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Article

SGLT2 Research Collaboration Networks: Structural and Temporal Dynamics in Scientific Cooperation

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Abstract: **Aim:** This study aims to explore the collaborative networks in Sodium/Glucose Cotransporter 2 (SGLT2) research, covering the period from 2000 to 2023. By conducting a co-authorship network analysis, I investigate the structure and dynamics of scientific collaboration, identifying key researchers, institutions, and trends in the field. This analysis provides insights into how research collaboration has evolved and highlights the influence of international cooperation on the development of SGLT2 research. **Method:** The data were collected from the Web of Science (WoS) Core Collection and included 6,999 publications on SGLT2 research. Using Python (Version 3.10.5) in the PyCharm development environment (Software Version 2022.1.3), I analyzed both macro and micro-level network indicators. Macro-level indicators included network density, clustering coefficient, components, and average distance, while micro-level indicators included degree centrality, closeness centrality, and betweenness centrality. These metrics were used to assess the structure of the co-authorship network and identify key contributors. **Result:** The network analysis revealed significant changes in collaboration patterns over the study period. From 2000 to 2023, the network became more fragmented, with an increase in the number of research clusters and components. However, influential researchers, such as Zinman B. and Heerspink Hiddo J. L., consistently emerged as central figures in terms of both degree and closeness centrality. The analysis also highlighted the rise of international collaboration, particularly involving researchers from the United States, Europe, and Asia, with Japan playing a growing role in recent years. **Conclusion:** This study demonstrates that SGLT2 research collaboration networks have evolved considerably over the last two decades. The identification of key researchers and institutions provides valuable insights into the field's development, emphasizing the importance of international cooperation in advancing SGLT2 research. These findings may guide future research strategies and promote further collaborative efforts.

Keywords: endocrinology and metabolism; SGLT2; co-authorship network analysis; network analysis; research collaboration; research trend analysis; research trends; key researchers; research strategies; internal medicine; planning future collaborative studies; interdisciplinary approach

Introduction

Background and Objectives

Sodium/Glucose Cotransporter 2 (SGLT2) inhibitors represent a major advancement in the treatment of type 2 diabetes and have recently expanded their therapeutic role into the management of heart failure and chronic kidney disease. This class of drugs works by reducing blood glucose levels by inhibiting the reabsorption of glucose in the kidneys. The global scientific community has shown increasing interest in SGLT2 inhibitors, leading to a surge in research outputs (Table 1). Investigating the collaborative patterns in this growing field is crucial for understanding the dynamics of research progress, identifying key contributors, and fostering further innovation [1,2].

Globally, SGLT2 research has been driven primarily by Western countries, especially the United States and Europe, where early clinical trials and major pharmaceutical developments took place. However, Asia, particularly Japan and China, has seen rapid growth in SGLT2 research output in recent years (Table 2). In Japan, the introduction of SGLT2 inhibitors has revolutionized diabetes treatment and expanded to address heart failure management, reflecting the therapeutic versatility

of these drugs. This has been reflected in a growing body of Japanese scientific literature and increased participation in international collaborative research efforts [3,4].

The purpose of this study is to analyze the co-authorship network in the SGLT2 research domain from 2000 to 2023, focusing on how collaboration among researchers has evolved over time. Through network analysis, I aim to identify structural patterns in scientific collaboration, highlight influential researchers and institutions, and evaluate the extent of international cooperation. Understanding these dynamics can provide insights into the evolution of research in this field and help shape future collaborative efforts.

Scope of the Study

This study analyzes co-authorship networks based on research articles on SGLT2 inhibitors, extracted from the Web of Science (WoS) Core Collection. The dataset spans the years 2000 to 2023, a period marked by significant advancements in SGLT2 research. The analysis aims to map the structure of scientific cooperation and track how collaborative networks have evolved in this period. By examining both macro and micro-level network indicators, the study will identify key players in the field and explore the extent of international and institutional collaborations.

Significance of the Study

This study offers valuable insights into the scientific collaboration networks in SGLT2 research, with several key contributions:

1. **Identification of Leading Researchers and Institutions:** By analyzing the degree centrality, closeness centrality, and betweenness centrality of the co-authorship network, this study will identify the most influential researchers and institutions in SGLT2 research. These key contributors often serve as hubs of collaboration, facilitating knowledge exchange and driving innovation.
2. **Evaluation of International Collaboration:** The study will also assess the development of international collaborative efforts in the SGLT2 field, highlighting how transnational research partnerships have contributed to the advancement of the field. Understanding the scope and nature of these collaborations can help inform future international research initiatives and funding strategies.
3. **Understanding Network Structure and Evolution:** By applying network analysis, the study will reveal structural features such as network density, clustering coefficients, and the formation of research clusters. These features offer insights into the connectivity and cohesiveness of the scientific community. Furthermore, tracking changes over time will provide an understanding of how research collaboration has evolved, particularly with the expansion of SGLT2 inhibitors into new therapeutic areas like heart failure treatment in Japan.

Material and Methods

In this section, I describe the data collection and network analysis methodology applied to investigate the co-authorship structure within SGLT2 research between 2000 and 2023. The analysis provides insight into both the macro- and micro-level characteristics of the scientific collaboration network, helping to identify key researchers, research institutions, and international collaborative trends. I employed methodology-established principles of social network analysis [5]. The detailed methodology is as follows:

Data Collection

To study the collaborative patterns in SGLT2 research, I utilized the WoS Core Collection database. I searched for publications using the topic keyword "Sodium-glucose cotransporter 2", and the time frame was limited from 2000 to 2023. This search yielded a total of 6,999 papers relevant to the field of SGLT2 research. These articles form the dataset used in the network analysis. The data

were extracted as of October 2024, including relevant metadata such as publication titles, author names, institutions, and cited references.

The extracted data are processed and analyzed using Python programming language (version 3.10.5) within the integrated development environment (IDE) PyCharm (software version 2022.1.3). This data process allows for a comprehensive study of both the structural features and dynamic changes within the SGLT2 co-authorship network.

Network Analysis Methods

The co-authorship network is created by defining the nodes as individual authors and edges as co-authorship relationships between them. Using this network, I apply both macro and micro-level network metrics to examine its structure and dynamics [5].

Macro-Level Metrics

Network Density: Network density measures the ratio of actual edges to the maximum possible number of edges within the network. This metric indicates the level of collaboration among researchers by evaluating the closeness of their connections.

Clustering Coefficient: The clustering coefficient assesses the degree to which nodes (authors) in the network form clusters. This metric reflects the tendency of researchers who collaborate with the same authors to also collaborate with one another, thus forming closely-knit research groups.

Components: A component is defined as a sub-network in which all nodes are connected either directly or indirectly through edges. The number of components is calculated to understand the fragmentation or connectivity of the overall network.

Average Path Length: Average distance represents the mean of the shortest path lengths between all pairs of nodes in the network. It provides insight into how far apart researchers are in the co-authorship network, indicating the ease or difficulty with which information can flow across the network [6].

Micro-Level Metrics

Degree Centrality: Degree centrality measures the number of direct connections each node has to other nodes. Researchers with a high degree centrality are considered well-connected and may play pivotal roles in disseminating knowledge across the network.

Closeness Centrality: Closeness centrality calculates how close a node is to all other nodes in the network, based on the shortest path lengths. Nodes with high closeness centrality are central within the network and can quickly interact with others.

Betweenness Centrality: Betweenness centrality quantifies how often a node appears on the shortest paths between other nodes. Researchers with high betweenness centrality act as important intermediaries in collaboration, facilitating interactions between otherwise unconnected groups [6,7].

The chosen metrics enable a detailed examination of the structural characteristics and key players within the SGLT2 research network. By applying these methods, I aim to elucidate the collaborative dynamics in this field and highlight influential researchers and research clusters.

Results

Network Analysis of SGLT2 Research (2000-2009)

The network analysis for SGLT2 research from 2000 to 2009 revealed a sparse and fragmented co-authorship network. The network density was calculated as 0.0085 (Table 3), indicating limited collaboration among researchers during this period (Figure 1). The average clustering coefficient was 0.939 (Table 3), suggesting that when collaboration did occur, it tended to form tightly knit clusters. The network contained 131 components (Table 3), signifying a high degree of separation between distinct research groups. The average distance between nodes was infinite due to the disconnected nature of the network [8].

At the micro-level, Meng Wei, Washburn William N., and Ellsworth Bruce A. were identified as key figures based on degree and closeness centrality, each with a degree centrality of 0.0377 (Tables 4 and 5). Their central role reflects their involvement in several collaborative efforts, though these collaborations were likely isolated within smaller clusters. In terms of betweenness centrality, Kinne RKH and Lang Florian emerged as central connectors within the network, albeit with low betweenness values (0.0004 and 0.0003, respectively), underscoring the overall limited interaction across research clusters during this early phase (Table 6).

2010-2019 Network Analysis

From 2010 to 2019, the collaboration network expanded significantly, with a network density of 0.0106 (Table 3), reflecting a moderate increase in collaborative efforts (Figure 2). The average clustering coefficient remained high at 0.915 (Table 3), indicating that research collaborations continued to occur within well-connected groups. However, the network became more fragmented, with the number of components rising to 755 (Table 3). As in the previous period, the average distance between nodes remained infinite, demonstrating persistent separation between various research teams [8].

On the micro-level, the degree centrality results highlighted the emergence of prominent researchers such as Zinman B. (0.1404), McGuire Darren K. (0.0814), and Ji Linong (0.0785), who played key roles in fostering collaboration within the SGLT2 field (Table 4). Zinman B. also exhibited the highest closeness centrality (0.1841), further solidifying his central position in the network (Table 5). Betweenness centrality analysis revealed that Zinman B. (0.0384) and Rosenstock Julio (0.0285) acted as crucial bridges between otherwise disconnected research groups, facilitating greater knowledge dissemination across the network (Table 6).

2020-2023 Network Analysis

The network analysis for the most recent period (2020-2023) showed a further decrease in network density to 0.0006 (Table 3), indicating a more scattered collaboration landscape, likely due to the increase in the number of publications and authors, resulting in more isolated groups (Figure 3). The average clustering coefficient was 0.913 (Table 3), maintaining a high level of local connectivity within smaller research clusters. The number of components continued to rise, reaching 1,379 (Table 3), reflecting the ongoing fragmentation of the research network. As with previous periods, the average distance remained infinite, underscoring the separation between different research communities [8].

Heerspink Hiddo J. L. emerged as the most influential researcher during this period, with the highest degree centrality (0.0175) and closeness centrality (0.1650) (Tables 4 and 5). He played a central role in connecting researchers across various studies. Verma Subodh, Butler Javed, and Kosiborod Mikhail N. also ranked highly in terms of degree centrality, illustrating their active participation in numerous collaborations (Table 4). Betweenness centrality analysis revealed that Heerspink Hiddo J. L. (0.0370) and Butler Javed (0.0184) were key intermediaries in the network, facilitating cross-group collaboration and information flow between otherwise disconnected clusters (Table 6).

Discussion

The findings of this study provide valuable insights into the evolution of research collaboration in the field of SGLT2 inhibitors from 2000 to 2023. By applying network analysis to co-authorship patterns, I identified significant trends in how collaboration among researchers has developed over time, highlighting both the strengths and limitations of scientific cooperation in this rapidly growing field.

Evolution of Collaborative Networks

Over the past two decades, SGLT2 research has experienced considerable growth, with marked increases in both the number of publications and the complexity of collaborative networks. In the early phase (2000-2009), the co-authorship network was relatively sparse, characterized by low network density and a high number of disconnected components. This reflects the nascent stage of SGLT2 research, where collaboration was limited and largely fragmented. The presence of isolated

research clusters during this period is not surprising, as the clinical relevance of SGLT2 inhibitors was still emerging, with most research likely being conducted in small, localized groups.

As the field matured between 2010 and 2019, there was a noticeable expansion in both the number of researchers involved and the extent of collaboration. The network density increased, and prominent researchers such as Zinman B. and McGuire Darren K. emerged as central figures in fostering collaboration across different research teams. This period corresponds to the growing clinical recognition of SGLT2 inhibitors, particularly with their approval for managing type 2 diabetes and, later, heart failure and chronic kidney disease. The rise in betweenness centrality values during this time suggests that key individuals played crucial roles in bridging otherwise isolated research clusters, thus facilitating greater knowledge dissemination.

However, despite these improvements, the research network remained highly fragmented, as indicated by the increasing number of components over time. This trend became more pronounced in the final period (2020-2023), where the sharp increase in publications further diluted the collaboration landscape. The decrease in network density during this period, along with a continued high clustering coefficient, suggests that while local research groups remained well-connected, the overall network was becoming more disconnected. The persistence of high numbers of components and infinite average distances indicates ongoing challenges in achieving widespread international collaboration, despite the global relevance of SGLT2 inhibitors.

Key Contributors and Institutions

The analysis identified several key contributors who have played a pivotal role in advancing SGLT2 research. Throughout the three periods, influential figures such as Zinman B., Heerspink Hiddo J. L., and Butler Javed have consistently maintained a high degree and closeness centrality, reflecting their active engagement in multiple collaborative projects. These individuals often serve as hubs within the network, fostering connections between different research groups and promoting interdisciplinary efforts. The high betweenness centrality scores of these researchers also highlight their importance as intermediaries, bridging gaps between otherwise unconnected research communities.

In terms of institutional contributions, the results indicate that leading academic and clinical research centers, particularly those in the United States, Europe, and Japan, have been instrumental in driving innovation in SGLT2 research. Notably, Japanese researchers have played an increasingly important role in recent years, particularly in studies related to the expanded therapeutic applications of SGLT2 inhibitors for heart failure and chronic kidney disease. This reflects the global spread of SGLT2 research, with non-Western countries like Japan and China becoming key contributors to the field.

Implications for Future Research Collaboration

The results of this study suggest several important implications for future research collaboration in the field of SGLT2 inhibitors. First, the increasing fragmentation of the research network over time underscores the need for more concerted efforts to enhance international and interdisciplinary cooperation. Given the expanding therapeutic scope of SGLT2 inhibitors, particularly in cardiovascular and renal health, fostering greater collaboration between researchers from different regions and specialties will be critical to driving future innovation.

Second, the identification of key researchers and institutions highlights the importance of leveraging existing hubs of collaboration to facilitate knowledge exchange and bridge the gaps between isolated research clusters. Targeted efforts to support collaboration between emerging research groups and established leaders in the field could help reduce network fragmentation and promote more cohesive research efforts.

Finally, as the field of SGLT2 research continues to grow, the development of collaborative networks will play an essential role in shaping the future of research. Network analysis can serve as a valuable tool for identifying areas where collaboration is lacking and for developing strategies to foster stronger ties within the global research community.

Limitations and Future Directions

This study has several limitations. The analysis relied on publication data from the WoS Core Collection, which may not capture all relevant research, particularly from emerging regions or non-English language journals. Additionally, while network analysis provides valuable insights into the structure of scientific collaboration, it does not fully account for the quality or impact of individual collaborations. Future research could incorporate citation analysis to provide a more comprehensive evaluation of research influence and collaboration effectiveness.

In conclusion, this study highlights the dynamic nature of research collaboration in the field of SGLT2 inhibitors. While significant progress has been made in fostering scientific cooperation, particularly in Western countries and Japan, the persistence of fragmented research networks indicates that more effort is needed to promote global and interdisciplinary collaboration. By identifying key contributors and structural patterns in the co-authorship network, this study offers a foundation for future research efforts aimed at enhancing collaboration and advancing the therapeutic potential of SGLT2 inhibitors.

Conclusions

The analysis of the co-authorship networks in SGLT2 research from 2000 to 2023 reveals significant trends and insights into the collaborative landscape of this rapidly evolving field. The findings highlight both the expansion of research activities and the diversification of collaborative structures over time.

In the early phase (2000-2009), the co-authorship network was sparse and highly fragmented, reflecting limited collaborative efforts. Key researchers such as Meng Wei and Washburn William N. played pivotal roles in small, tightly knit clusters, but overall connectivity remained low. As SGLT2 inhibitors gained prominence as a therapeutic option, particularly for diabetes treatment, the field witnessed a substantial increase in research output. This growth was accompanied by the emergence of influential researchers, like Zinman B. and McGuire Darren K., who drove collaboration in the following decade (2010-2019). The increase in network density and the central role of these researchers in bridging disconnected clusters underscored the growing interconnectedness within the SGLT2 research community.

However, in the most recent period (2020-2023), despite further expansion of the field, the co-authorship network became more fragmented, with a decrease in network density. This suggests that while more researchers and publications entered the field, collaborations became more dispersed. Influential figures such as Heerspink Hiddo J. L. and Verma Subodh played central roles in maintaining connectivity within certain research clusters, but the overall structure reflected increasing specialization and separation between distinct groups.

Overall, this study provides valuable insights into the evolution of scientific collaboration in SGLT2 research, identifying key contributors and highlighting the dynamic nature of collaborative efforts. The findings emphasize the importance of fostering broader collaborations to enhance connectivity and knowledge dissemination across the research community. As SGLT2 inhibitors continue to expand their therapeutic applications, especially in heart failure and chronic kidney disease, international and interdisciplinary collaborations will be critical to driving future innovation and breakthroughs in this field.

Abbreviations: WoS, Web of Science; IDE, Integrated Development Environment; SGLT2, Sodium/Glucose Cotransporter 2.

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