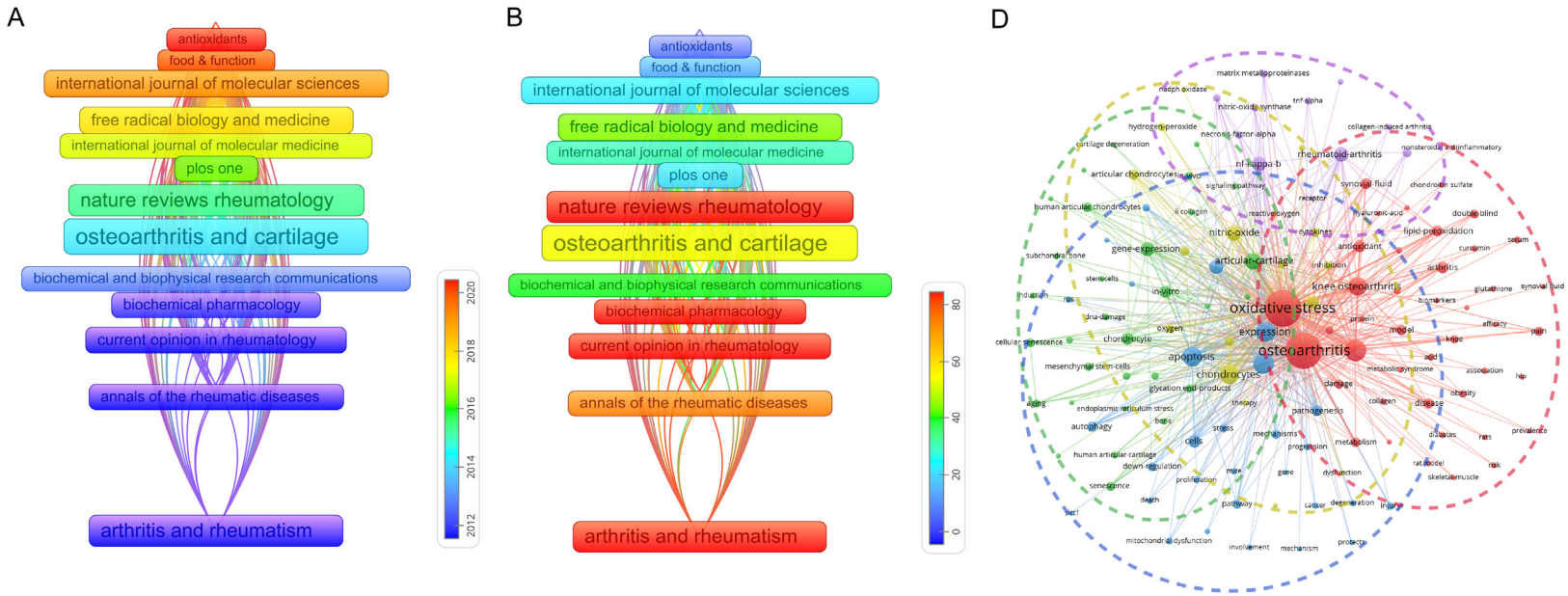
Figure 2. Contributions of various countries, institutions and authors to the research of oxidative stress in osteoarthritis. A. Cooperation network of the top 25 productive countries/regions. B. Geographic map in production and collaboration of countries/regions. A darker blue means more publications, and a thicker red line represents a stronger cooperation between countries/regions. C. Cooperation map of institutions to publications regarding research into oxidative stress in osteoarthritis. The size of node represents the sum of articles published by the institution, and the link represents their collaboration. D. Maps visualizing the authors' partnership. Each node represents an author, and the size of each node is proportional to the productivity of authors. Lines between two nodes represent the cooperation between two authors.



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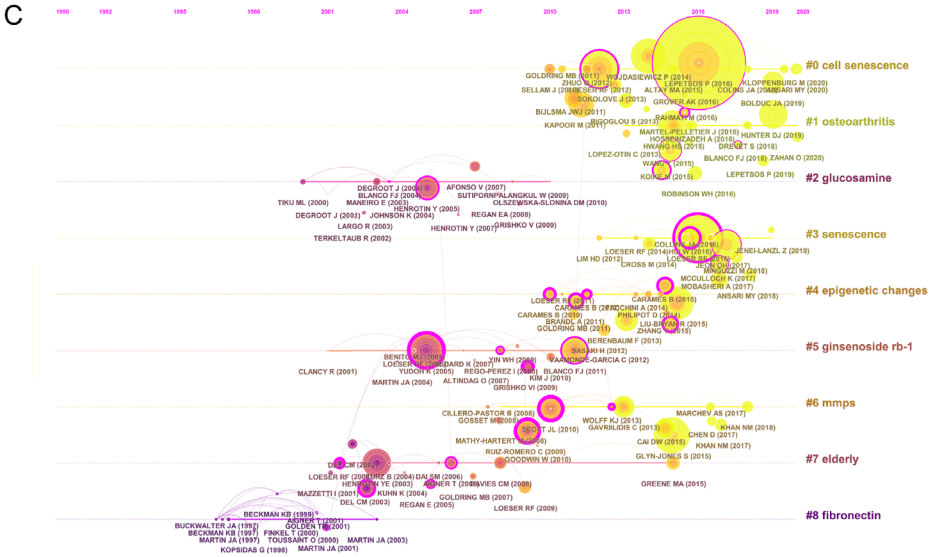

E

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	1998 - 2021
hydrogen peroxide	1999	7	1999	2013	
free radical	1999	5.39	1999	2011	
superoxide dismutase	2001	4.49	2001	2014	
lipid peroxidation	2001	8	2005	2013	
oxygen	2005	7.44	2005	2013	
antioxidant	2007	4.93	2007	2011	
human articular chondrocyte	2001	8.85	2008	2016	
nitric oxide	1998	7.94	2008	2010	
damage	2008	5.2	2008	2011	
rheumatoid arthriti	1998	4.56	2008	2016	
cell death	1999	4.5	2008	2013	
down regulation	2009	6.39	2009	2016	
vitamin e	1999	5.06	2009	2012	
disease	2001	5.93	2012	2015	
gene expression	2002	10.48	2016	2017	
arthriti	1999	5.29	2016	2018	
synovial fluid	2001	5.53	2017	2019	
pathogenesis	1998	4.8	2017	2018	
in vitro	2002	4.33	2017	2018	
model	2013	10.96	2018	2021	
cell	1998	4.6	2018	2021	
inflammation	1999	12.03	2019	2021	
pathway	2019	11.32	2019	2021	
cellular senescence	2005	8.27	2019	2021	
mechanism	2001	7.11	2019	2021	

Figure 3. A. Average year of all publications in a journal represented by different color. B. Average citations of high productive journals regarding research into oxidative stress in osteoarthritis. The color evolution from blue to red denotes the journal with higher average rate of citations. C. Timeline view of co-cited references with cluster labels. This cluster analysis presents the differences in the appearance time point and time span of those clusters. D. The distribution of the keywords' occurrence per year on oxidative stress in osteoarthritis. The nodes represent the keyword, and the sizes of the nodes are determined by the frequency of co-occurrence for each keyword. E. Top 25 keywords with citation burst. The bars colored with red represent their duration time.

erature anticipated to exhibit a consistent growth trend in the coming years.

The distribution of publications across countries/regions indicates that China ranks as the most productive nation, followed by the USA. The aggregate publication output of these two countries constitutes approximately 615, surpassing half of the total. This highlights the preeminent positions held by China and the USA in this field. The findings also indicate that economic development significantly influences academic achievement to a certain extent. This makes it particularly crucial for countries with limited research capabilities to prioritize economic growth in order to foster a conducive academic environment. The centrality of Wenzhou Medical University ranked highest among the top 10 institutions, suggesting that it plays a pivotal role in the network of institutional cooperation. Although a few countries such as China and the United States have established close cooperative relationships, the majority of countries and institutions operate independently and research foci are scattered. This indicates that there is a lack of academic cooperation among research nations and institutions. Accordingly, it is advisable for the countries and research institutions to intensify academic collaboration in order to accelerate the progress of research in this field.

Loeser RF and Blanco FJ played a crucial role in the outstanding publications making the most substantial contribution to the research of oxidative stress in OA. Loeser is particularly interested in determining how reactive oxygen species regulate chondrocyte signaling downstream of integrins, cytokines and growth factors through the oxidation of specific cysteine residues in kinases and phosphatases as well as other intracellular proteins. Meanwhile, he and his research group are concentrating on investigating how oxidative stress, which occurs concurrently with aging and joint injury, may influence the functionality of these signaling pathways.

The citation rate serves as an objective and equitable indicator to assess the scholarly impact of journals. In this research, *Arthritis & Rheumatology* and *Nature Reviews Rheumatology* were the most cited journals. Accordingly, those journals exert the most significant academic influence within this domain. The articles published in these journals are generally acknowledged by research scholars. The most recent journals in this field include *Antioxidants*, *Food & Function* and *International Journal of Molecular Sciences.* Hence, those journals have increasingly focused on the study of this field in recent years, and the research outcomes related to oxidative stress in OA are more often published in these journals.

The results of the keyword burst detection demonstrated that the investigation of the senescence mechanism induced by oxidative stress in OA has been a cutting-edge and hotspots in recent years. Furthermore, cluster analysis of co-cited references also suggests that senescence is a prominent focus in recent research on oxidative stress in OA.

Oxidative stress represents an imbalance between reactive oxygen species (ROS) and antioxidants. The presence of unpaired electrons in ROS endows them with high reactivity and instability. Although the highly reactive ROS could oxidize cellular macromolecules such as nucleic acids, proteins, and lipids, the physiologic level of ROS is crucial for maintaining cellular function, including signal transduction and gene regulation [14]. Unfortunately, excessive ROS generated by various pathologic processes may perturb cellular homeostasis or may pose health risks. In pathological conditions, an excessive production of ROS in chondrocytes can accelerate the progression of OA by inhibiting the synthesis of extracellular matrix, activating matrix metalloproteinases, and triggering chondrocyte death [15]. Moreover, it was reported that ROS could facilitate chondrocyte senescence and death by regulating the expression of p53 and p21, while also activating p38, MAPK, ERK, and the phosphatidylinositol 3-kinase/Akt (PI3K/Akt) signaling pathways [16, 17]. Chondrocyte senescence, characterized by telomere shortening and cell growth arrest, as a critical hallmark of aging, significantly contributes to the pathogenesis of OA. Oxidative stress can contribute to the progression of OA by abbreviating telomeres and diminishing the replicative capacity of chondrocytes, thereby accelerating cellular senescence [18]. The most prevalent etiology leading to mitochondrial dysfunction is senes-

cence, which disrupts the redox equilibrium of mitochondria and enhances ROS generation in chondrocytes [19]. The excessive generation of ROS triggered by senescence can oxidize both genomic and mitochondrial DNA, which, in turn, exacerbates the senescence of chondrocytes and arrests their proliferation [20]. These results indicate that the senescence of chondrocytes triggered by oxidative stress may facilitate the advancement of OA, and employing antioxidants to counteract oxidative stress could emerge as a promising therapeutic approach for managing OA.

This is the first bibliometric analysis of "oxidative stress in OA", and some limitations should be mentioned. First, we selected the WoSCC as the exclusive source for literature collection. While the WoSCC is considered as the most comprehensive database, there are still publications that are not included in its scope. Second, the database is continuously updated, with an ever-increasing number of literature available. We obtained the literature covering the period from 2002 to 2021, and it is possible that more recent literature has not been included. The language to search was limited to English, which could have led to the overlooking of pertinent literature during data processing.

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Disclosure of conflict of interest

None.

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References

[1] Yao Q, Wu X, Tao C, Gong W, Chen M, Qu M, Zhong Y, He T, Chen S and Xiao G. Osteoarthritis: pathogenic signaling pathways and therapeutic targets. Signal Transduct Target Ther 2023; 8: 56.

[2] Safiri S, Kolahi AA, Smith E, Hill C, Bettampadi D, Mansournia MA, Hoy D, Ashrafi-Asgarabad A, Sepidarkish M, Almasi-Hashiani A, Collins G, Kaufman J, Qorbani M, Moradi-Lakeh M, Woolf AD, Guillemin F, March L and Cross M. Global, regional and national burden of osteoarthritis 1990-2017: a systematic analysis of the Global Burden of Disease Study 2017. Ann Rheum Dis 2020; 79: 819-828.

[3] Li J, Zhang H, Han Y, Hu Y, Geng Z and Su J. Targeted and responsive biomaterials in osteoarthritis. Theranostics 2023; 13: 931-954.

[4] Pizzino G, Irrera N, Cucinotta M, Pallio G, Mannino F, Arcoraci V, Squadrito F, Altavilla D and Bitto A. Oxidative stress: harms and benefits for human health. Oxid Med Cell Longev 2017; 2017: 8416763.

[5] Iddir M, Brito A, Dingeo G, Fernandez Del Campo SS, Samouda H, La Frano MR and Bohn T. Strengthening the immune system and reducing inflammation and oxidative stress through diet and nutrition: considerations during the COVID-19 crisis. Nutrients 2020; 12: 1562.

[6] Hui W, Young DA, Rowan AD, Xu X, Cawston TE and Proctor CJ. Oxidative changes and signalling pathways are pivotal in initiating age-related changes in articular cartilage. Ann Rheum Dis 2016; 75: 449-58.

[7] Ansari MY, Ahmad N and Haqqi TM. Oxidative stress and inflammation in osteoarthritis pathogenesis: role of polyphenols. Biomed Pharmacother 2020; 129: 110452.

[8] Smith DR. Bibliometrics, dermatology and contact dermatitis. Contact Dermatitis 2008; 59: 133-6.

[9] Xie L, Chen Z, Wang H, Zheng C and Jiang J. Bibliometric and visualized analysis of scientific publications on atlantoaxial spine surgery based on web of science and VOSviewer. World Neurosurg 2020; 137: 435-442, e4.

[10] Zhu H and Zhang Z. Emerging trends and research foci in cataract genes: a bibliometric and visualized study. Front Genet 2021; 12: 610728.

[11] Sood SK, Rawat KS and Kumar D. Analytical mapping of information and communication technology in emerging infectious diseases using CiteSpace. Telemat Inform 2022; 69: 101796.

[12] Chen C. Searching for intellectual turning points: progressive knowledge domain visual-

ization. Proc Natl Acad Sci U S A 2004; 101 Suppl 1: 5303-10.
[13] van Eck NJ and Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 2010; 84: 523-538.
[14] Juan CA, Pérez de la Lastra JM, Plou FJ and Pérez-Lebeña E. The chemistry of reactive oxygen species (ROS) revisited: outlining their role in biological macromolecules (DNA, lipids and proteins) and induced pathologies. Int J Mol Sci 2021; 22: 4642.
[15] Xu C, Zhai Z, Ying H, Lu L, Zhang J and Zeng Y. Curcumin primed ADMSCs derived small extracellular vesicle exert enhanced protective effects on osteoarthritis by inhibiting oxidative stress and chondrocyte apoptosis. J Nanobiotechnology 2022; 20: 123.
[16] Yu SM and Kim SJ. The thymoquinone-induced production of reactive oxygen species promotes dedifferentiation through the ERK pathway and inflammation through the p38 and PI3K pathways in rabbit articular chondrocytes. Int J Mol Med 2015; 35: 325-32.
[17] Nelson KJ, Bolduc JA, Wu H, Collins JA, Burke EA, Reisz JA, Klomsiri C, Wood ST, Yammani RR, Poole LB, Furdui CM and Loeser RF. H(2) O(2) oxidation of cysteine residues in c-Jun N-terminal kinase 2 (JNK2) contributes to redox regulation in human articular chondrocytes. J Biol Chem 2018; 293: 16376-16389.
[18] Liu L, Luo P, Yang M, Wang J, Hou W and Xu P. The role of oxidative stress in the development of knee osteoarthritis: a comprehensive research review. Front Mol Biosci 2022; 9: 1001212.
[19] Leduc-Gaudet JP, Hussain SNA, Barreiro E and Gouspillou G. Mitochondrial dynamics and mitophagy in skeletal muscle health and aging. Int J Mol Sci 2021; 22: 8179.
[20] McCulloch K, Litherland GJ and Rai TS. Cellular senescence in osteoarthritis pathology. Aging Cell 2017; 16: 210-218.