Int J Endocrinol Metab. 2023 January; 21(1):e131812. https://doi.org/10.5812/ijem-131812.

Published online 2022 December 31. **Review Article**

Scientific Publishing in Biomedicine: A Brief History of Scientific Journals

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Received 2022 September 18; **Revised** 2022 November 14; **Accepted** 2022 November 22.

Abstract

Scientific publishing, with about 350-year historical background, has played a central role in advancing science by disseminating new findings, generalizing accepted theories, and sharing novel ideas. The number of scientific journals has exponentially grown from 10 at the end of the 17th century to 100,000 at the end of the 20th century. The publishing landscape has dramatically changed over time from printed journals to online publishing. Although scientific publishing was initially non-commercial, it has become a profitable industry with a significant global financial turnover, reaching $28 billion in annual revenue before the COVID-19 pandemic. However, scientific publishing has encountered several challenges and is suffering from unethical practices and some negative phenomena, like publish-or-perish, driven by the need to survive or get a promotion in academia. Developing a global landscape with collaborative non-commercial journals and platforms is a primary proposed model for the future of scientific publishing. Here, we provide a brief history of the foundation and development of scientific journals and their evolution over time. Furthermore, current challenges and future perspectives of scientific publishing are discussed.

Keywords: Journal, History, Scientific Publishing, Scientific Paper

1. Context

Science is a continuous effort to understand the world and humans and grew out of mythology and philosophy (1). In fact, the method for separating ideas that worked from those that did not work was organized into science (2). The word "science" comes from the Latin word Scientia, meaning knowledge (3). In its older broad usage, the word science often meant knowledge in general. Still, by the 17th and 18th centuries, it meant systematic knowledge. In the 19th century, its modern and narrow meaning, i.e., a special kind of firmer and less fallible knowledge generated by scientists, was adopted (3-5). Scientific means "pertaining to science" (i.e., demonstrable knowledge) and is used to distinguish between scientific and everyday knowledge (5). In the Aristotelian sense, sciences were specialized branches of philosophy (5). William Whewell first proposed the word scientist in 1834, when he served as an anonymous reviewer for Quarterly review (5) and again in 1840 in his book, The Philosophy of Inductive Sciences, to describe a cultivator of science in general (5) and to be replaced the older term natural philosopher, which became obsolete in the period of increasing professionalization (4).

The word journal comes from the French word jour, meaning "day" (6). Early English usage of the word journal goes back to the 14th century (1355 - 56) and means "book of church services," in which passages for use on a specific day of the year were included (7, 8). In 1540, the meaning shifted to the daily record of commercial transactions (day book), and in 1552, it became associated with "the journey," a book containing notices concerning the daily stages of routes and other information for travelers (8). In 1565, it meant a record of public events that occurred day by day or on successive dates (7, 8). In 1610, it meant a record of events of personal interest for their own use (7, 8), and in 1728 "journal" became synonymous with "newspaper" and extended to any periodical publication (8). Nowadays, "journal" refers to a periodical issue on a time-frame basis, such as daily, fortnightly, monthly, or yearly (9). A scientific journal is a periodical publication aiming to provide a channel for scientific communication (10), and an "article" is considered a basic unit of research communication (11).

From the beginning of the scientific revolution in the 16th and 17th centuries, beginning in 1543 after the publications of two books by Nicolaus Copernicus (1473-1543) about the nature of the heavens and the human body (1), communication of scientific discoveries was done by two forms: (1) Self-published books and pamphlets and (2) personal letters to other scientists (12). Books constituted a collection of one's life work (12) and formed an integral part of the Renaissance (13). For example, William Harvey published his book (De Motu Cordis, meaning about the heart's motion) in 1628 in Frankfort in Latin (13). Letters were used to spread more timely results and claim priority for them (12). With time, letters took on a more communal form and often were shared between many scientists, providing the base for today's professional societies (12). By the end of the 18th century, books, in large part, were replaced by journals (13), and publication in a scientific journal became routine in the early 19th century (14). It should be noted that the term scientific journal is a creation of the early 19th century, and some prefer periodicals to refer to earlier periods (15).

Nowadays, almost all scientific advances occur through scientific articles (12), and scientific journals are the backbone of scientific communication (16, 17). Functions of a scientific journal include registration (i.e., establishing the precedence of an idea for authors), dissemination (i.e., providing access for the intended audience), certification (i.e., ensuring quality control by peer review), and archiving (i.e., maintaining the scientific record) (15, 16). Knowing the history of science helps science education, provides professional orientation, and makes science more understandable (18). Here, we provide a brief history of the foundation and development of scientific journals and their changes over time. Furthermore, current challenges and future perspectives of scientific publishing are discussed.

2. Birth of Scientific Journals

The publication of the first scientific journals dates back to about 358 years ago. In 1665, following the publication of *Le Journal des Sçavans* (Journal of the experts) in France (5 January 1665) and Philosophical Transactions in the UK (6 March 1665), scientific journals were borne (15, 19, 20). *Le Journal des Sçavans* (later named *Journal des Savants* (21)) is the oldest scholarly journal in the world; it was founded in Paris in 1665 by Denis de Sallo at the time of Louis XIV and is still active (22). Savant comes from the Latin "sapere" (to be wise), meaning "to know," referring to a person with detailed knowledge in some specialized field. This journal served as scholarly communication in the Republic of letters during the 17th and 18th centuries (22). The focus of Journal des Savants was primarily scientific but in the 19th century shifted from science toward belles-lettres (22).

Established in 1660 by Charles II (12, 13), The Royal Society of London founded *Philosophical Transactions* (23). Henry Oldenburg, the first secretary of the Royal Society, read letters from the society's monthly meetings and copied and sent them to members who could not attend the meetings (12). In March 1665, Oldenburg published a printed version of the papers presented in the meetings, and *Philosophical Transactions*, a monthly periodical, was born (12). "*Philosophical Transactions*" passed four stages from 1665 - 1800 (23): (1) Reports of events (1665 - 1700), (2) arguments over the results (1700 - 1760), (3) explaining unusual events (1760 - 1780), and (4) claims and experimental proofs (1790 - 1800). In addition, *Philosophical Transactions* published papers on medical topics between 1700 and 1750 (23). Finally, in 1887, it was divided into two sections related to mathematical and physical science (A) and biological science (B) (23).

3. Growth of Scientific Journals

De Derek J. Solla Price, providing the first attempt to quantify the growth of science, reported that science had had an exponential growth during three centuries (between 1665 and 1961), with the crude size of science tending to double about every 10 - 20 years (24). During the 17th to 20th centuries, active scientific journals grew by a rate of 3.46% per year, which means that the number of active journals has doubled every 20 years (25). In the 20th century, the growth rate was 3.23% in 1900 - 1940, 4.35% in 1945 - 1976 (the Big Science period), and 3.26% from 1976 to the present day (25). The exponential growth proposed by Price was held for about three centuries; however, it is not the case nowadays, where the number of scientific journals is less than predicted values (11) (Figure 1A). Critics of the Price model of scientific growth can be found elsewhere (21). As Figure 1A shows, the number of scholarly journals was about 10 at the end of the 17th century, which raised to about 100 at the end of the 18th century, to 10,000 at the end of the 19th century, and to 100,000 at the end of the 20th century.

Providing the accurate number of scholarly journals is difficult (21); the number of science periodicals was estimated to be about 30 - 90 in 1700 (21), 100 (14) or 755 (21) in 1800, 300 in 1833 (24), 1,400 in 1866 (15), 10,000 in 1900 (14), 50,000 in 1961 (24), 57,400 in 1977 (11), and 70,000 - 80,000 in 1995 (11). There are different estimates of the number

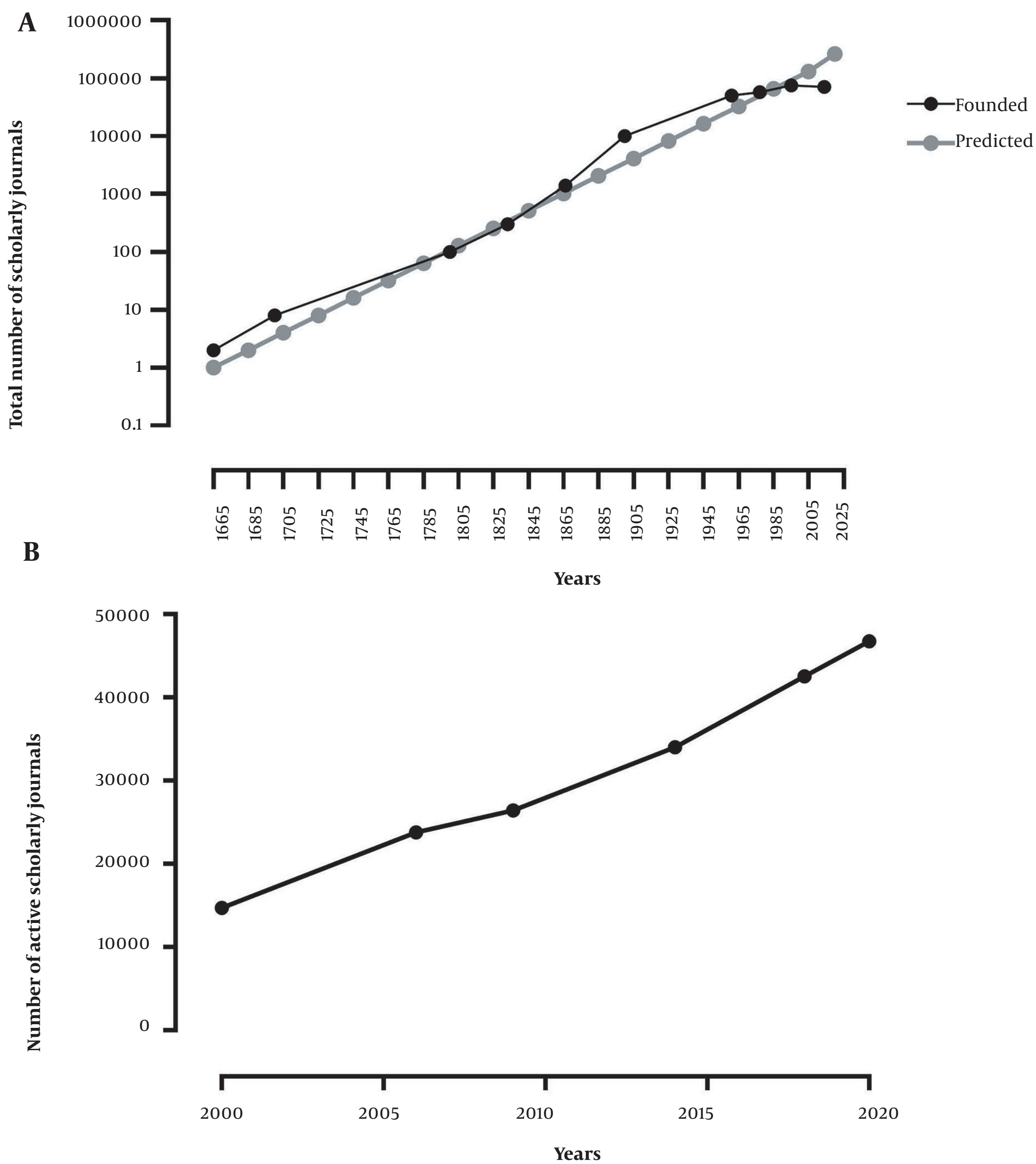

Figure 1. A, Increased number of scholarly journals from their birth (1665). The predicted number of journals ($2^{(\text{year} - 1665)/20}$) was calculated based on the assumption that the number of journals is doubled about every 20 years, as proposed by Price (see text for details); B, Increased number of active scholarly journals in the last two decades.

of scholarly journals; one explanation is that some estimations consider all scientific journals founded, whereas others include only active (those still publishing) peer-reviewed journals (25). The number of active scholarly peer-reviewed journals has been estimated to be 30,000 in 1961 (24), 14,694 in 2001 (25), 23,750 in 2006 (11), 26,406 in 2009 (11), 34,000 in 2014 (26), and 46,736 in 2020 (27), indicating a linear growth at least in the last two decades (Figure 1B). Currently, among 52,564 active journals in the field of biomedical sciences, 13,928 journals are indexed by the

Institute for Scientific Information (ISI), and 1,960 journals have an impact factor (IF) of zero. The last version of Journal Citation Reports (JCR) (i.e., JCR released annually by the ISI), reporting on the IF of 19,011 journals in 2022, attributes a journal's IF of 285 as the highest IF to "A Cancer Journal for Clinicians." The median journals' IF in 2022 is 2.766 (interquartile range: 1.646 - 4.508).

Considering that each journal published about 73 (11) or 74 (26) articles per year, the estimated number of published articles in 2020 would be 3.4 million; this is in line with the 2018 scientific, technical, and medical (STM) report of over three million articles published per year (28). However, the mean number of published papers per journal has increased from 74.2 in 1999 to 99.6 in 2016 (26).

On average, ~ 92% of founded journals remain active, and ~ 8% become one of three inactive journals, i.e., ceased, merged or incorporated, and suspended (29). About 88% of inactive journal titles are ceased (discontinued) journals for various reasons, i.e., publication concerns (i.e., concerns regarding the quality of editorial practices or other issues that have an impact on its suitability for continued coverage) and journal metrics (30), lack of financial support, low-quality submissions, or difficulty to find reviewers (31).

4. Science Transformation

Two types of science, the science of prototype and the science of neotype, coexist today (32). At the time of the foundation of the Royal Society of London (i.e., 1660), science was called natural philosophy (12). Scientists of the late 19th century and the first 20th century followed their curiosity even at their own expense (32). This type of science has been called the science of prototypes, which is almost always open-ended (32). Robert K. Merton has described norms shared by scientists of this type of science. According to Merton, scientists need to search for universal knowledge (universalism), pursue the truth in nature (disinterestedness), use critical tests to provide sufficiently reasonable evidence (organized skepticism), and publish their results to be available for everyone (communism) (32).

The science of neotype emerged in the second half of the 19th century. It is mission-oriented, in which organizations outside the scientific community present their missions to scientists, and scientists respond to them (32). In neotype science, research is usually conducted as a project, and the mission is not simply the goal of research but the goal of development (32). Norms covered by scientists of neotype science, as proposed by John Ziman, include proprietary, local, authoritarian, commissioned, and expertise. These norms are opposite to those norms of scientists of prototype science (32).

5. Over-time Changes in Scientific Writing

Since the birth of scientific journals, many changes have occurred in different aspects of scientific publishing, including language, structure and organization of papers, specialization of the scientific journals, and the practice of peer review, authorship, and citations (12). These changes are due to cultural, logistic, technical, and political factors; the emergence of new technologies, the exponential rate of discoveries, growing expectations of readers, reviewers, and editors, changes in reading behavior, and the emergence of new business models of publishing affected the scientific publishing environment (33).

5.1. Structure and Organization

Initial papers during the 17th and 18th centuries were in the form of letters and purely descriptive experimental reports (34). A universal method for the generation of the new science was enunciated by Francis Bacon (1561 - 1626) in his Novum Organum of 1620 (35). First, experiments were described in detail to allow readers to repeat them, which currently constitutes the Materials and Methods section of a research paper (23). By 1775, results were starting to receive interpretive discussion (36). In the 19th century, the organization of theory → experiment → discussion was typical, and methods were described in more detail (36). Around 1850, the modern pattern of referencing previous works appeared (24). Transformation of the scientific paper to its modern state was completed in the 19th century (24) when structured papers appeared (17), and its standardized structure known as Introduction, Methods, Results, and Discussion (IMRaD) evolved in the 20th century (34), especially after the Second World War (17).

Until 1945, medical papers were organized like a book chapter with headings associated with the subjects (34). After World War II, the IMRaD structure was proposed to standardize the reporting of research findings (23). Assessing 1,297 original articles from leading medical journals, Sollaci and Pereira reported no IMRaD article in 1935, while only 10% of all articles were presented in this form in 1950; but after 1965, this began to predominate (34). In 1978, the IMRad structure became a uniform technical requirement by several biomedical journal editors (International Committee of Medical Journal Editors (ICMJE)) (23). The *New England Medical Journal, the British Medical Journal, JAMA, and The Lancet* adopted the IMRaD structure in 1975, 1980, 1985, and 1985, respectively (34).

Analyzing more than 120 million publications in > 20,000 journals, with 528 million references and 35 million authors from 1900 to 2014, Fire and Guestrin (26) reported the following changes in scientific papers over time: increased title lengths (mean words: 8.71 in 1900 vs. 11.83 in 2014) (26), increased abstract lengths (mean words: 116.3 in 1970 vs. 179.8 in 2014), and the increased mean number of keywords and references per paper (26). In addition, the total number of self-citations and the percentage of papers with self-citations increased (26).

5.2. Authorship

The current role of authors in taking responsibility for the paper content was established in the 19th century (12). When learned periodicals replaced books in the 17th century, original publications were short papers by single authors (24), with multi-authored papers becoming popular from the second half of the 20th century (12). From the beginning of the 20th century, the mean and maximum number of authors of scientific papers (mean number of authors for a single paper: 1.41 in 1900 vs. 4.51 in 2014) and the number of hyper-authorship papers (papers with hundreds or even thousands of authors) have increased (26).

5.3. Peer Review

Peer review, in its broadest sense of the term, has existed since people began to identify and communicate knowledge (37). The first documented description of a peer review process to regulate the medical profession is attributed to the Syrian physician Ishaq bin Ali Al-Rahawi (854-931 A.D.). In his book, Ethics of the Physician (Adab al-Tabib) (38), Al-Rahawi indicated that a physician should write duplicate notes for patients and that after a patient's recovery or death, the physician's practice should be assessed according to the standards of the time (38). The first scientific journal that had peer review was the *Edinburgh Medical Journal*; its papers have been peer-reviewed since 1733 (13, 23). *Philosophical Transactions* had no peer review until 1752 (12). Following the Earl of Macclesfield's suggestion, a review committee was founded to assess all papers submitted to the journal before publication to improve the quality of articles (23).

During most of the 19th century, journal editors performed reviews, and the modern peer review process became common after World War II (1939 - 1945) (12). When the Xerox photocopier became commercially available in 1959, peer review was facilitated (35). Nowadays, peer review (refereeing) is an accepted method and best available practice of pre-publication scrutiny (39) and acts as a foundation (40) and an integral part (41) of publishing in the sciences. Peer review has been liked a journal's lifeblood (42). Constructive peer reviewer comments are necessary for the editorial process and help a scientifically sound paper improve (43).

5.4. Digital Transformation

Upon the introduction of the World Wide Web in 1991, web-based scientific publishing emerged, eliminating the need for printing journals; today, many journals no longer print on paper scientific articles but only electronically on the Web in formats, including hypertexts in the Hypertext Markup Language (HTML), Portable Document Format (PDF), and open e-book standard format (electronic publication, ePub) (44). In 1996, the "Electronic Submission and Peer Review (ESPERE)" system started and provided a good sample of a commercial manuscript management system (45). The internet offers a basis for scientists enabling them to publish all their thoughts, results, conclusions, and data, openly and widely available to everybody; in such a community, knowledge could flow quickly, regardless of institutions and personal networks (46).

5.5. Modes of Publishing

Over the last two decades, the publishing mode has rapidly changed from printed form and mailing journal hard copies to libraries/scientists to instant online digital access to scientific literature (47). Different publication models have been used by the publishers (48): (1) The subscription-based publishing model or paywall journals (the traditional model in which readers are typically required to pay for the content that they read), (2) the pure Open Access (OA) model (in which an article is made freely available online upon its publishing, and authors or their institute pays "Article Processing Charge" (APC)), and (3) hybrid model (in which journals offer authors to publish their article via subscription or OA model). The subscription-based publishing model was developed by books and periodicals in the 17th century (49). The OA movement began in the 1990s (50). The OA mode is now a common scientific publication strategy; it guarantees faster communication and discussion of scientific results and promotes transparency and insight for the public into scientific outcomes (46). The BioMed Central (BMC) and the Public Library of Science (PLOS) are for-profit and non-profit pioneers of OA publishers developed in the early 2000s and have remained successful OA publishing businesses to date (51). In 2000, OA journals and OA published papers increased by 18% and 30%, respectively (50).

The funding bodies like the National Institutes of Health (NIH), DFG in Germany, SURF in the Netherlands, and JISC in the United Kingdom have created rules for the openness of their funded research. They called for supporting projects to be OA and to develop appropriate infrastructure (52). Following the "Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities" in October 2003, the European Commission defined OA to scientific publications as a general principle of Horizon 2020, and all papers funded by Horizon 2020 were made freely available for the public (52). The Royal Society published a report in 2013 as "Science as an open enterprise," focusing on both "open publication" and "open access research data" (53). Several online databases for genomics, proteomics, and metabolomics are now publicly available, referred to as "Open Data" (54). The OA publishing not only resulted in new business models but also accelerated some critical changes in scientific publishing, e.g., the open interactive peer review model (52). However, some open questions need to be answered, and the main one is "who will financially support new models of scientific publishing?" (54).

Some believe that the current publishing model may distort science or make science inapplicable (55, 56) and propose different scenarios for the future of scientific publishing. Forcing to change scientific publishing entirely to OA, referred to as "Plan S," is one scenario that was initiated by a group of national research funding organizations, with the support of the European Commission and the European Research Council (ERC) (57). Reforming the current system of publishing and traditional model of peer review (which is criticized for its redundancy, inconsistency, sluggishness, and opacity) to a new model in which "publication is guaranteed, but pre-publication peer review still occurs, allowing the authors to revise their work following a mini pre-reception from the field" (58), is another proposed model.

5.6. Types of Articles

Different papers are published in scientific journals, including original research articles, case reports, technical notes, pictorial essays, reviews (e.g., narrative reviews, systematic reviews, meta-analyses), commentaries, and editorials (59). Compared to the original research papers, the reviews have little contribution to scientific publications (about 2.5% in the 1980s to 4.7% in the earlier 2000s) (60). Figure 2 displays the trend of total published documents and different types of scientific papers from PubMed resources within the last two decades (2000 - 2020). Except for clinical trials that show a plateau during recent years, the number of other paper types is increasing. During the past two decades, the number of clinical trials has increased only twofold, while the number of total articles published has increased threefold, and the number of systematic reviews and meta-analyses has increased 19fold.

5.7. Trends of Citations

The number of citations a paper receives is considered a measure of the paper's impact and quality. As reported by STM in 2018 (28), the distribution of papers' citations follows a Pareto pattern (the 80/20 rule), with about 80% of citations coming from about 20% of articles and 32% of papers remaining uncited. The number of citations is increasing faster than the number of publications; the mean citations per paper from the Web of Science database raised from 10.1 in 1999 to 11.8 in 2017. The growth of published papers, the growth in co-authorship, and longer reference lists of papers are among the most common reasons for the rising trend of citations worldwide (28).

6. Scientific Publishing Market

Although scientific publishing was initially a non-commercial practice and survived at the scientist's own expense (32), it has been changed into a hugely profitable industry with unusual business models (54). Although it differs from a traditional market in several aspects (e.g., the nature of payments), it presents the commodity (i.e., knowledge) from its producers (i.e., scientists) to its consumers (i.e., other scientists, administrators, physicians, patients, and funding agencies) (55). Scientific journals are now the products of a large industry, mainly in Western Europe and North America, comprised of for-profit and not-for-profit organizations, with a global annual turnover exceeding $25 billion in 2015 (44), $27 billion in 2018, and $28 billion in 2019 (27). The global market contracted to $26.5 billion in 2020, which is expected to regain its pre-pandemic (i.e., COVID-19 pandemic) value of $28 billion by 2023 (27). The costs of publishing a research article consist of submission, peer review, publication, indexing, and archiving, ranging from less than US$200 up to US$1000 per article (US$400 on average for a representative scientific paper) in modern and large-scale publishing platforms to prestigious journals with a high rejection rate of 90% (61).

7. The Challenges of Scientific Publishing

High subscription charges for accessing published papers that impose financial pressures on stakeholders of the publishing market, i.e., institutions and individuals such as clinicians and scientists, the over-tasked and unpaid editors and peer reviewers of the journals, the emergence of predatory or pseudo-journals, and increased rates of papers' retraction and plagiarism have become alarming concerns for scientific publishing (54).

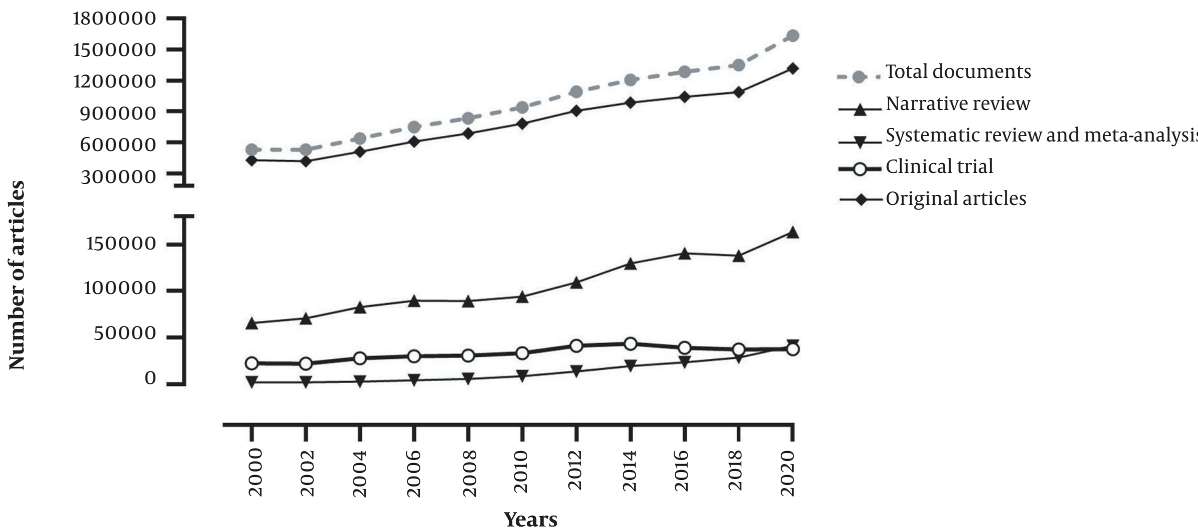

Figure 2. Trends of various types of published papers in PubMed from 2000 to 2020.

Predatory publishers and journals threaten the scientific community globally (62). The number of predatory publishers has increased from 18 in 2011 to more than 1,100 in late 2016; these publishers use journal titles similar to well-established journals, announce editorial boards that include members with prestigious but unverified affiliations, and present misleading metrics (63). The term predatory refers to entities that prey on academicians for financial profit via article processing charges for OA articles without external peer review, quality check, and meeting standard policies advocated by organizations like Committee on Publication Ethics (COPE) and the ICMJE (64). In 2017, 1,155 predatory publishers and 1,294 predatory journals were listed by Jeffrey Beall, a librarian at Auraria Library and associate professor at the University of Colorado Denver. It is now estimated that about 8,000 predatory journals annually publish more than 400,000 papers (64, 65).

Publication delay, the time gap between finishing data collection and publication, has increased over time from ~ 1.4 ± 0.2 years in 1912 to 2.6 ± 0.1 years in 2020 and 3.2 ± 0.1 in 2021 (66). Furthermore, biased peer review processes (38, 67) and unethical publishing practices such as plagiarism, data fabrication, manipulation, and data beautification (68, 69) are unsolved problems in scientific publishing. Publication bias, defined as "the tendency of investigators, reviewers, and editors to submit or accept manuscripts for publication based on the direction or strength of the study findings" (70), is one of the worst challenges threatening the validity of scientific research. Sterling initially conceptualized this term in 1959 when he observed that 97% of published papers in four major psychology journals had provided statistically significant results (71). About 50% of studies may not be published in a particular area of research, and the chance of remaining unpublished is about two-fold for statistically nonsignificant studies (null studies) (72). The tendency of publication bias was greater in observational and experimental studies compared to randomized clinical trials (OR = 3.79, 95% Cl = 1.47 - 9.76 vs. OR = 0.84, 95% Cl = 0.34 - 2.09) (72).

Emerging scientific publishing lobby (56), establishing the triad of "Publication, Power, and Patronage" (73), growing unfairness (e.g., authorship inequality) (74), and becoming scientific publishing a means of gaining position and academic promotion (75) may change scientific community and deviate science from its original mission. Deciding on hiring, promotion, and funding based on publishing in high-prestigious journals and productivity, and the "branding" (i.e., appreciating a research result and authors of a paper published in selective journals, independent of the manuscript's content) leads to an increased frequency of questionable research practices and false-positive results (55, 76, 77). Pressure on publishing as the gold standard of scientific productivity, which led to the "publish-or-perish" paradigm, may alter the actual reasons and motivations for publishing (47). Furthermore, the emergence of "follow-the-leader" behavior, a phenomenon that refers to replicating the papers published in prestigious journals, may lead to the neglect of novel ideas and an independent investigative path (55).

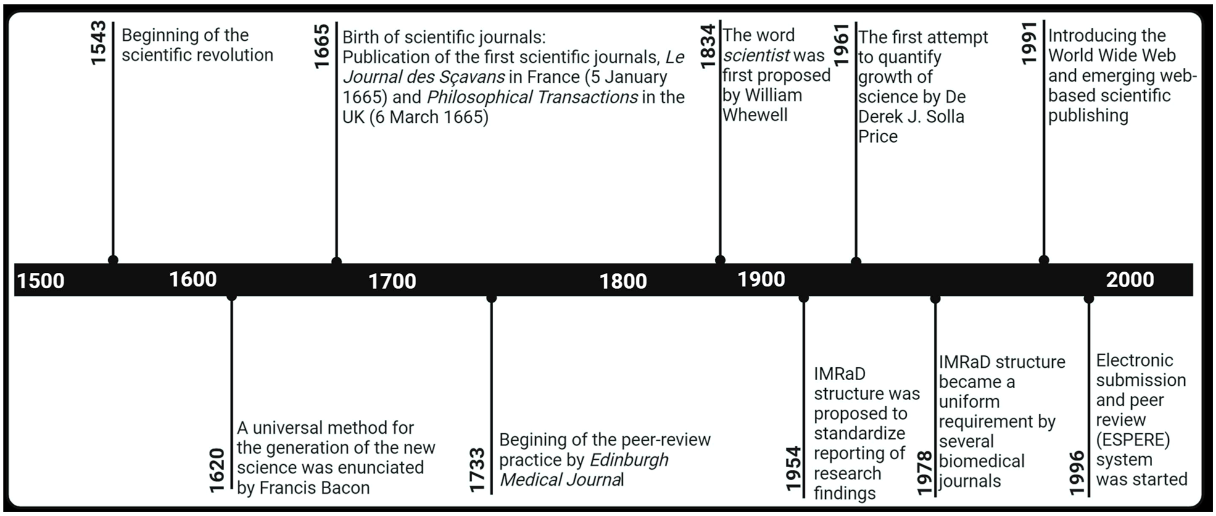

Figure 3. Main events in the history of scientific journals from 1500 to 2000 AD. Created with BioRender.com

8. Conclusions

Scientific journals are primary vehicles for communicating research results (21), published as scientific papers (78). The main events in the history of scientific journals are presented in Figure 3. According to the 2018 STM report, 42,500 active scholarly peer-reviewed journals published over three million articles annually (28). This number increased to 46,736 in 2020 (27). The total number of published peer-reviewed scholarly articles from 1665 was estimated to be about 50 million in 2009 (11). Scientific journals record scientific progress and provide foundations for new achievements, remembering the notion of Isaac Newton as he wrote in a Letter to Robert Hooke (5 February 1676): "If I have seen further, it is by standing on the shoulders of giants." (79).

Despite the long history of publishing scientific papers, there is still evidence of poor research documentation in the research findings report (80). This may be partly because some authors are unaware of the functions of a scientific article. Presenting scientific writing in the context of its evolving history to science students may help to overcome this issue.

Footnotes

Authors' Contribution: Study concept and design: Asghar Ghasemi and Zahra Bahadoran. Drafting of the manuscript: Asghar Ghasemi, Zahra Bahadoran, and Parvin Mirmiran. Critical revision of the manuscript for important intellectual content: Khosrow Kashfi and Parvin Mirmiran.

Conflict of Interests: We declare that two authors (A. Gh. and P. M.) are associate editors of the International Journal of Endocrinology and Metabolism.

Funding/Support: This study was supported by Shahid Beheshti University of Medical Sciences (Grant number 43003493), Tehran, Iran.

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