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Global research interest regarding silver diamine fluoride in dentistry: A bibliometric analysis

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ABSTRACT

Objective: This study aimed to investigate the global research interest regarding silver diamine fluoride (SDF) in dentistry using a bibliometric approach.
Methods: A literature search was conducted in the Web of Science Core Collection database to identify studies related to SDF. Bibliometric data from the selected publications were exported and analysed using the Bibliometrix Biblioshiny R-package software. The type of research and main contents of the publications were summarised. One-way analysis of variance was used to detect the differences in the citation counts of the publications with various types of research. In addition, Google Trends was used to investigate the popularity of the search term "silver diamine fluoride".
Results: A total of 259 publications were included and analyzed. The annual scientific production of SDF studies increased significantly per year in the past five years, and it mainly concerned dental caries. The three main types of research were laboratory/animal study ($n = 114$, 44%), review/guideline ($n = 56$, 22%), and clinical trial ($n = 44$, 17%). The citation count related to the type of research ($p < 0.01$). The citation count of clinical trials was significantly higher than that of laboratory/animal studies ($p < 0.05$). As quantified via data from Google Trends, the search popularity of "silver diamine fluoride" also increased significantly.
Conclusion: Based on the results of bibliometric analysis, global research interest regarding SDF has rapidly increased in recent years.
Clinical significance: This paper presents an overview of scientific evidence and impact of SDF use in dentistry. SDF attracts a growing interest globally and there has been a steady increase in scientific research into its use in dental practice.

1. Introduction

Silver diamine fluoride (SDF), also known as diammine silver fluoride, is an alkaline solution composed of diammine silver ions and fluoride ions [1]. The use of SDF in dental care is drawing increasing attention worldwide. Fluoride can promote the remineralisation of dental hard tissues by the deposition of a combination of fluorapatite and fluorohydroxyapatite on the tooth surface [2]. Silver ion plays an important role in inhibiting bacterial growth and dentine collagen degradation [3, 4]. The combination of silver and fluoride in an alkaline solution has a synergistic effect in arresting active dentine caries, which is an advantage of SDF over other topical fluoride agents [5]. SDF can also act as a desensitiser to reduce pain caused by dentine hypersensitivity [6]. The topical application of SDF on exposed dentine surface leads to the formation of deposits that partially plug dentinal tubules [7]. This could be related to its effect of reducing dentine hypersensitivity, as explained by the hydrodynamic theory of dentine hypersensitivity.

Bibliometric analyses use quantitative measures to assess the scientific impact of research as well as the impact of individual and group researchers in a particular field by using citation metrics, such as citation counts, lists of author productions, national or subject bibliographies, and publishing patterns [8]. Bibliometric data can be used to perform a structured analysis for voluminous information, infer changing trends over time, identify the dominant area of a research field (as well as its growth and development), detect the most prolific scholars and institutions, and present an overview of extant research [9]. In addition, by extracting the keywords and main content of selected

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studies, content analysis can be integrated into bibliometric analysis to provide more information that could help in identifying emerging and promising research fields [8]. Bibliometric analyses are widely used in various disciplines (such as social sciences, economics, and medicine) and have been used to analyse research trends in oral radiology, orthognathic surgery, and periodontics. Attention to SDF in dental care is increasing, but no bibliometric study has been conducted to assess and summarise the scholarly literature regarding the use of SDF in dentistry.

In the present study, we aimed to investigate the global research interest regarding SDF using a bibliometric approach.

2. Materials and methods

An electronic literature search was conducted in the Web of Science (WoS) database in December 2020. The search strategy was Topic= (“silver diamine fluoride") OR Topic= ("silver diammine fluoride") OR Topic= ("silver fluoride") OR Topic= ("diamine silver fluoride"). Two independent investigators screened titles and abstracts of potential references, and publications on SDF studies in dentistry were included. A publication was excluded if it was (1) not related to SDF (publications not pertaining to SDF), (2) a conference abstract, or (3) not a research article (e.g., comments, editorials, letters, communication, and news). The bibliometric data of the included publications were exported from WoS for analysis. Information was extracted from the abstracts and full texts of manuscripts regarding the type of research and the main content. In addition, Google Trends was used to investigate the popularity of the search query “silver diamine fluoride” across various geographic regions. The same two independent investigators performed publication inclusion and data extraction. In case of a disagreement on data inclusion and extraction, the two investigators reached a consensus through discussion with a third independent investigator.

2.1. Data analysis

The bibliometric data, including study title, citation count, citation density, year of publication, authorship, authors’ countries, institution of publication, and keywords, were obtained from the Clarivate Analytics WoS Core Collection. The bibliometric data were analysed using the Bibliometrix Biblioshiny R-package software (https://bibliometrix.org/Biblioshiny.html) [9]. Citation density, defined as the average number of citations per year, was calculated by dividing the total citation count by the number of years elapsed since the publication of the study. One-way analysis of variance (ANOVA) test was employed to compare the citation count of publications with different types of research using the SPSS software (Version 25, IBM SPSS statistics, USA). Multiple comparisons were conducted using the Bonferroni method. The statistical significance level was set at 0.05.

The Hirsch index (*h*-index) is defined as the number of papers with a

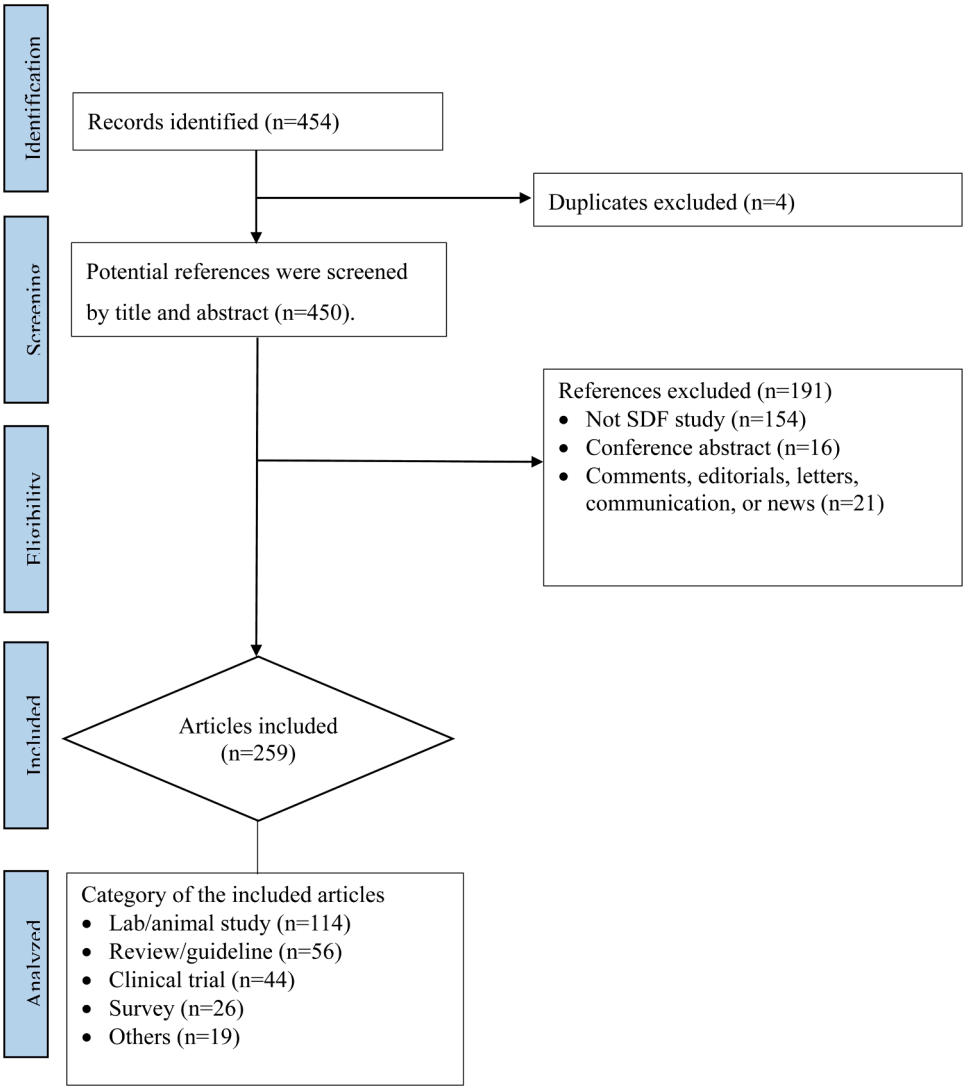

Fig. 1. Flow diagram of the protocol of the study.

citation count ≥h, which is a useful index to characterise the scientific impact of a researcher/journal [10]. In the present study, the *h*-index, was generated from the bibliometric data provided by WoS. We adopted the Bradford's law to cluster related journals: "If the journals are arranged in descending order of the number of articles they carried on the subject, then successive zones of journals containing the same number of articles on the subject form the simple geometric series $1:n:n^2:n^3$." The "first zone" defined by Bradford included the "core" journals devoted to a particular subject in a discipline [11]. International collaborations for SDF studies were quantified using the multiple country publication (MCP) and single country publication (SCP) scale.

3. Results

A total of 454 references were identified in the WoS database (Fig. 1). After removing duplicates ($n = 4$), the titles and abstracts of the references were screened, and 191 references were excluded for various reasons (not related [$n = 154$]; conference abstracts [$n = 16$]; or comments, editorials, letters, communication, or news [$n = 21$]). Finally, 259 publications were included in this study to investigate the global research interest regarding SDF (Appendix Table 1).

The annual scientific production of SDF studies and their citation counts have increased considerably in recent years (Fig. 2). Fourteen articles were published in 2017, and this markedly increased to 42, 52, and 59 in 2018, 2019, and 2020, respectively. The articles have increasingly been cited since 2016 (Fig. 2). In this collection of SDF publications, the highest citation count was 186, and the mean citation count per article was 16.3. The articles published in 2012 have obtained the highest total citation count (more than 700) (Fig. 3). Regarding the annual citation count (average citations per year since its first publication), the article published in 2002 was the highest with around 10 citations per year (Fig. 3). In fact, only one article was published in 2002; it reported a clinical trial comparing the effectiveness of SDF application with sodium fluoride varnish in arresting dentine caries in preschool children [12].

In addition, based on the data from Google Trends, the search popularity of "SDF" has increased significantly since 2016 (Appendix Fig. 1). The United States showed a high search interest, followed by Canada, Egypt, Australia, and India. The most common related search topics included "silver diamine fluoride-medication", "fluoride-chemical compound", "silver-chemical element", "dentistry-branch of medicine", and "tooth decay-syndrome". Users searching for "SDF" also searched for related queries. The most popular search queries were "SDF", "silver diamine fluoride code", "silver diamine fluoride application", "advantage arrest silver diamine fluoride", and "silver diamine fluoride staining".

The main type of SDF studies was laboratory/animal study ($n = 114$, 44%), followed by review/guideline ($n = 56$, 22%) and clinical trial ($n = 44$, 17%) (Table 1). The mean (± standard deviation) citation counts for clinical trial, review/guideline, and laboratory/animal study were 29 ± 41, 22 ± 36, and 13 ± 17, respectively. Based on logarithmic transformation of the data, the results of one-way ANOVA indicated significant differences in the citation counts for publications of different research types ($p = 0.001$). Multiple comparisons using the Bonferroni method showed that clinical trial publications had a higher citation count than laboratory/animal study ($p = 0.02$), survey ($p = 0.006$), and others (such as protocol and case reports) ($p = 0.009$). Meanwhile, no significant difference was observed between clinical trial and review/guideline ($p = 0.52$) in citation count.

Regardless of the type of research, "dental caries" was the most frequent keyword in SDF studies (Appendix Fig. 2). Laboratory studies investigated the antimicrobial and antifungal effects of SDF and its function in the process of demineralization and remineralization and effects on the bond strength of dental tissues. The concentration, fluoride-releasing ability, stability, toxicity, and cytotoxicity of SDF products have been assessed. Clinical trials were conducted to evaluate the effectiveness of SDF application in preventing and arresting dental caries occurring in the primary teeth of young children and root caries of older adults. Apart from the assessment of effectiveness via clinical indicators, studies have also analyzed the effects of SDF treatment on the patients' oral health-related quality of life and perspectives on this non-conventional treatment method. Surveys were conducted to explore the acceptance of SDF application among patients and dental professionals.

Table 1
Types of research and citation count of the included studies.

Category	Study topic	Mean total citation count (SD)	Mean citation density (SD)
Laboratory/ animal study[a]	Antibacterial, antifungal effect	12.7 (16.6)	1.8 (1.9)
	Bond strength		
	Changes in tooth structure change, collagen degradation, histological assessment, tooth strength, matrix metalloproteinase		
n=114 (44%)			
	Demineralization and remineralization, microhardness		
	Stain, color change products, dose and concentration, stability		
	Fluoride uptake, fluoride-releasing		
	Micro-ecology change		
	Toxicity, cytotoxicity		
Review/ guideline	Systematic review, narrative review, guideline	22.2 (35.5)	4.5 (4.9)
$n = 56$ (22%)			
Clinical trial [b]	Prevention and arrest of dental caries in primary and permanent teeth		
Colour change of carious lesions		28.9 (40.6)	3.8 (4.0)
$n = 44$ (17%)	Adverse effects of SDF application		
	Satisfaction and acceptance		
Survey [c]	Parental satisfaction and acceptance regarding SDF treatment	4.6 (9.9)	1.4 (2.4)
	Dental professional's knowledge, perspective, and adoption of SDF treatment		
$n = 26$ (10%)	Teaching and utilization of SDF in dental education		
Others [d]			
-Protocol	Caries prevention and arrest in children/adolescents and elderly population	5.1 (4.1)	1.6 (1.0)
$n = 7$ (3%)			
-Case report	Root caries treatment	4.4 (4.0)	1.3 (0.9)
$n = 5$ (2%)	SDF treatment for individuals with special needs		
	Reverse SDF staining using potassium iodine		
-Model analysis	Pharmacokinetic study	10.4 (12.3)	2.2 (2.3)
	Policy analysis		
$n = 7$ (3%)	Economic impact		
	Statistical model		
		*$p = 0.001$	
Total $n = 259$		16.3 (27.2)	2.7 (3.4)

SD, standard deviation; SDF, silver diamine fluoride.
*p-value was derived using one-way analysis of variance, which was employed to compare the mean total citation count of publications of different research types. Superscript letters indicate multiple comparisons among research types using the Bonferroni method, b > a ($p = 0.02$), b > c ($p = 0.006$), b > d ($p = 0.009$).

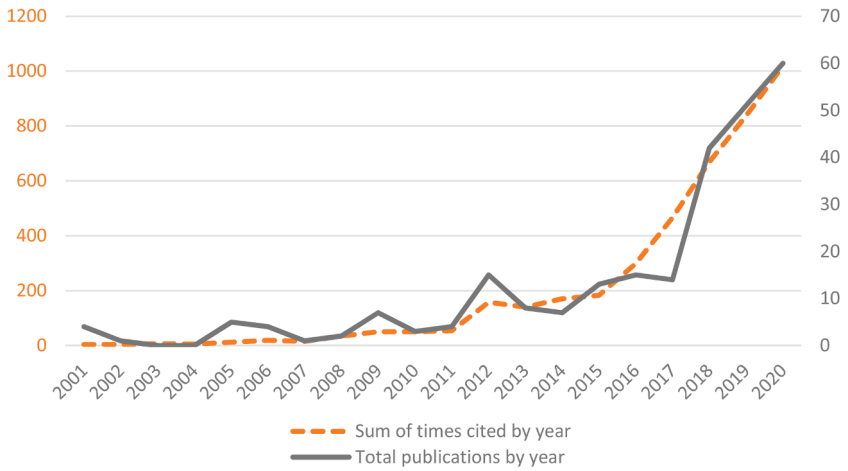

Fig. 2. The annual scientific production and total citation count of SDF studies. The annual scientific production of SDF studies (solid grey line) has increased considerably since 2017, and these articles have increasingly been cited (dotted orange line) during the past five years. SDF, silver diamine fluoride (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Fig. 3. The total and average citation count of articles per year. The peak of the total citation count over years can be seen in 2012 (solid green line), which indicates that the articles published in 2012 were cited the maximum number of times. The average citation count per article per year since the first year of its publication is shown with a dotted purple line, and the peak indicates that the article published in 2002 were cited around 10 times per year since the first year of publication (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Several publications reported possible side effects and disadvantages of SDF application. Several studies have also explored the pharmacokinetics, policies, and economic impacts of SDF treatment.

Most included studies were published in dental journals (Appendix Fig. 3). One-third of the articles were published in the *Journal of Dentistry* ($n = 23$), *Australian Dental Journal* ($n = 20$), *Journal of Dental Research* ($n = 17$), *BMC Oral Health* ($n = 14$), and *Pediatric Dentistry* ($n = 12$), which were considered the core cluster of journals according to the Bradford's law. In the past decade, the number of scientific articles pertaining to SDF published in journals has increased significantly. As measured by the h-index, the *Journal of Dental Research* (*h*-index=15) had the maximum impact, followed by the *Journal of Dentistry* (*h*-index=14) and *Australian Dental Journal* (*h*-index=12).

Regarding the number of publications, the University of Hong Kong reported the maximum number of studies with 77 SDF research publications, followed by the University of Washington ($n = 33$), New York University College of Dentistry ($n = 29$), Tokyo Medical and Dental University ($n = 17$), and University of Michigan ($n = 16$). According to the country of the corresponding author, most studies were reported in the United States ($n = 68$), China ($n = 61$), Brazil ($n = 24$), and Australia ($n = 22$). Global collaborations for SDF research were common and an international collaboration map is provided (Appendix Fig. 4). As measured by the MCP scale, the United States (MCP = 14) showed a high level of global collaboration, while other counties such as China (MCP=11) and Japan (MCP = 11) were also involved in international collaborations.

4. Discussion

The global research interest regarding SDF has increased significantly in recent years. Owing to a better understanding of dental caries and other oral health conditions, dental professionals have advocated a shift from surgical to preventive and minimal-intervention approaches for the management of dental diseases [13]. Accordingly, the non-invasive, simple, and painless SDF treatment is gaining increasing attention worldwide [14].

Although SDF has been used since a considerable period in some regions (Japan, Hong Kong, and Brazil), the clearance of SDF products for market use by the U.S. Food and Drug Administration might have triggered a worldwide attention towards SDF [15]. However, many countries have not approved the use of SDF in dental care. Further clinical research in various geographical areas is necessary to provide reliable evidence for stakeholders and local authorities to make an informed decision regarding the approval of SDF treatment. Meanwhile, alternate methods should be developed for patients in regions where SDF products are unavailable [16]. An obvious drawback of SDF treatment is the black-stained appearance of arrested carious lesions [17], which is an aesthetic concern [18, 19]. For good aesthetic outcomes, novel materials such as fluoride with nano silver that are as effective as SDF in caries management but do not stain carious lesions should be developed [20].

Despite the relatively limited number of publications reporting clinical trials on SDF, the citation count of these publications is significant, reflecting their considerable impact. Nowadays, evidence-based dentistry is emphasized, which is defined as an approach in which oral healthcare is provided considering the relevant scientific evidence, dentists' clinical expertise, and patients' needs and preferences [21]. The relevant scientific evidence is mainly derived from high-quality research studies, such as systematic reviews and randomized controlled trials. Reliable evidence derived from well-conducted clinical trials and systematic reviews plays a crucial role in evidence-based dentistry. This may explain the high citation counts of publications reporting SDF clinical trials and reviews.

According to the Bradford's law, the core journals have published one-third of the SDF studies. Therefore, readers and future researchers interested in SDF research may focus their analyses on these core journals. In addition, this study provided abundant information on the most relevant and impactful research networks around the world. Publications with international co-authorship and increasing geographical distances among the collaborating counties yield higher citation counts and impacts [22,23]. As international co-authorship is highly encouraged in the scientific community, the international collaboration map provided in the present study would be valuable for researchers to search future collaborators, both domestically and internationally.

In the present study, we selected the WoS Core Collection database to identify SDF studies for three main reasons. First, journals in the WoS Core Collection are cautiously selected by the editorial board using a set of criteria with objectivity, selectivity, and collection dynamics as basic principles [24]. This ensures that the journals in the WoS Core Collection meet editorial standards, as do the articles published in these journals. Second, the WoS Core Collection provides comprehensive information on the citation network of 1.5 billion cited references [24]. Third, the journals included in the WoS Core Collection are indexed cover-to-cover, and no other resource indexes as deeply and completely as the WoS Core Collection does. Thus, based on the complete and reliable bibliometric data provided by the WoS Core Collection, a bibliometric analysis can be conducted.

Besides the increasing research interest regarding SDF quantified by the citation counts of academic papers, we used the online tool Google Trends to investigate the search popularity of the term "SDF" over time. Google originally launched this tool as *Google Insights for Search* in 2008, and it provided a sophisticated and advanced service displaying search-trend data. It was reformed and merged with a new interface to become *Google Trends* in 2012 [25]. This tool tracks various words and phrases typed in the Google search box and allows the further analysis of the search query data. Although designed for marketers, it is open for use by anyone in any field. In fact, data from Google Trends have increasingly been used in the medical field to investigate diverse topics, such as influenza-like illnesses [26], tobacco substitutes [27], asthma [28], and tick-borne encephalitis [29]. However, the utilisation of Google Trends in dentistry has been limited. This is the first study to use data from Google Trends to analyse changes in the popularity of dental treatment methods in various geographical areas over time. In the present study, the Google Trends data implied growing widespread interest in SDF, which aligns with the emerging research trend found in WoS. However, caution should be exercised while interpreting findings from Google Trends. The utilization of Google services is blocked or limited in some regions. Therefore, data from Google Trends cannot represent the overall global impact.

The present study has some limitations. As discussed previously, only one database (WoS) was used to obtain bibliometric data; some SDF-related publications might have been missed. Although language restriction was not an exclusion criterion, only English and Portuguese articles were identified in this SDF research collection. SDF was originally developed in Japan [30]; so, some publications in Japanese might have been missed. Furthermore, despite performing a bibliometric analysis, we did not conduct quality assessments of the included studies. In contrast with qualitative evaluation, citation counts enable a quantitative evaluation of the scientific impact of publications in a particular field. Notably, an article with a high citation count does not imply that it has high quality. Citations can be manipulated, and the citation count relates to the number of researchers in the field. Additionally, we did not exclude self-citations from the total citation count. The misconduct of self-citing to increase the citation count of the publication is never encouraged, but sometimes authors need to cite their previously published papers in a research series. Despite these limitations, we used the available up-to-date data from WoS to present a broad global picture regarding the current research trend regarding SDF.

5. Conclusion

The results of this study showed that the global research interest regarding SDF has increased rapidly in the past five years.

Declarations of Competing Interest

The authors declare no conflict of interest.

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CRediT authorship contribution statement

Chloe Meng Jiang: Conceptualization, Methodology, Investigation, Writing – original draft, Formal analysis. **Duangporn Duangthip:** Conceptualization, Methodology, Writing – review & editing, Formal analysis. **Alice Kit Ying Chan:** Investigation, Writing – review & editing. **Manisha Tamrakar:** Investigation, Writing – review & editing. **Edward Chin Man Lo:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Chun Hung Chu:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2021.103778.

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