


Regenerative Endodontics Research Performance and Trend in Saudi Arabia: A Visualized Bibliometric Analysis



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Abstract:

Objective: This study aims to explore and characterize Saudi Arabia's research contributions to the emerging field of regenerative endodontics through a bibliometric analysis. The goal is to assess the growth, impact, and collaboration patterns of Saudi research in this promising area of dentistry

Methods: A comprehensive search of the Web of Science database was performed without limitations. Search terms related to regenerative endodontics were combined with terms specifying Saudi Arabia. Bibliometric indicators and visualization tools like Biblioshiny and VOSviewer were used to analyze and map publication trends, collaborations, and citation patterns.

Results: A total of 113 articles were included. Publication output grew exponentially, peaking at 24 articles in 2021. King Abdulaziz University and King Saud University led research productivity. The Journal of Endodontics, The Journal of Personalized Medicine and the Saudi Dental Journal primarily disseminated this scholarship. Citation levels peaked in 2017. Collaborations were observed with countries including the US, Egypt, and India.

Conclusion: Saudi Arabia has made notable contributions to regenerative endodontics research during the past decade, as evidenced by increasing publications and global impact. Strategic investments have strengthened specialized capacities at leading universities. Efforts building on established conceptual and methodological bases can bring further advances in this promising field.

Keywords: Regenerative endodontics, Bibliometric analysis, Scientometric analysis, Saudi Arabia, VoS viewer, Endodontics.

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1. INTRODUCTION

Regenerative dentistry is an innovative field within

dentistry focusing on the repair or regeneration of dental tissues and structures that have been damaged due to disease or trauma [1]. This approach employs a

combination of biocompatible materials, stem cell technology, and growth factors to stimulate the body's natural healing processes [2]. Tissue regeneration is widely applied in several dental fields. In the context of dental implants, regenerative techniques can be used to promote bone growth and enhance the integration of the implant with the jawbone, which results in improved stability and longevity of dental prostheses [3-5]. In periodontics, regenerative methods such as guided tissue regeneration are employed to reconstruct periodontal tissues and support the reattachment of gums to teeth [6]. In the field of endodontics, regenerative procedures have emerged as a potential alternative to conventional root canal treatments. These procedures aim to revitalize the pulp tissue within a tooth and allow for the natural healing process to restore dental pulp and nerves [7-10].

These pioneering biologically-based procedures aim to recreate the natural dentin-pulp complex present in vital pulp teeth, providing an alternative to traditional root canal therapy for immature or necrotic teeth with open apices [10-14]. The minimally invasive regenerative treatment approach involves thorough disinfection of the root canal system using a combination of potent antibiotics and sodium hypochlorite solutions. The ultimate goal is to eliminate all microorganisms, thus creating a completely aseptic environment conducive to regeneration [15]. To promote the regeneration of the dentin-pulp complex after its loss, three essential components must be present: viable dental pulp stem cells, signaling molecules such as growth factors, and a suitable scaffold or matrix that facilitates cell homing, migration, proliferation, and differentiation [15]. Due to the significance of this field in endodontics, the Journal of Endodontics published an article in 2007 with a "call to action" title. This article urges endodontists, researchers, scientists, and funding institutions to prioritize the study and development of this area [11]. Since that year, clinicians and researchers have focused their efforts on regenerative pulp treatments, resulting in a significant increase in the number of publications in recent years.

Saudi Arabia presents an intriguing case study due to its significant geographical and socio-economic disparities and notable economic advancements. According to the General Authority for Statistics, Saudi Arabia was ranked as one of the world's top 50 most populous countries in 2020 [16]. This progress in Saudi Arabia encompasses various aspects of daily life, including scientific research, which is of great significance. In order to ascertain specific factors and their relationships, it is imperative to foster diverse collaboration among researchers in specific fields to consolidate knowledge. This can be achieved through various methods such as systematic reviews and scientometric analyses. Systematic reviews have extensively covered multiple aspects of regenerative endodontic therapy.

Science mapping, also known as scientometrics and bibliometric analysis, is a discipline utilized to measure and analyze the impact of different categories of scientific materials. The information extracted from this analysis

can be visually represented to interpret the relationships between publications [17]. The output of bibliometric analysis can provide valuable guidance to public health researchers and institutions, aiding in decision-making processes and identifying areas within a specific field that have been under-investigated [17, 18]. Furthermore, bibliometric mapping allows for identifying potential collaborations by enabling researchers to visualize the relationships among the extracted articles in their field. This visualization provides a concise summary of the publication history, reveals current trends in the field of science, and identifies gaps in existing knowledge that could benefit from further investigations and collaborations to advance the topic [17, 19-22].

With the increasing dissemination of published studies [23-31] in this field, it is worth noting that no previous bibliometric analysis has explored the research output in the field of regenerative endodontics from Saudi Arabia. Therefore, the present study aims to conduct a scientometric evaluation in order to analyze the current status and trends of publications originating from the country. The specific objectives of this study include investigating the trends in publication volume over time, identifying prevalent research topics, and examining collaboration patterns. Additionally, the study seeks to map the landscape of contributing journals, institutions, and authors to gain insights into the key players and the development of the field. This will be achieved through the application of bibliometric methods. Furthermore, the analyzed bibliometric data will be utilized to identify existing gaps and potential opportunities for further research in the field of regenerative endodontics in Saudi Arabia. The ultimate goal of this study is to provide a quantitative evaluation of the scholarly publications, which will shed light on the role and impact of Saudi Arabia in this scientific domain.

2. MATERIALS AND METHODS

2.1. Study Setting & Design

The Web of Science (WoS) search engine was selected as the primary tool for the bibliometric search due to its extensive collection of 1.6 billion cited references, covering the time from 1900 to the present. This feature significantly enhances the reliability and validity of bibliometric analysis. One notable advantage of utilizing WoS is its comprehensive and wide-ranging resource, further strengthening the bibliometric analysis's reliability and validity. The comprehensive coverage and robust indexing of scientific literature make the Web of Science database an ideal option for conducting a bibliometric analysis. This extensive and comprehensive resource greatly improves the reliability and validity of the bibliometric analysis [32].

2.2. Search Strategy

The search strategy involved using specific keywords and search terms in the WoS database. The keywords and search terms used were: "Dental pulp regeneration" or "Pulp revascularization" or "Regenerative endodontics" or

“Root canal revascularization” or “Tissue engineering of pulp” or “Tissue regeneration of pulp” or “Pulp regeneration” or “Pulp tissue engineering” or “Stem cells for pulp regeneration” or “Growth factors in pulp regeneration” or “Scaffold materials for pulp tissue engineering” or “Cell homing for pulp regeneration” or “Pulp stem cells” and (“Saudi Arabia” or “KSA” or “Kingdom of Saudi Arabia” or “Saudi”). The searches were performed in WoS's author keywords, abstract, and title fields to capture all relevant records focused on regenerative endodontics research conducted in Saudi Arabia, without any language or time limitations.

2.3. Eligibility Criteria

To be included in this bibliometric analysis of regenerative endodontics research in Saudi Arabia, studies had to meet specific criteria: only peer-reviewed journal articles were considered, excluding conference papers and non-scientific literature. Publications needed to focus on regenerative endodontics, addressing topics such as pulp regeneration and stem cell applications. Additionally, research must originate from Saudi Arabia, must be authored by local researchers or affiliated with Saudi institutions, and only articles published in English were included. The analysis aimed to capture a broad range of studies to accurately reflect trends and developments in the field. These criteria ensured a comprehensive examination of the contributions and trends in regenerative endodontics research within the Saudi context. In total, 113 articles meet the above criteria. These articles will be analyzed to assess trends, collaboration patterns, and the overall impact of Saudi Arabian research in the field of regenerative endodontics.

2.4. Data Collection

As a result, a total of 113 scientific articles on the topic of regenerative endodontics in the context of Saudi Arabia were obtained. To ensure consistency and address any uncertainties, a standardized data extraction form was developed and tested on a subset of 10 studies. In cases where consensus could not be reached, AB and MM were consulted to make the final determination. Data extraction was independently conducted by two authors, HH and MH. This form captured various study identifiers, including author names, publication year, title, and main outcomes. HH and MH independently extracted the data from the included studies using the standardized form. Detailed records were maintained throughout the screening and extraction process, including reasons for excluding studies at each stage. Regular reliability checks were performed by having both authors extract data from the same five randomly selected studies to ensure accuracy and consistency. Any discrepancies were resolved through discussion and consensus.

2.5. Statistical Analysis

The data was visually represented using Biblioshiny and VOSviewer. The Biblioshiny tool was implemented using R-studio software developed by the R Foundation for Statistical Computing based in Vienna, Austria. The

extracted data from the Web of Science database were imported into Microsoft Excel for initial sorting, analysis, and exclusion of irrelevant publications. Bibliometric indicators, such as publication count, h-index, and total citation count, were used for data analysis.

3. RESULTS

3.1. Most Globally Cited Documents

The purpose of the extensive search was to identify the most widely cited documents published by or in collaboration with Saudi affiliations, institutions, or authors globally. Specifically, the focus was on documents that have garnered the highest overall number of citations. Based on the applied citation criteria, it was determined that the article authored by Husain S H in 2017 received the highest number of citations compared to the other articles [23]. The identified articles underwent a thorough analysis to identify the top 10 most cited articles. The findings of this analysis are presented in Table 1. This particular article, titled “Chitosan Biomaterials for Current and Potential Dental Applications,” was published in the Materials journal, as depicted in Table 1.

3.2. Institutions with the Most Relevant Articles

Based on a bibliometric analysis of the literature on regenerative endodontics research in Saudi Arabia, the study identified the top 15 contributing institutions. King Abdulaziz University emerged as the institution with the highest number of published articles, with approximately 54 research articles on the topic. Following closely behind was King Saud University, which produced around 49 relevant articles. Jazan University has made a significant contribution to the field of regenerative endodontics, having authored approximately 45 articles on the subject. Similarly, King Khalid University has shown noteworthy research output, publishing around 24 articles on regenerative endodontics (Fig. 1). King Abdulaziz University and King Saud University have emerged as the key collaborative institutions in Saudi Arabia for regenerative endodontics research, as illustrated by the network visualization in Fig. (2). These two universities have not only collaborated extensively but have also established themselves as leaders in research by publishing the highest number of articles in this field. It is worth noting that while other institutions in Saudi Arabia are involved in cooperative research on regenerative endodontics, their level of engagement appears to be comparatively lower. The network diagram emphasizes the significance of King Saud University and King Abdulaziz University in leading research initiatives and making scholarly contributions to the field of regenerative endodontics within Saudi Arabia.

3.3. Journals with the Most Relevant Articles

After conducting a thorough analysis of the data, the results of the journals that featured the highest number of articles related to regenerative endodontics, authored by either Saudi authors or Saudi institutions, are presented in Fig. (3). The Journal of Endodontics emerged as the

foremost journal in this particular field, having published approximately 10 articles that specifically centered on regenerative endodontics. Following closely behind, The Journal of Personalized Medicine made a substantial contribution with around eight articles on the same subject. Securing the third position, the Saudi Dental Journal presented seven articles exploring regenerative

endodontics (Fig. 3). In addition, Fig. (4) illustrates the network of journals that published articles on regenerative endodontics and their connection to Saudi Arabia. This network provides valuable insights into the most notable journals and their interrelationships in terms of Saudi publications on this particular topic.

Table 1. Top 10 articles on regenerative endodontics in Saudi Arabia based on number of citations received (TC = Total citations).

| Authors/Refs | Total Citations | TC per Year | Year | Title | Journal |
|-----------------------|-----------------|-------------|------|---|----------------------|
| Husain S [23] | 112 | 14.00 | 2017 | Chitosan biomaterials for current and potential dental applications | Materials |
| Chalisserry EP [24] | 110 | 13.75 | 2017 | Therapeutic potential of dental stem cells | J Tissue Eng |
| Alraies A [25] | 68 | 8.50 | 2017 | Variations in human dental pulp stem cell ageing profiles reflect contrasting proliferative and regenerative capabilities | BMC Cell Biol |
| Abou Neel EA [26] | 67 | 6.70 | 2015 | Nanotechnology in dentistry: Prevention, diagnosis, and therapy | Int J Nanomed |
| Ballini A [27] | 64 | 10.67 | 2019 | A comparative study on different stemness gene expression between dental pulp stem cells vs. dental bud stem cells | Eur Rev Med Pharmac |
| Zafar MS [28] | 61 | 12.20 | 2020 | Biomimetic aspects of restorative dentistry biomaterials | Biomimetics-Basel |
| Zafar MS [29] | 59 | 5.90 | 2015 | Oral tissue engineering progress and challenges | Tissue Eng Regen Med |
| Bottino MC [31] | 50 | 5.00 | 2015 | A novel three-dimensional scaffold for regenerative endodontics: Materials and biological characterizations | J Tissue Eng Regen M |
| Youssef AR [30] | 47 | 7.83 | 2019 | Effects of mineral trioxide aggregate, calcium hydroxide, biodentine and Emdogain on osteogenesis, odontogenesis, angiogenesis and cell viability of dental pulp stem cells | BMC Oral Health |
| Almutairi W [33] | 44 | 7.33 | 2019 | Regenerative endodontics: A systematic analysis of the failed cases | J Endodont |

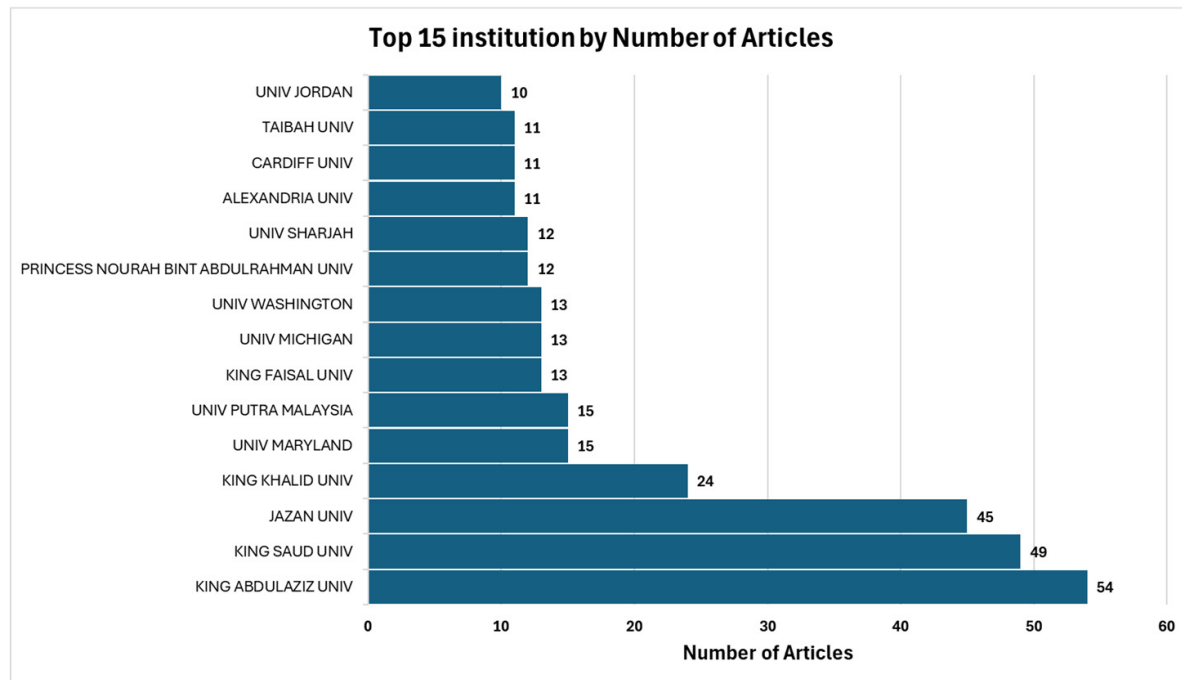


Fig. (1). Top 10 academic and research institutions with the most Saudi publications on regenerative endodontics.

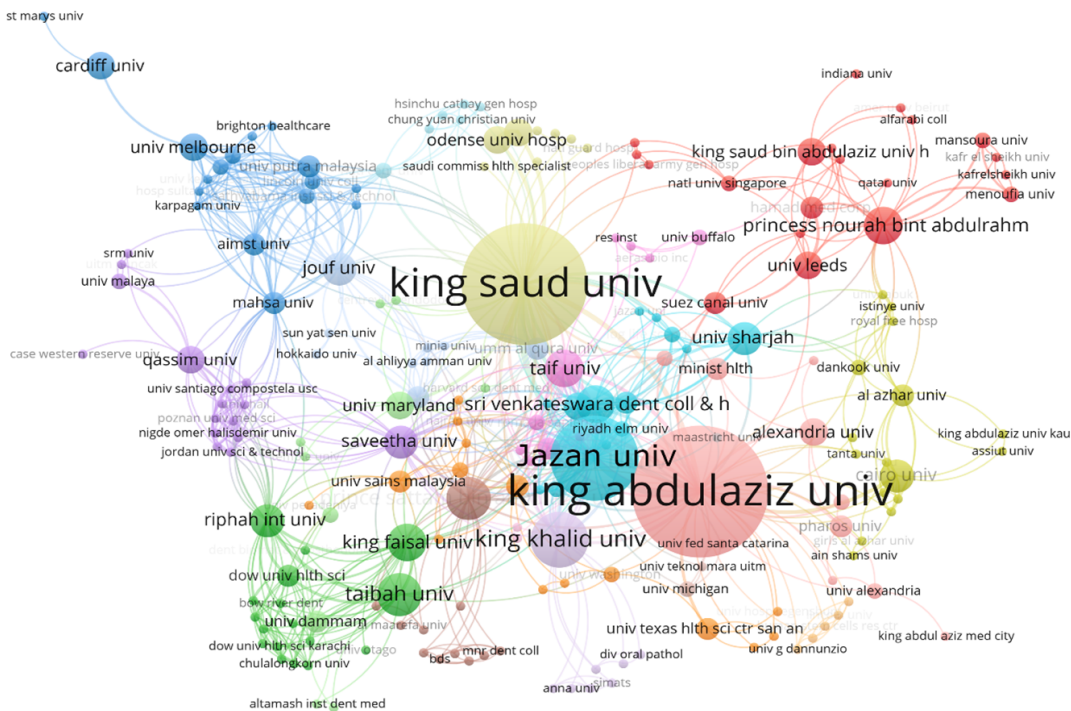


Fig. (2). Collaboration network of institutions that have collaborated on regenerative endodontics research in Saudi Arabia.

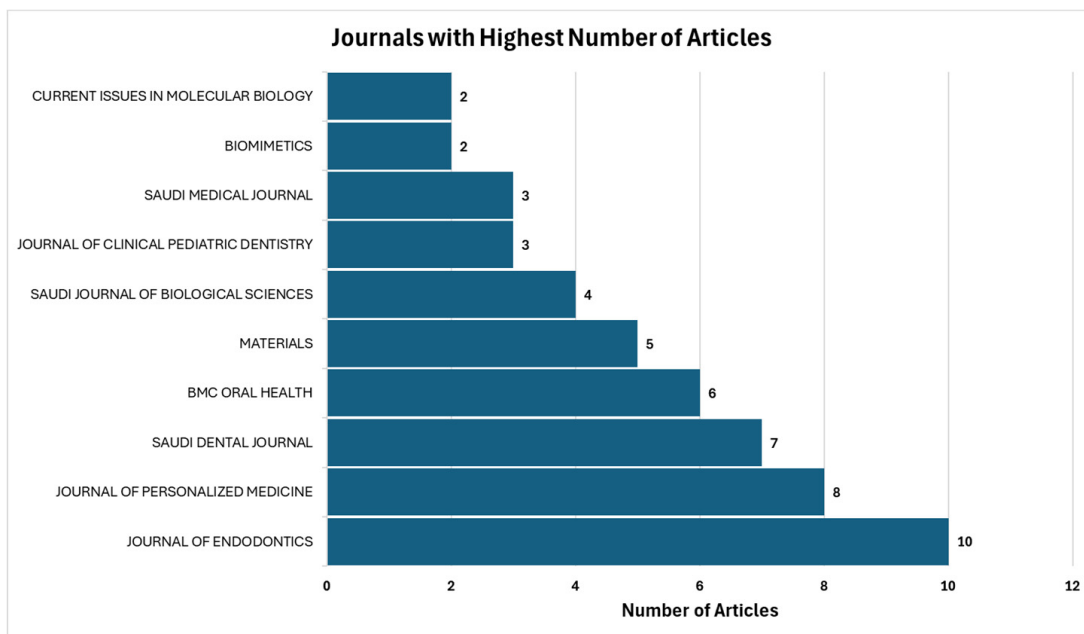


Fig. (3). Journals with the highest number of Saudi publications on regenerative endodontics.



Fig. (6). Yearly scientific contribution and trends in publications on regenerative endodontics in Saudi research.

3.4. Type of Articles

The majority of the articles consist of *in vitro* studies, followed by systematic reviews, case reports, and *in vivo* studies. Additionally, there are limited cohort studies, randomized controlled trials, and cross-sectional studies. In terms of the hierarchy of evidence, *in vitro* studies are regarded as the lowest level of evidence, followed by case reports, cohort studies, randomized controlled trials, and systematic reviews. Fig. (5) demonstrates a notable increase in research on regenerative endodontics in Saudi Arabia. However, it is worth noting that the majority of the research falls within the lower levels of evidence.

3.5. Yearly Scientific Contribution

A comprehensive analysis of the available publication data from 2011 to 2023 reveals a significant increase in scholarly contributions related to the field of regenerative endodontics during this period. Fig. (6) clearly illustrates the upward trend in research output over the years. In particular, the year 2021 emerges as a pivotal moment, with the highest number of articles published compared to all other years, reaching a peak count of approximately 24 scholarly pieces. This surge in publications highlights the growing body of knowledge and the recent intensified research efforts dedicated to advancing the understanding and applications of regenerative endodontic procedures. These findings, derived from a systematic literature evaluation, demonstrate the quantifiable trends in this field.

3.6. Citations per Year

A thorough analysis of publications and citation data on regenerative endodontics research reveals an interesting trend in the average number of citations received yearly. Starting in 2015, the average number of citations per year increased steadily. This upward trend in citation counts peaked in 2017, as shown in Fig. (7). After 2017, there was a gradual decline in the mean yearly citations. This rise in interest and recognition of contributions to the literature until 2017, followed by a slight decrease, suggests that regenerative endodontics gained significant momentum and recognition within the endodontic research community during that period. Many studies were built upon and referenced the work of others. Although interest and citations remain high compared to the beginning of the analysis, it appears that the field may have reached a plateau in terms of the highest level of annual inquiry, discussion, and dissemination of new findings during the peak period in 2017, depicted in the graph.

3.7. Citation and Keyword

The co-citation network displayed in Fig. (8) is a useful tool for understanding the prominent scholarly journals involved in the widespread distribution of research on regenerative endodontics from Saudi Arabia. The co-citation occurs when two articles are cited together by a third, suggesting a link between them. The network analysis revealed that The Journal of Endodontics, The Journal of Personalized Medicine, Saudi Dental Journal, and Materials and BMC Oral Health had the highest

number of co-citations, making them crucial sources for Saudi researchers in this field. These periodicals are the largest components in the network, highlighting their importance and influence within the academic community. This co-citation evaluation emphasizes the important role played by these selected journals in shaping and advancing research on regenerative endodontics in the Saudi Arabian context. Fig. (9) illustrates the co-occurrence network of the most frequently used keywords in Saudi publications on regenerative endodontics. Co-occurrence refers to the presence of multiple terms or concepts together in a text, indicating possible connections or trends. The size of each node corresponds to the frequency of the keyword, while thicker connecting lines indicate a higher rate of co-occurrence between two keywords within the same papers. Some noteworthy keywords and their relationships provide valuable insights. For example, the prominent node representing “regenerative endodontics” is strongly connected to “stem cell” and “revascularization”, where stem cells assist in tissue regrowth. Another significant node is “differentiation”, which is connected to “dental pulp stem cells” and “regeneration”, referring to the process in which stem cells specialize into different cell types to facilitate tissue regrowth. The node “*in vitro*” signifies laboratory experimentation, simulating biological processes in a controlled environment outside of a living organism.

3.8. Authors with the Most Articles

According to the analysis, it was discovered that Patil

S authored the highest number of publications, with approximately 14 articles, making them the top contributing authors. Following closely was Bhandi S, who contributed around 10 articles to the field of regenerative endodontics. Additionally, both Testarelli I and Raj AT made substantial contributions, each publishing about nine and seven articles, respectively, as shown in Fig. (10).

3.9. Collaboration with Countries

In the examination of research contributions originating from Saudi Arabia, it was observed that collaborative affiliations were established with various countries, including the United States of America, Canada, the United Kingdom, Oman, India, Egypt, Japan, Finland, and others, as shown in Fig. (11). These partnerships exemplify the global nature of regenerative endodontics research and the exchange of knowledge and expertise among researchers from diverse nations. Notably, the United States, Egypt, and India emerged as significant collaborators in joint research endeavors with Saudi Arabia in the field of regenerative endodontics. These international collaborations signify the active participation of scholars from the countries in this area of study, as well as their commitment to advancing knowledge and seeking practical solutions. By transcending borders, these collaborations facilitate a more comprehensive understanding of regenerative endodontics through research and contribute to the development of effective interventions and treatments.

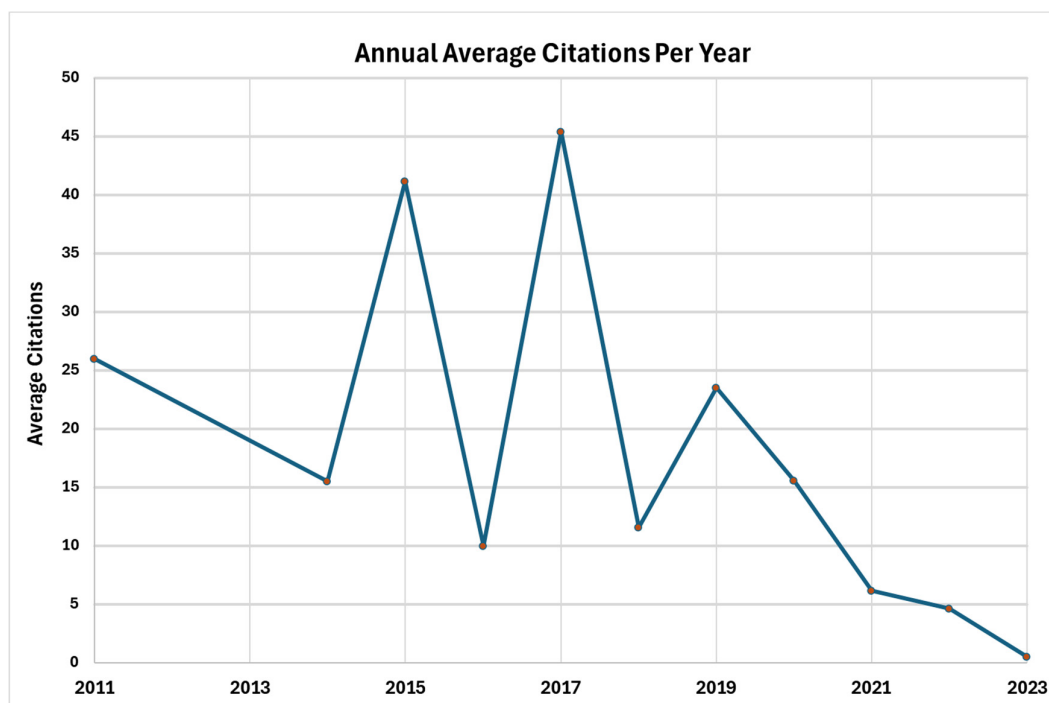


Fig. (7). Average citation trends over time for publications on regenerative endodontics research from Saudi Arabia.

The rising trend in publications observed between 2011 and 2023, reaching its peak in 2021, signifies the growing interest and progress in the field of regenerative endodontics. However, the stagnation of citations after 2017 indicates the necessity for novel studies to maintain the current momentum. This highlights the importance of translating research into practice by incorporating recent findings, particularly innovative materials and techniques, and giving priority to clinical trials instead of *in vitro* studies to achieve higher levels of clinical evidence.

For contributions from journals and authors, The Journal of Endodontics has emerged as a prominent platform for disseminating research in this area. Notably, authors such as Patil S and Bhandi S have played a significant role in shaping research directions, as depicted in Fig. (10). It is recommended that researchers aim to publish their work in high-impact journals to maximize visibility and influence. Additionally, fostering collaborations with prolific authors can enhance the quality and dissemination of research.

The study has revealed robust collaborative links between Saudi researchers and colleagues in nations such as the United States, Egypt, and India, underscoring the global scope of regenerative endodontics research. To enhance future research endeavors, it is advised to expand international networks to gain access to diverse expertise, funding opportunities, and innovative methodologies. Furthermore, conducting cross-cultural studies can yield valuable insights into the applicability and adaptability of regenerative techniques in varying contexts.

According to the pyramid of evidence, the categorization of studies by quality is determined by the level of evidence (LOE), wherein lower numbers indicate higher quality. As of now, the prevailing LOE for 73% of publications is LOE 5, primarily consisting of *in vitro* / *ex vivo* studies. However, it is anticipated that this landscape may change by 2024 [34].

A considerable number of studies that have been conducted in Saudi Arabia have undergone a bibliometric analysis to comprehensively evaluate and determine the prevailing topics, themes, and areas of focus that scholars and scientists in the country have been exploring over time, based on the volume and frequency of publications [35-39]. The current study is the first bibliometric analysis to explore the research output in regenerative endodontics from Saudi Arabia. It shows that the peak in annual output achieved in 2021, when applied to the international study might be indicated to consider further study on a global base to analyze the new improvements in this field. Similar to Shamszadeh *et al.*'s study, our bibliometric analyses found that 72% of the published work was LOE 5, which means that the level of publications in the regenerative endodontics field is low [34]. This is not necessarily surprising, as regenerative endodontics is a relatively new field and there is still a lot of basic research that needs to be done. However, it is important to keep in mind the limitations of these types of studies when interpreting the results. For example, *in vitro* studies cannot always be extrapolated to humans, and case reports are often biased.

So, more high-quality research on a national and international basis are needed to confirm the potential of this new treatment approach. This scientometric analysis will help the researcher to raise the relative evidence level in the regenerative endodontics field, which will help them innovate and prevent research repetition to improve the level of evidence.

5. LIMITATIONS

This study, although it has made extensive use of the Web of Science database for bibliometric analysis, possesses certain limitations. Firstly, the exclusive focus on a single database might result in the omission of relevant publications present in other databases, thereby leading to a potentially biased representation of the field. Subsequent research endeavors could address this issue by incorporating multiple databases, such as Scopus or PubMed, to ensure a more comprehensive analysis. Additionally, the study is confined solely to research carried out in Saudi Arabia, which may fail to capture global trends in the realm of regenerative endodontics. Broadening the geographical scope of the study could yield a more comprehensive perspective on the subject matter. Another limitation is the dependence on keywords for data extraction, which may result in the exclusion of relevant studies that employ different terminologies. Future studies could utilize machine learning techniques to improve the search strategy and achieve a more accurate identification of pertinent literature. Lastly, while the data extraction process was independently conducted by two authors, the inclusion of a larger and more diverse team could further enhance the reliability of the findings while minimizing bias.

This bibliometric analysis has shed light on the significant contributions made by Saudi Arabia to the field of regenerative endodontics. By fostering collaboration, focusing on high-impact research, and effectively translating findings into clinical practice, researchers can continue to propel this essential field forward. Future research must prioritize the enhancement of international collaborations and the advancement of clinical evidence to effectively support innovative therapies.

CONCLUSION

This bibliometric analysis provides valuable insights into the increasing research output and trends in the field of regenerative endodontics from Saudi Arabia over the past decade. There has been a significant exponential growth in annual publications, particularly reaching its peak in 2021, which signifies the growing importance placed on this area. King Abdulaziz University and King Saud University have emerged as the most productive institutions, highlighting Saudi Arabia's strategic development of specialized research capacity. The Journal of Endodontics, The Journal of Personalized Medicine, and the Saudi Dental Journal have prominent roles in disseminating this scholarly work internationally. Citation levels reached their highest point in 2017 when fundamental concepts and methods were being established, yet the impact remains substantial compared

to the beginning of the analysis period. Collaborative partnerships with countries such as the US, Egypt, and India have been observed, leveraging global networks to tackle interdisciplinary challenges in regenerative endodontics. Overall, Saudi Arabia has made significant contributions to this field, and further efforts building upon the established foundations can continue to drive meaningful progress.

AUTHORS' CONTRIBUTION

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

LIST OF ABBREVIATIONS

| | | |
|-----|---|-------------------|
| WoS | = | Web of Science |
| LOE | = | Level of Evidence |
| TC | = | Total citations |

CONSENT FOR PUBLICATION

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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